Bren School of Environmental Science and Management
University of California, Santa Barbara

Santa Cruz Island Biosecurity

Development of a Plan to Prevent the Establishment and
Spread of Invasive Organisms on Santa Cruz Island

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. It is a three-quarter assignment in which groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific issue related to the environment. This *Santa Cruz Island Biosecurity* report is authored by MESM students and has been reviewed and approved by:

LEE HANNAH, PH.D.

Abstract

Santa Cruz Island (SCI) is a unique island ecosystem managed jointly by the National Park Service (NPS) and The Nature Conservancy (TNC) with a common mission to protect native ecosystems and species diversity. A large part of protecting these resources relies on the management of invasive species, a biological threat to which island species tend to be particularly vulnerable. To date, managing this threat has been done in a largely reactive manner, through the eradication of invasive species and restoration of native populations. In the past 10 years alone, this approach has cost TNC $11.4 million dollars. The purpose of this group project is to inform the development of a proactive approach to invasive species management through the development of an island biosecurity plan. Biosecurity is the application of protocols and policies to protect an area or a population from biological harm, premised on the concept that preventative policies will be more cost effective than reactive ones.

The result of this project was the creation of a draft biosecurity plan for SCI and a framework that facilitates future plan expansion and modifications. This framework is meant to be used repeatedly as part of a process to continually adapt the biosecurity plan to deal with new problem species and the incorporation of new information. This framework includes an assessment of the risks posed by species of concern, and an evaluation of the cost and effectiveness of potential management responses to those risks, including both prevention and reaction strategies. The framework was used to make protocol recommendations based on an initial list of priority species supplied by TNC. Information about the cost, effectiveness, and risks addressed by each prevention protocol is contained in a query-ready database, allowing managers to organize information based on their risk preferences and budgetary constraints. Protocols were selected to address all high risks at the lowest available cost. The project also includes a review of effective public education strategies to encourage voluntary participation in biosecurity measures and the development of early detection and rapid response plans for select high risk species.

The framework developed here can be used as part of an overarching passive adaptive management program for managing SCI biosecurity. This program would include an annual or biennial internal audit and review of the plan in order to incorporate new information as it becomes available, decrease uncertainty, evaluate plan effectiveness, and improve implementation and compliance. This informed and adaptive approach will facilitate proactive island management and preservation of this unique and valuable resource.

Executive Summary

Islands are home to unique and sensitive biological communities that are subject to degradation from competition, predation, and disease as a result of the introduction of invasive species (Fritts & Rodda, 1998). Santa Cruz Island (SCI), the largest of the Channel Islands off of the Southern California coast, is one example of this type of unique island system. The island's geographic isolation from the mainland, diverse habitats, and Mediterranean-like climate all contribute to its distinctive and highly diverse native plant and animal communities. The island is home to over 1,000 species, 60 of which are endemic to the Channel Islands (The Nature Conservancy, 2010). The ecosystems of SCI have had a long history of human alteration including the introduction of non-native organisms, including livestock, non-native grasses and forbs, and ornamental plants introduced by visitors and ranchers on the island (Roemer, Donlan, & Courchamp, 2002). The island however, has so far escaped other non native species invasions such as black rats and tree diseases, which have caused conservation problems in other island ecosystems.

Present island managers, The Nature Conservancy (TNC) and the National Park Service (NPS), have spent millions of dollars restoring native flora and fauna and removing the invasive species that threaten them over the past several decades. In the last 10 years alone, TNC has spent nearly $11.4 million on island ecosystem recovery in response to non-native species invasions, including large-scale feral animal eradication, invasive plant removal, and a captive breeding program for the endemic island fox. In an effort to avoid expensive and controversial tactics in the future, TNC is hoping to develop a biosecurity plan for the island. A principle belief in the field of biosecurity is the concept that investment in preventing invasive species introductions will be more cost effective than reactive eradication and restoration of native species. Holistic biosecurity incorporates risk prioritization, prevention, early detection and rapid response, control, research and review, and education. NPS had a biosecurity plan developed for the park in 2004, but many of the protocols have not been implemented because they were considered financially and logistically infeasible.

This project presents a framework through which to develop and continually adapt the biosecurity general plan and methods for SCI. The steps included in this framework are as follows:

1. *Species & Vector Characterization*: Selection of the species of concern should be based on current invasive species knowledge and manager concerns. Selection is followed by accumulation of biological and ecological information about these species to inform a risk evaluation. Important to this process is the identification of vectors by which the species may arrive on SCI.
2. *Risk Evaluation*: The species and vectors representing potential threats to the island are prioritized using a risk evaluation tool that was developed based on invasion ecology and risk theory.

3. *Protocol Evaluation*: Prevention protocols obtained from other biosecurity plans are evaluated by their cost and effectiveness. Information about species risk and prevention protocol cost and effectiveness is contained in a query-ready database, allowing managers to organize information based on risk preferences and budgetary constraints.
4. *Decision Making*: This involves the selection of protocols which manage high risk species-vector combinations at a low cost. Risk can be reduced either by reducing the probability of invasion through prevention protocols or by reducing the consequences through early detection, rapid response, control or eradication. Reducing the probability of introduction is chosen when available protocols to prevent introduction of high risk species are effective, and have a defensible cost. Reducing consequences is chosen when the vectors for introduction cannot be fully addressed through protocols, when the probability of introduction is very low, or when the cost of effective control or eradication is lower than the cost of prevention.

These steps can be repeated as part of a process to adapt the biosecurity plan to new information about invasive species which may adjust priorities, or to new protocol technologies and options. They should also be part of a passive adaptive management program for managing invasive species on SCI. This program would include an annual or biennial internal audit and review of the plan in order to incorporate new information as it becomes available, decrease uncertainty, evaluate plan effectiveness, and improve implementation and compliance.

We used this framework to develop an initial set of prevention protocol recommendations to reduce the risk posed by the high risk species and vectors from the TNC priority list. We determined that in most cases, the cost of reacting to invasive species through eradication and restoration may be prohibitively high, often in the millions, and that proactive biosecurity approaches can often be more cost effective in the long run. However, in cases where no prevention protocols can be implemented, as is the case for West Nile virus and other naturally vectored species, it may be more economical to forgo investment in prevention and focus instead on reactive strategies. We find that there are many cases in which the decision of whether to prevent or to control is not clear because of uncertainty or lack of data. This highlights the need for regular reviews and additional information gathering.

While it was not the emphasis of the project, included within it is a review of effective public education strategies to encourage voluntary participation in biosecurity measures and the development of early detection and rapid response plans for select high risk species. Early detection and rapid response plans for three non-native species threats of particular concern were designed to reduce the consequence of a potential invasion. Public education programs are meant reduce the probability of introduction by increasing visitor prevention protocol awareness and implementation. Suggestions for the components of an effective educational outreach plan were described, a survey was developed to gauge the attitude of the private boating community towards island conservation, and flyers marketing the existing landing permit regulations and the survey were created to launch a portion of this educational outreach program.

The purpose of the development of this framework was to find a way to ensure informed decision making in the face of extreme uncertainty. Quantitative data regarding the probability with which introductions occur, effectiveness of individual prevention protocols, and the costs associated with eradication and control is rare and would greatly improve managers' ability to make cost effective decisions about managing risky species. If possible, managers should track the success of implemented protocols and make these data available to other resource managers, facilitating collaboration and reducing uncertainty in the discipline as a whole. Ultimately, management decisions will be based on the tolerance that managers have for ecological risks and their financial ability to invest in prevention, but we believe that this informed and adaptive approach can facilitate proactive island management and preservation of this unique and valuable resource.

Acknowledgements

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1 Introduction

Santa Cruz Island is the largest and most diverse of California's Channel Islands (seen in Figure 1). Located off the coast of Santa Barbara County, the island is 96 square miles in size and has 77 miles of rugged coastline (Figure 2). The island's geographic isolation from the mainland, diverse habitats, and Mediterranean-like climate all contribute to its distinctive and highly diverse native plant and animal communities. Santa Cruz Island is home to over 1,000 species including 60 species endemic to the Channel Islands (The Nature Conservancy 2010). Amongst those, the island scrub jay (*Aphelocoma insularis*), Santa Cruz Island Fox (*Urocyon littoralis santacruzae*), two species of mice (*Peromyscus maniculatus santacruzae, Reithrodontomys megalotis santacruzae*) and eight plant species are found nowhere in the world aside from Santa Cruz Island (National Park Service 2006). The National Park Service (NPS) owns and manages 24% of the island as part of Channel Islands National Park while the other 76% is owned and managed by The Nature Conservancy (TNC) as a nature preserve. Both organizations, NPS and TNC, manage the island with a common mission to protect native ecosystems and native species diversity.

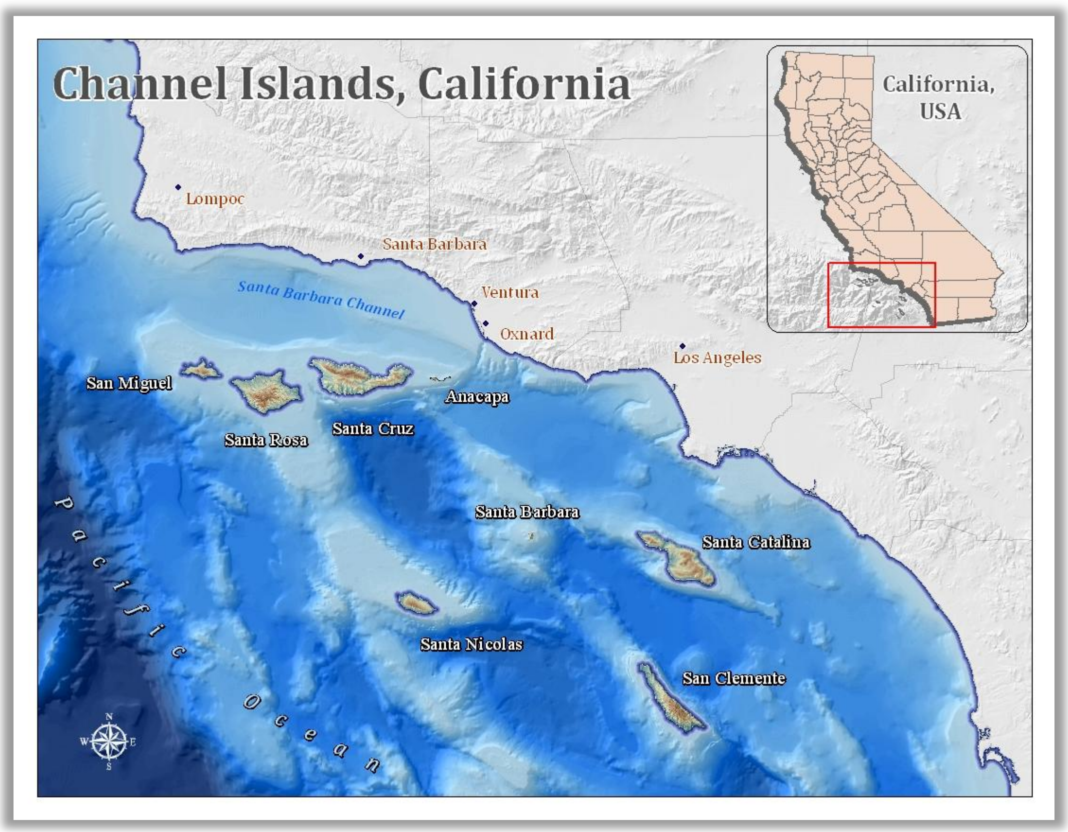

Figure 1 - Area Map: Channel Islands of Southern California

Figure 2. Location of Santa Cruz Island and the border between NPS and TNC property.

Protecting these unique natural communities relies largely on the management of invasive species. Island species tend to be particularly sensitive to the impacts of non-native species invasions; the introduction and establishment of non-native species is estimated to be the largest cause of species extinction in island systems (Vitousek et al. 1996). A variety of invasive plants and animals have been introduced both accidentally and intentionally on Santa Cruz Island throughout its recent history, which included active ranching and agricultural operations until 1978 on what is now TNC property. These invasions have resulted in biodiversity loss through predation, habitat modification, and competition with native species (Roemer et al. 2002). Since taking ownership, TNC has undertaken an ambitious restoration project to promote ecosystem health and function of the island and to restore the viability of its threatened and endangered species. In the last 10 years, TNC alone has invested nearly $11.4 million dollars to remove golden eagles (*Aquila chrysaetos*) and feral ungulates such as cattle (*Bos primigenius*) and pigs (*Sus scrofa*) from the island which helped stabilize imperiled native plant and animal populations, including the federally endangered Santa Cruz Island fox (The Nature Conservancy, 2010). Efforts to restore damaged plant communities and control or eradicate invasive weeds, introduced through agriculture, natural and widespread ungulate disturbance, are ongoing and also resource intensive.

Control and eradication is a reactive approach to invasive species management that has been necessary on the island thus far to reverse the ecological changes that accompanied ranching and agricultural land use under previous ownership. TNC and NPS are shifting to a more proactive approach, incorporating the development of an island biosecurity plan. Biosecurity is the application of protocols and policies to protect an area from biological harm (Galapagos Conservancy 2008). Within the field of biosecurity is the concept that an ounce of prevention is worth a pound of cure, that investment in preventing invasive species introductions will be more than worth the avoided costs of eradication and restoration of native species (Stohlgren & Schnase 2006). The use of biosecurity measures is well established in the realms of agricultural pest control, disease control, both in humans and livestock, and has been increasingly applied to the management of invasive species. Biosecurity plans have been developed and implemented on islands managed for conservation elsewhere around the world, particularly in New Zealand, Australia, the Galapagos Islands, and Alaska.

Island managers have indicated that the terrestrial and freshwater invasive species of greatest concern to biodiversity and ecological integrity on SCI include forest pests such as fungi and exotic insects (ants and beetles), rodents, canine and avian diseases that might harm the endemic island fox and island scrub-jay, and invasive plants that compete with native plants and alter habitat for native species. Many of these organisms are already causing great damage on the California mainland but are not currently present on the island (ISSG 2010). It is the invasion of these species and taxonomic groups that TNC and NPS would most like to prevent on Santa Cruz Island.

1.1 Problem Statement

TNC and NPS are currently in need of a practical and effective biosecurity program to address the threats outlined in the previous section. NPS has put some biosecurity measures in place, however compliance is not universal and extends no further than the NPS staff and boats, and to some extent the island ferry concessionaire – Island Packers Company (IPCO). Biosecurity protocols can be drawn from similar plans and protocols for invasive species that have been implemented on islands around the world. However, the particular human and ecological context of Santa Cruz Island need to be considered before a set of biosecurity protocols will be successful in this context. The framework developed here includes a process for evaluating risk and the protocols designed to address it, an evaluation of risks and protocols given an initial set of priority species, rapid response plans for highly invasive species to be utilized in the event of an introduction, and a literature review of methods for developing an effective public outreach plan to encourage voluntary compliance from island visitors.

1.2 Project Significance

A biosecurity plan that reduces the likelihood of invasive species introductions and can incorporate new information as it emerges is a key element to lasting protection of the island's unique resources. Many of the species on Santa Cruz Island are endemic; a total loss on the island would mean global extinction of the species. Preventing the introduction of harmful invasive species is often easier and cheaper than implementing containment or eradication programs after invasive organisms have established in a new environment (Zavaleta 2000). A biosecurity plan that aids in the prevention of additional invasive species establishments will also preserve the investments NPS and TNC have already made to restore island ecosystems.

Preservation of Santa Cruz Island biodiversity is important to a variety of island users. Integral to the missions of TNC and NPS is the desire to preserve global and national biodiversity. Visitors to the Channel Islands National Park enjoy camping, hiking and engaging in variety of water sports including diving, swimming and kayaking in the context of a protected native California landscape. Additionally, the island has hosts a valuable research station for the UC Natural Reserve System (UCOP 2010). The fulfillment of these island uses relies on maintenance of the native biodiversity of the island.

The guidelines and procedures of this biosecurity plan will be applicable to protected natural areas beyond Santa Cruz Island. The plan can be applied to other islands, particularly those in the Channel Islands chain, many of which have also had problems with invasive species. Channel Islands National Park encompasses four other Channel Islands; procedures suggested in this report can be applied to all of the National Park islands. Moving beyond the Channel Islands, the successes and lessons learned from this plan can be shared with other land managers to increase the level of knowledge and experience behind biosecurity plan development. From a global perspective, the education of island visitors will promote a biosecurity culture - raising awareness about the impact of invasive species on biodiversity worldwide and the importance of individual action in preventing these introductions.

Inherent in creating a practical and effective biosecurity plan is the prioritization of species based on the threat they pose to the island. By prioritizing species, managing agencies can prioritize conservation funds for prevention and response. It is also beneficial to determine how much investment in protection is necessary. This type of information also aids in the determination of whether eradication or prevention is more cost effective. Being able to make a strong argument that the implementation of prevention measures is the most economically efficient way to protect the island will give TNC and NPS greater leverage in obtaining the funding to implement biosecurity protocols associated with the overall plan.

1.3 Project Goals and Deliverables

The goal of this project is the development of a biosecurity plan for Santa Cruz Island including protocols for the prevention of invasive species introductions, rapid response plans in the event of an introduction, and a basic educational plan to encourage voluntary compliance from island visitors. In order to achieve this overall goal, a repeatable and broadly applicable framework was developed including:

- A risk evaluation of potentially invasive species and their vectors to Santa Cruz Island. The identification of priority invaders will be drawn from client priorities and supported with literature review and an evaluation scheme based on species biology and invasion ecology. This risk evaluation will inform prioritization of management action.
- Identification of financially feasible and practically implementable protocols to reduce the risk of non-native species introduction for island users including: TNC staff, NPS staff, IPCO staff and visitors, UC Reserve visitors, the US Navy, the Institute for Wildlife Studies, short-term contractors, recreational users, and commercial fishermen.
- An estimation of potential future eradication costs of invasive species based on invasions of these species in other areas in order to identify situations in which control or eradication are not cost effective options.

Additional work completed to support a holistic biosecurity plan includes:

- Creation of species-specific Emergency Detection Rapid Response (EDRR) plans to swiftly respond to the initial appearance of three high-priority non-native species on Santa Cruz Island. These species include rats (*Rattus* spp), sudden oak death (*Phytophthora ramorum*), and the gold-spotted oak borer (*Agrilus coxalis*). These plans give managers the information and tools necessary to react quickly if an incursion is detected, eradicating invading individuals before a population becomes established or widespread.
- A review of education strategies in order to identify the best media and methods of outreach to island visitors, especially the private boating community, whose access to the island is generally unmonitored. This includes the development of a survey to gauge the boating community's current activities, attitudes toward island use, and willingness to comply with various prevention strategies and the existing permitting program. Several educational strategies are included in the recommended protocols.

1.4 Report Structure

This report contains both biosecurity guidelines to be used by TNC and NPS and a description of the biosecurity plan development process. The background information required to develop this project can be found in Section 2. The framework developed for risk prioritization and prevention protocol selection is contained within Section 3 of this report. These tools were used to prioritize and develop recommendations for a list of species determined by TNC, the analysis of which can be found in Section 4. Additional components of biosecurity plans dealt with to a lesser degree in this project, early detection & rapid response and education, can be found in Sections 5 and 6, respectively. Section 7 describes the issues with the biosecurity plan process identified through this project which are important to be aware of if this methodology is to be used. The appendices contain deliverables of the project such as a risk evaluation framework, the effectiveness evaluation form, species descriptions, visitor statistics, and recommended protocols. These deliverables are a combination of methods developed throughout this project which TNC and NPS can use in the future, and recommendations to be delivered to them. Additionally, a Microsoft Access Database mentioned in this report will be delivered to NPS and TNC with species, vector, and protocol information.

2 Background

2.1 Invasive Species

Non-native (or alien) species are often defined as those that were absent from a region previous to the arrival of humans (Sax et al. 2002). A non-native species is considered to be invasive if it is able to establish, proliferate, and spread to the detriment of the local environment (Mack et al. 2000). Invasive species are a major cause of species extinctions worldwide (Vitousek et al. 1996). Island biotas are thought to be more prone to the effects of non-native species invasions due to the geographic isolation under which they evolved. The symptoms of this isolation that make island species vulnerable to invasions include: limited spatial extent of ecosystems, low species richness, a reduced competitive ability or predator awareness among native species, and the inherently small and thus vulnerable population sizes (Fordham & Brook 2010)(Denslow 2003). Islands are also particularly at risk to invasion because human activities there often require the importation of a large quantities of foodstuffs and other goods (Denslow 2003). The shipping of these products from their various sources can heighten exposure of island habitats to a variety of non-native species from a variety of locations (Denslow 2003). The Hawaiian Islands have 946 alien plant species compared to 2690 native species. Of the Hawaiian natives, 800 are endangered and more than 200 endemics are believed to have gone extinct because of alien species (Pimentel et al. 2005, Vitousek 1988). Serious deleterious effects amongst island species resulting from an invasion have been most dramatic when the introduced organism is a vertebrate animal. The introduction of the brown tree snake (*Boiga irregularis*) in Guam for example, led to expatriation or decline in 17 of the island's 18 native bird species (Wiles et al. 2003). Goats on San Clemente Island in California's Channel Islands were responsible for the extinction of 8 endemic species (Pimentel et al. 2005). The extent to which invasive plants have led to extinctions of island flora is unclear (Sax et al. 2002); however it is known that non-native plants can initiate feedback cycles that reduce survival of native species through the alteration of disturbance regimes or through changes to nutrient cycling properties in the soil (Ehrenfeld 2003).

There are also striking economic costs associated with invasions. Invasive species are responsible for economic losses in agriculture, recreational value, property value, and can additionally generate very high direct management expenses. Direct costs generated through prevention, control, and eradication methods on islands are not well covered in existing scientific literature. However, cost estimates do exist for specific states and sectors in the continental United States and can serve as a representation of the magnitude of possible economic impact. The US government, for example, invests $100 million per year in control of alien species of aquatic weeds (Office of Technology Assessment 1993). The cost of introduced rats (*Rattus* sp) in the United States is estimated at $19 billion per year in the consumption and destruction of grain stores alone (Pimentel et al. 2005). Purple loostrife (*Lythrum salicaria*) occurs in 48 states and is spreading over an estimated 115,000 ha/year (Pimentel et al. 2005). Costs of control and forage losses are estimated at $45 million per year (Pimentel et al. 2005). These studies refer to a much larger scale of invasion than is relevant on Santa Cruz Island, but the point remains that invasive species have the potential to cause huge ecological and economic harm.

2.2 Vectors and Pathways

Historically, invasive species have been introduced outside their native range through natural and anthropogenic means. Natural transport occurs through natural means such as animals, oceanic currents, freshwater flows, and wind (Ruiz & Carlton 2003). Anthropogenic introductions are known to occur, intentionally or unintentionally, through the transportation of people and goods worldwide. Any mode or material through which an introduction can occur is referred to as a *vector*. Vectors for intentional introductions include methods of transportation such as aircraft, boats, trains, and vehicles (Ruiz & Carlton 2003). Unintentional introductions may occur through any vector that can carry reproductively viable individuals in large enough numbers to establish a population (Ruiz & Carlton 2003). Known vectors of unintentional introductions include transported animals, boats, cargo, clothing, construction equipment, foodstuffs, footwear, gear, open containers, plants, soil, vehicles, and waste (ISSG 2009). Prevention protocols address both types of introductions, however the methods used to prevent intentional introductions may differ from prevention methods for unintentional introductions.

In order for a species to cause ecological damage on SCI, the species must reach the island. The means by which a potential threat arrives on the island is referred to as a vector. A pathway is the means by which that vector reaches the island. Pathways for SCI include aircraft and boats; however these may also be vectors if these vessels carry the invasive species, as opposed to carrying the vector of the invasive species. Vectors of invasive species for SCI include known vectors for the invasive species selected by

TNC which were refined through observation of stakeholder practices. Some known vectors of invasive species include agricultural byproducts which are not transported to the islands.

Table 1. The vectors used in the risk prioritization.

Vector	Description
Aircraft	Airplanes and helicopters
Animals	Wild and domestic animals
Bulk soil	High volume soil
Container	Any open container, including unsealed bags and cardboard, metal, and plastic boxes
Dumpster	Dumpster
Firewood	Untreated wood perhaps with bark still attached for the purpose of a fire
Foodstuffs	All food including fresh produce and sealed goods
IPCo boat	All IPCo boats
Lumber	Any wood used for construction or restoration with no bark, usually treated
Miscellaneous equipment and supplies	Anything not including in personal gear: shovels, pots, rakes, etc.
NPS boat	All NPS boats
Personal gear	Clothing, camping supplies (tent, sleeping bag, cooking supplies, etc), packs
Plants	Any plant including personal plants and plants used for restoration
Private boat	Any boat not owned or operated by IPCo, NPS, or any other agency (local, federal, or state), includes possible transport by dinghy
Staff and Contractor footwear	Footwear worn by NPS, TNC, contractor staff while working
Vehicles	Cars, construction vehicles, contractor vehicles, and maintenance vehicles
Visitor footwear	Footwear worn by anyone other than footwear worn by NPS, TNC, or contractor staff while working
Water	Carried by natural ocean currents
Wind	Carried by wind

2.3 Biosecurity

Islands are vulnerable to invasions by alien species due to their limited spatial extent, low species richness, reduced predator awareness among native species, and small population sizes. The very same qualities that make islands inherently susceptible to invasion can also make them receptive to biosecurity measures aimed at preventing invasion. Islands have less territory to monitor and fewer native species to account for, so invasive populations may be detected earlier than on vast mainland areas. While human activity on islands pose specific risk to invasion, it can easier to control human interactions with islands when there are a limited number of access points for island visitors. (Fordham & Brook 2010, Denslow 2003)

Biosecurity is a concept that is prevalent in many disciplines including medicine, research laboratories, agriculture, livestock, and environmental health. The Food and Agriculture Organization of the United Nations defines biosecurity as:

> "…a strategic and integrated approach that encompasses the policy and regulatory frameworks (including instruments and activities) that analyzes and manages risks in the sectors of food safety, animal life and health, and plant life and health, including associated environmental risk. Biosecurity covers the introduction of plant pests, animal pests and diseases, and zoonoses, the introduction and release of genetically modified organisms and their products, and the introduction and management of invasive alien species and genotypes. Biosecurity is a holistic concept of direct relevance to the sustainability of agriculture, food safety, and the protection of the environment, including biodiversity." (2011)

In the context of securing the environment and biodiversity, a holistic biosecurity program focuses on two major goals: reinstating ecosystem security and monitoring for new risk factors (Hathaway & Fisher 2010). The first goal of reinstating ecosystem security involves prevention protocols, early detection monitoring, rapid response measures, and education. Prevention protocols minimize new species introductions by treating risky materials before they reach the island or prohibiting them all together. Early detection monitoring is used to identify new invasive populations before they thoroughly establish. Rapid response planning involves preparing the methods, materials, and regulatory approval necessary to implement an eradication effort soon after an incursion is detected. Both early detection and rapid response operate under the assumption that it will be operationally and financially easier to eradicate a small group of individual organisms compared to a well established and broadly distributed population. Responding quickly can also minimize ecological damage to native biota and help to insure the success of the larger restoration efforts underway (Myers et al. 2000). Finally, reinstating ecosystem security involves education of island staff and visitors to promote the awareness of threats and compliance with protocols amongst individuals. These are the components of a complete biosecurity plan, each of which we developed to varying degrees in this project. The second goal, monitoring for new risk factors, involves adaptive management- audit, review, reassessment of risk priorities- and development of offsite controls to address the non-native species at the source to reduce potential to gain access to a protected area (Hathaway & Fisher 2010). The decision making tools outlined in this report can be used to guide updates made to TNC and NPS strategies based on new information and new priorities.

Several nations have taken the lead in the development and implementation of biosecurity plans and it is no surprise that many of these are island nations, or nations with significant island territories. New Zealand has several plans ranging from specific invader plans to general plans that target all invaders. Australia has an extensive number of biosecurity plans, a Biosecurity Services section under their Department of Agriculture, Fisheries, and Forestry, and over 60 agencies involved in biosecurity development and implementation (Australian Biosecurity Intelligence Network 2009). The Galapagos has extensive prevention and response measures in place. These measures include inspection upon arrival, monitoring, and rapid eradication of newly introduced pests (Galapagos Conservancy 2008a). In the United States, Hawaii and Alaska have existing biosecurity plans. Hawaii department of agriculture manages a State wide plan aimed at reducing the effects of invasive species on Hawaii's economy, environment, public health and quality of life (The State of Hawaii Department of Agriculture Plant Industry Division 2007). Alaska has a biosecurity plan specifically targeting rat invasions with protocols detailing current eradication plans and future prevention and response (Fritts 2007). In each of these cases, governments have come to believe that an ounce of prevention through science-based early detection, rapid response, and education will be worth a pound of cure (Stohlgren & Schnase 2006).

2.4 Risk Management

Land managers responsible for invasive species management often ask two simple questions: "Where is it?" and "How do I kill it?" (Stohlgren & Schnase 2006) However, the fundamental challenge is selecting and prioritizing species of plants, animals, and diseases for control based on the risk associated with their invasion, while staying within budgetary limitations (Stohlgren & Schnase 2006). The measure of risk associated with invasive species is the magnitude of the ecological consequence associated with their invasion, weighted by the probability that the species will become invasive (Bartell & Nair 2004). Ecological risk analysis methods are commonly used to inform a triage approach for dealing with existing invasive species problems. The methodology for risk management of invasive species is similar to strategies employed to manage risk in a variety of disciplines.

The International Organization for Standardization (ISO) developed a family of standards related to risk management – ISO 3100:2009 – which are aimed at providing consistency and reliability in risk management by creating a standard that is applicable to all forms of risk and all organizations dealing with those varied forms of risk (Purdy 2010). The ISO standards broadly define risk as "the consequence of an organization setting and pursuing objectives against an uncertain environment," or more simply the "effect of uncertainty on objectives." In this context, objectives are the goals and mission of an organization and uncertainty is the internal and external factors that an organization cannot completely control, but which may cause them to fail to achieve their desired goal (Purdy 2010). The ISO 3100:2009 standards further define risk by defining risk management, which is a process of optimization that makes the achievement of objectives more likely. The optimization process involves a series of steps through which an organization identifies or establishes control factors that can change the magnitude and likelihood of consequence in order to achieve a net benefit. This process results in control factors that can be used by an organization with the purpose of modifying risk (Purdy 2010). It is important to note that while risk management is more or less a step by step process; there are two major themes that are continuously applied: communication and consultation and monitoring and reviewing. Communication and consultation between internal and external stake holders ensures that objectives are properly identified and monitoring and review to ensure that proper actions take place as new information and new risks emerge (Purdy 2010).

In the world of conservation and environmental management, where an organization such as The Nature Conservancy or National Park Service's objectives are to conserve biodiversity, the risk analysis framework is a valuable tool for informing conservation strategies (i.e.: biosecurity programs) for invasive species that are not yet present. The U.S. Environmental Protection Agency (EPA) developed a risk management process specifically geared toward estimating ecological risk. It is a broad framework for evaluating scientific information on the adverse effects of environmental stressors. In this context, stressors are defined as any physical, chemical, or biological entity that can induce an adverse effect (U.S. Environmental Protection Agency 1992). Stohlgren and Schnase (2006) have adapted that same ecological risk analysis framework used by the EPA for use with harmful invasive species. Their framework is unique because it focuses on biological invasions, a class of stressors known to have long lag times from introduction and establishment to successful invasion, be highly reproductive, and spread rapidly by physical and biological processes (Stohlgren & Schnase 2006).

The 4 basic steps of the ecological risk analysis framework include: (Stohlgren & Schnase 2006)

(1) Problem formation: scoping the problem, defining assessment endpoints
(2) Analysis: information on species traits, matching species traits to suitable habitats, estimating exposure, surveys of current [or potential] distribution and abundance;
(3) Risk characterization: understanding of data completeness, estimates of the potential distribution and abundance; estimates of potential rate of spread; and probable risks, impacts, and costs; and
(4) Risk management: containment potential, costs, and opportunity costs; legal mandates and social considerations and information science and technology needs

Ultimately, in the conservation and environmental management setting, where goals and objectives are to preserve and protect biodiversity, risk analysis can provide a prioritized set of biosecurity actions that can be used in combination with risk preferences and budgetary constraints to inform specific prevention plans.

2.5 Invasion Ecology

In order for a species to become established and invasive on the island, a series of events or transitions must occur (Figure 3) (Kolar & Lodge 2001, Sakai et al. 2001).. A large body of literature has developed aimed at predicting invasive potential based on characteristics of the species and ecosystem however there remain few consistent predictors of invasion success.

To begin the invasion process, a reproductively viable individual or propagule, from here on referred to as an *agent*, of a non-native species must first come in contact with a vector and become entrained in a transport pathway that reaches the area of interest. For example, a seed may become attached to a person's clothing or gear, which they may then bring to the island. Next the agent must survive transport and arrive on the island. Founding individuals must reproduce sufficiently to establish as a self-sustaining population. Finally, the established population must spread in terms of area or density to the point that ecological harm is caused to the system, at which point it is considered invasive (Kolar & Lodge 2001).

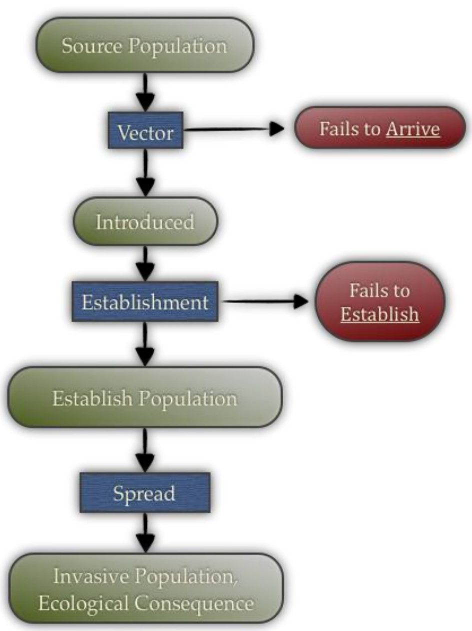

Figure 3. Conceptual model of the invasion process.

Several factors are likely to influence the probability that an agent or species will complete each transition successfully. Empirical examinations of successful and unsuccessful introductions, establishments, and invasions provide insight into the factors influencing each step, the most important information to consider when predicting potential invasions. It is important to consider these transitions separately because the characteristics that determine the probability that a species or agent will complete each transition can be different (Kolar & Lodge 2001). Early reviews of this topic did not consider the transitions of the invasion process separately, which may explain why clear and consistent patterns in species characteristics across studies did not emerge (Kolar & Lodge 2001).

Factors that influence species introduction are not well understood due to the difficulty of acquiring data on accidental introductions, and particularly accidental introductions that failed to establish or become invasive (Hayes & Barry 2008). Most studies use data from deliberate introductions, which can still provide insight into predictors of establishment and invasion, but is not ideal for understanding accidental introductions.

The most empirically consistent predictors of whether a species will become established after introduction are propagule pressure, habitat and climate match, and the species' history of invasiveness. These factors are consistent across all taxa and multiple international datasets (Kolar & Lodge 2001, Hayes & Barry 2008). In some cases, additional characteristics have been identified that are associated with establishment success for a specific taxon. Species origin, taxon, flowering period length, height or body length, and range area have all been found associated with establishment success in plants, however are not supported by more than one study (Kolar & Lodge 2001, Williamson & Fitter, Goodwin et al. 1999). For birds, species origin, broods per season, temperature and habitat match, and body mass have all been associated with establishment success (Kolar & Lodge 2001, O'Connor et al. 1986, Veltman et al. 1996).

The only factor associated across taxa with a species ability to transition successfully from established to invasive is climate and habitat match, and even this is subject to some disagreement between datasets (Hayes & Barry 2008). In these studies, invasiveness is defined as exotic range size. Plant characteristics associated with abundance in invaded range, another definition of invasive, include: length of juvenile period, growth form, vegetative reproduction, length of flowering period and flowering season (Hayes & Barry 2008). None of these characteristics are supported across any other biological groups.

Characteristics of the new environment and its interaction with the invading species are also important to consider but tend to be difficult to quantify. These relationships are more often described through case studies and ecological theory than empirical relationships. The vacant or under-utilize niche hypothesis suggests that a non-native species can thrive when introduced to an area with unfilled or underutilized niches. Community species richness is similar to the vacant niche hypothesis, further supposing that an area with a greater number of native species will have fewer unfilled or under-filled niches and thus be more resistant to invasion (Mack et al. 2000). By the same theory, areas containing fewer native species, such as islands, will be less resistant to invasion (Mack et al. 2000, Fordham & Brook 2010). Demonstrating vacant niches has proven very difficult however, making this theory difficult to verify (Simberloff 1995). Another theory is that invaders are those species able to escape from biotic constraints. According to this hypothesis, species are more likely to become invasive if the introduced environment does not contain the same predators, competitors, parasites, or grazers that kept restrain population size and density in its native range (Mack et al. 2000, Strong et al. 1984). A final hypothesis is that disturbance predisposes a landscape to invasion because some native species will be unable or poorly able to adapt to the altered conditions, creating an unfilled and under-filled niches for an invading species to occupy (Mack et al. 2000, D'Antonio & Vitousek 1992).

3 Risk Prioritization & Decision Making

The following risk prioritization and decision making process is intended for use by TNC and NPS with invasive species management. The process described in this section has been key in the development of our biosecurity recommendations, but more importantly, it can used by TNC and NPS in the future for their own risk prioritization and decision making processes.

Our process was adapted from the 4 steps of ecological risk analysis presented by Stolghren and Schnase (2006) as described in Section 2.4. The project began with a scoping of the problem and defining assessment endpoints through client consultation and an evaluation the existing biosecurity plan, written for NPS in 2004 by Island Conservation, intended to identify what was hindering its implementation (results summarized in Appendix 1). From there, it was determined that a more formal biosecurity plan development process was necessary; a plan that would take into account the basic goals of a biosecurity program: to reinstate ecosystem security and monitor for new risk factors. Inherent in this process was developing a process for identifying and reducing invasive species risk based on theory from the field of risk management. Thus, the second phase of the project included the acquisition of ecological and biological information about potential risks, in this case invasive organisms, in order to inform an evaluation of the degree of risk they present. This phase is comparable to steps 2 and 3, Analysis and Risk Characterization, of Stohlgren and Schnase's ecological risk analysis. We further developed the Risk Characterization step in our project by creating a framework for consistently evaluating risk and utilizing it to assess each species-vector combination. The resulting prioritization of species by their risk, as well as the evaluation of alternative actions, leads to knowledge upon which to base management actions and complete step 4, Risk Management. The process outlined here is meant to be iterative, allowing for adjustments to be made to decisions, which adheres to the second overarching goal of biosecurity which is to continuously monitor for new risk factors.

3.1 Species & Vector Characterization

Selection
Before evaluating the risks posed to SCI, it is necessary to first identify and characterize threats. In the context of invasive species, a threat to the island is an agent of a potentially invasive species that reaches the island. Priority species should be selected based on knowledge of current invasive species problems in other areas, particularly in areas from which travel to the island occurs.

Characterization
To facilitate evaluation of the risk posed by a particular agent, information about each species' unique biology and ecology is to be compiled into species characterizations. Specific detail and attention are to be paid to identifying traits that indicate a species' invasive tendencies in general and on SCI. The ability for a species to establish in a new area depends on its biology and ecology, as described in the discussion of invasion ecology above (Bartell & Nair 2004). For this reason, many risk evaluations rely on information about invasive biology and include a formal description of species traits (Stohlgren & Schnase 2006, Harris et al. 2005, Fowler & Borchert 2006).

Information about the species of concern is collected through both literature reviews and communication with experts. Information outlined in each species characterization includes: a physical description, natural and invasive range, habitat, dispersal, historical impacts, introduction pathways to Santa Cruz Island, and options for eradication or control. The physical description is meant to help identify the species if it is present. The native and invasive range informs whether a vector is likely to pass through an area populated by the species. Comparing a species' habitat and climate preferences to the habitat and climate of the island helps determine whether it could survive on the island and where it might be most likely to establish. Historical information about the impact the species has had on other ecosystems helps identify what the consequence of invasion by the species could be. Knowledge of these traits allows for the ability to summarize the probability that the species may arrive, establish, and have an impact on Santa Cruz Island.

Describing introduction pathways includes defining the vectors and pathways by which an agent could potentially reach the island. Agents reach the island on a vector, which is associated with a pathway. A vector is anything on which an agent can directly stow away and a pathway is the means by which that vector reaches the island. An agent, an individual rat, for example, may be carried in someone's luggage on a boat, on just on the boat itself. In the first case, the luggage is the vector and the boat is the pathway. In the second case, the boat is both the vector and the pathway. The distinction is practical in that the vector is the level at which biosecurity action takes place and the pathway indicates the organization or party that will be responsible for implementing it. The agent's size, dispersal characteristics, life history, and history of accidental introductions can help determine whether it is physically possible and probable that it will find its way on to a given vector. If a material could harbor agents from the organism's dispersal modes, it should be considered a vector. If the material is habitat or food for the agent at some point in its life cycle, it should be considered a vector. If the material has been the known or suspected vector of the species elsewhere, it should be considered a vector.

It is also necessary to gather information regarding eradication or control costs of the agents in other locations, and how effective these efforts have been. This information is useful in determining whether control is a feasible alternative to prevention. For some species, such as rats, domestic cats, and cape ivy, control information can be obtained from other Channel Islands. For other species, information can only be obtained from more distant areas. It is not clear how well the cost and success of control events in other areas can inform potential costs on Santa Cruz Island, even in comparison to the other islands. The size and presence of unique sensitive species introduce variables that make prediction of control difficult (Donlan & Wilcox 2007). For some control methods, there is no information about cost or effectiveness. Lastly, for some species there are no known control measures. It is important to report the best information which can be found, but to be explicit about the uncertainty involved in extrapolating to predict costs for control or eradication on SCI.

3.2 Risk Evaluation

The risk posed by a threat is the product of the probability that it will occur and the magnitude of the associated consequences (Bartell & Nair 2004). Evaluating the risk of species-vector combinations gives managers a means by which to prioritize potential biosecurity actions. Species-vector combinations are the most appropriate level at which to evaluate risk because risk is both species and vector specific. In other words, each species will have a level of risk particular to a given vector because the vector affects the probability of introduction and the species affects the magnitude of potential consequences.

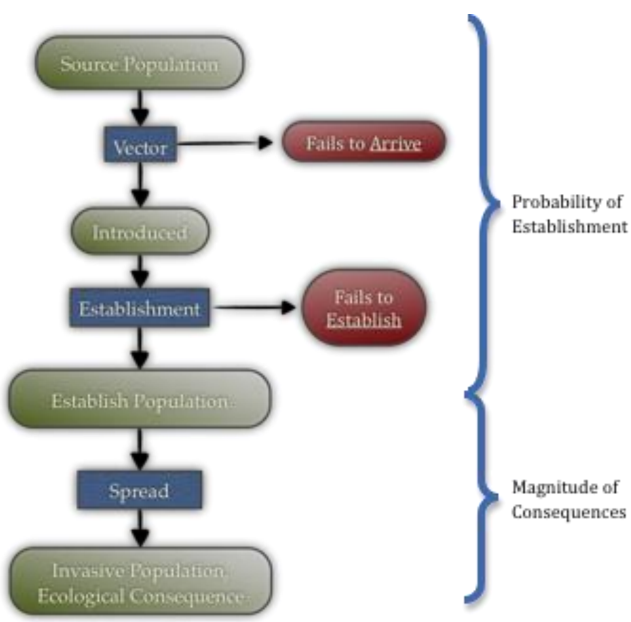

Figure 4. Risk is probability x consequence, shown here as it relates to the invasion process

Additionally, biosecurity protocols act on the species-vector level, meaning they are applied to vectors and may encompass one, some, or all of the species that could be associated with it. The vectors through which a species may pose a risk can be determined as a result of the species characterization process.

The risk evaluation worksheet (REW) draws upon the invasion process and risk theory to develop a qualitative risk score. The scores fall into six categories: high, medium high, medium, medium low, low, and none. A high risk highlights an area in which some management action is necessary. This worksheet can be used to evaluate new potential threats in a consistent manner with each new analysis.

The worksheet consists of two sections representing the probability of establishment and the magnitude of consequences. Each section has preliminary criteria for analysis, which serve to screen out those species that are not a threat, and subsections representing the controlling factors for the section overall. In the invasion process, we consider the probability of occurrence to be the probability that a species will be introduced and become established and the consequence to be the potential ecological impacts of that population (Figure 4). The REW and instructions for use can be found in Appendix 3. Reasons for the selection of each criterion within the framework follow.

Probability of Establishment

The purpose of this section is to gauge the likelihood that a species will be introduced and establish relative to other species. Preliminary criteria are used to eliminate species vector combinations that do present a threat on SCI, even though they may present a risk elsewhere. Probability of establishment is influenced by propagule pressure and the suitability of conditions on SCI.

Propagule Pressure

In determining the likely propagule pressure resulting from the vector, we consider the likelihood that an agent is associated with the vector and survives transport, the frequency with which the vector reaches the island, and the volume of the vector relative to agent size and detectability. Frequency with which private, contractor, and agency vessels arrive at the island's various anchorages and harbors was gathered from NPS and SAMSAP visitation data (Appendix 4). Frequency with which other vectors are transported to the island was attained through consultation with TNC and NPS staff. As in the preliminary criteria, we take a precautionary approach to uncertainty in that if the likelihood of association is unknown, it is treated as high.

Suitability of Conditions

The other facets controlling probability of establishment are the habitat and climate match and the species history of invasiveness. The criteria in this section consider the likelihood that the species to find conditions on SCI suitable enough to reproduce and establish a self-sustaining population. If the habitat and climate conditions on SCI are somewhat suitable for the species based on its current range and known tolerance limits, we assume an individual has some chance of establishing. If conditions are highly suitable, we assume there is a higher chance of establishing. If the species has a history of invasiveness, we assume that the species has an increased ability to establish under a variety of conditions and therefore has a higher chance of establishing.

Now we have two ratings that will need to be combined to represent the overall probability of establishment. To do this, we multiply the total score from each category and match it to a HIGH, MEDIUM, or LOW rating depending on whether it falls in the top, middle, or lower third of possible resulting values. Multiplication is used to combine the scores because of the sequential nature of the invasion process; each step relies on the other in order for a successful establishment to occur. A break in the chain of events lowers the overall probability that establishment will occur. After converting the multiplied score into High, Medium, and Low categories, the categories are then transformed back into a numerical score of 3 (HIGH), 2 (MEDIUM), or 1 (LOW). This effectively reduces the complexity with which we report and propagate the results of the analysis, which serves to account for uncertainty in the degree to which the parameter choices completely and accurately capture the factors controlling probability of establishment and the uncertainty under which managers may answer questions. It is also a way of putting the value for probability on the same scale as the value we will generate for consequences. The two values are equally considered in determining risk and should therefore be on the same scale before they are combined.

Magnitude of Consequences

Consequence is controlled by the value of the impacted resource, the degree of impact to the resource, and the rate at which that impact is likely to occur. Preliminary criteria are used to define "impact," species that will not result in an impact fitting that definition are not considered to be a threat. Predictions are based on the historical impact of the species on other islands or in mainland ecosystems and on the effect that similar organisms have had on island biota. Where data was available, habitat suitability was modeled to give an indication of the size and distribution of a potential invasion. Point values for the subsections are combined in the same way as described in the previous section and for the same reasons.

Value of the impacted resource

Species, ecosystems, or ecosystem processes likely to be impacted by the spread of the invasive are classified in this section based on client priorities. Sensitive, protected, rare, or keystone species are of the highest priority, as are large or unique habitats. Widespread or resilient endemic species or habitats and collections of multiple native species are of the next highest priority. Native species and habitat types neither sensitive nor unique to the island are the lowest priority considered here. Impacts on non-native species are not considered to be of consequence since island managers currently seek to remove them and foster the restoration of native and endemic species.

Degree of impact

The extent to which the invasive is likely to impact the resource is evaluated as the potential impacts on population or habitat viability, described here as the level of impact on individuals and the proportion of the resource as a whole that could be affected. On the high end of this would be a disease that could cause mortality in all or most of a species population, on the low end would be a slight reduction in individual fitness for a small proportion of individuals.

Rate of spread
This refers to the rate at which the impact spreads through the affected species population of affected habitat type. A species with a high rate of spread becomes unmanageable by land managers more quickly. In scientific literature, rate of spread is usually reported in area units per time. For example, red imported fire ants (*Solenopsis invicta* Buren) have been shown to spread 10-40 meters/year in Texas (Porter et al 1988). In our analysis, rate of spread can be categorized as rapid, moderate, or slow relative to the area occupied by the native resource that may be impacted. Species with excellent dispersal adaptations, such as by wing, water, animals, zoospores, or pelagic stages, are more likely to spread rapidly (Stohlgren & Schnase 2006).

Risk
The scores for probability of establishment and magnitude of consequence are multiplied together to get a score for the risk of the species-vector combination to SCI. Each unique value represents a different level of risk. We feel that simplification of the contributing scores adequately account for the uncertainty within those sections and that the increased level specificity will give managers a more detailed and therefore more useful ranking on which to base management priorities.

3.3 Protocol Evaluation

A prevention protocol is an action meant to reduce the probability of invasion of a non-native species. Prevention protocols are to be gathered from existing biosecurity plans and evaluated on three criteria: the degree of risk from the species being prevented, the effectiveness, and its cost. The degree of risk is what was previously determined by the risk evaluation. Ideally, protocols should be chosen if they are effective protocols which reduce risk at the lowest cost. However, quantitative effectiveness determinations have been mostly unavailable for our suggested methods. Protocols have been gathered from the following biosecurity plans which are currently being implemented elsewhere:

- Chatham Islands Biosecurity Strategy Draft
- Codfish Island-Whenua Hou Biosecurity
- NPS Non Native Species Prevention Plan for Channel Islands National Park
- Rangitoto/Motutapu Rangitoto/Motutapu Pest Eradication Biosecurity Plan
- Southland Conservancy Island Biosecurity SOP Best Practice Manual
- Southland Conservancy Island Biosecurity Plan

Protocols from these plans were condensed by removing repetitive protocols and protocols that addressed agricultural practices. These protocols were then paired with species-vector combinations, based on the description of the protocol and the vector's ability to transport a given species. Some of the protocols address vectors that do not currently have species of concern for Santa Cruz Island associated with them. However, they were included in order to provide potential protocols for species of concern that may arise in the future.

Effectiveness

Effectiveness is the degree to which risk is reduced as a result of protocol implementation. However, it is hard to know how effective a protocol would be for Santa Cruz Island because effectiveness is a hard quality to measure. The number of intercepted agents is measurable, but the number of agents that are not intercepted through protocol implementation is difficult to ascertain without direct experimentation. The best way to gauge effectiveness within the time constraints of this project was to solicit the opinion of people who currently implement these protocols. Specifically, the managers who implement the biosecurity plans from which potential protocols were drawn were asked to describe their impression of each protocol's success.

A questionnaire has been developed for managers implementing other biosecurity plans so they can identify the effectiveness or their protocols, and the degree of effort being invested in them. The format of this questionnaire was a spreadsheet which can be seen in Appendix 5. Since risk has been defined based on criteria rather than a probability, the questionnaire asks managers to identify which of these risk criteria they believed the protocol contributes to reducing. Protocols probably have different levels of effectiveness for different species, so they are to be evaluated separately for four categories of invasive species: mammals, invertebrates, weeds, and fungus/disease. Additionally, in order to define the protocols in more detail and understand the level of effort being invested in the protocol, managers should define the number of hours spent on implementation and the amount of material used for each protocol. The evaluation also allows them to make any additional comments or clarifications. One issue with this evaluation method is that their answers do not indicate that the protocol completely reduces the risk associated with a risk criterion, only that it contributes to this reduction. Also, it is uncertain how applicable success in another area is to Santa Cruz Island.

Cost

Protocol costs have been gathered for the previously mentioned biosecurity measures compiled for TNC and NPS. The same method should be used to gather cost information for additional protocols. Equipment costs were determined through sourcing a market sale price from reputable local and national suppliers. Suppliers are considered reputable if the business has been in operation over five years, or if they are known in related industries for products or services they are providing, and if the equipment or service cost is reflective of other similar products or services on the market. These costs range from physical equipment to advertising placement in area media outlets. All equipment costs include detailed notes with supplier contact information, bulk order pricing breaks, and short descriptions of the equipment recommendation. Labor estimates were also incorporated into all of the applicable protocols. A blended labor rate was determined incorporating employee salary and benefits cost for both NPS and TNC employees. An estimate of first year time requirements for implementation of the protocols was used to determine the annual labor cost in the initial year of protocol enactment. Because the labor cost is subject to change over subsequent years of protocol implementation, the labor aspects of the annual protocol implementation cost should be treated as a preliminary budget and subject to frequent review and modification.

Database

The collection of information about the species of interest, vectors that may transport these species to the island, protocols that act on these vectors, and the potential associations of all three is stored in a Microsoft Access database. Additional descriptive information about each of these features is included in their respective tables. The database allows the data to be organized, updated, and selected based on specific criteria. New information about any of these features should be added to the appropriate tables of the database.

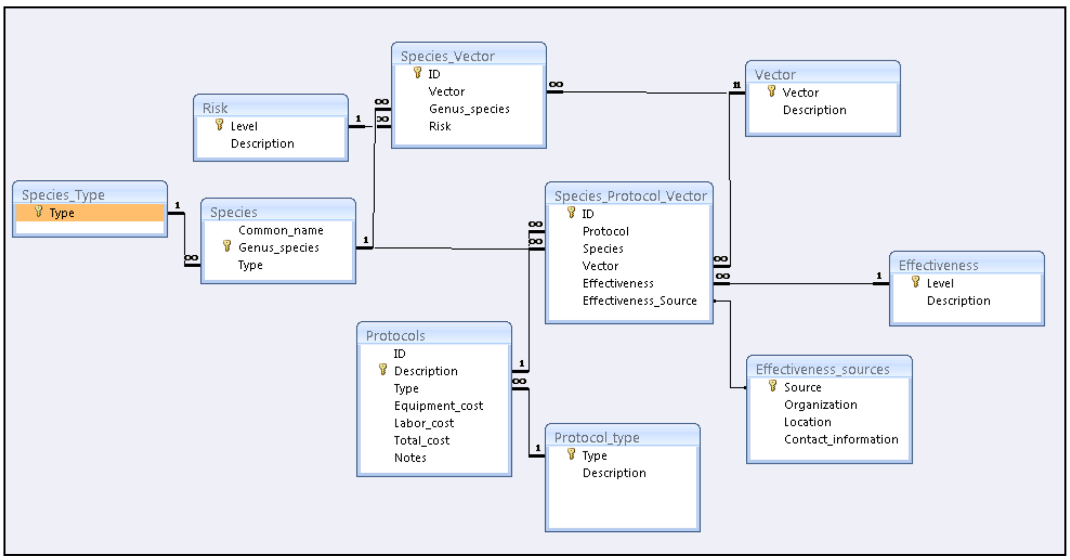

Figure 5. Relationships in the protocol database

Within the database there are 9 tables: Species, Vector, Protocols, Species_Vector, and Species_ Protocol_Vector, Risk, Protocol_Type, Effectiveness, Effectiveness_Sources, and Species_Type. Each table contains information about its components, or specifies relationships among different components. The Species table contains a common name, scientific name, and taxonomic type for each species of interest for this project. The species types include invertebrate, fungus, disease, plant, mammal, and reptile. The Vector table contains a list of vectors relevant to the island, and a description characterizing each vector. Vectors of invasive species include aircraft, animals, boxes, bulk soil, dumpsters, firewood, foodstuffs, footwear, IPCO boats, lumber, miscellaneous equipment and supplies, NPS boats, plants, private boats, vehicles, water (the ocean), and wind. The Protocols table includes an ID, a description, which defines the protocol, a labor cost, an equipment cost, an effectiveness description, the source for the effectiveness description, and any notes. The Protocols table has an ID to match the protocols to the costing information stored in an excel file. The Species_Vector table relates species with the potential vectors they may be transported on, and the risk level associated with each species-vector combination. The Species_ Protocol_Vector table relates protocols with the vector and species the protocol acts upon. Figure 5 illustrates the relationships between the database tables. The Species_Vector table and Species_Vector_Protocol tables represent many-to-many relationships, in that one vector may transport many species and one protocol may act on many vectors which transport many species. The Effectiveness, Protocol_Type, Risk, and Species_Type tables specify the possible inputs for these fields and define what these inputs mean. The Effectiveness_Source table includes the name, organization, and contact for each individual who provided effectiveness information.

3.4 Decision Making

Protocol Selection

The preceding information is to be used in order to inform decision making meant to reduce the risk posed by an invasive species. Actions should be prioritized toward species which obtained the highest risk rating. In order to select which prevention protocols may be best to implement, a query can be performed in the protocol database to select protocols based on priorities. Instructions for performing a query can be found in Appendix 6. Within the query, high protocols which meet desired effectiveness and cost standards can be selected for the species of interest. The result of such a query is the menu of recommended protocols based on the risk, effectiveness, and cost previously determined through this process.

Control & Eradication

Risk can be reduced as a result of either reducing the probability of establishment through prevention protocols, or reducing consequences through early detection and rapid response, eradication, or control. Movement from one risk category to another can be visualized on a matrix illustrating the probability of establishment and magnitude of consequence (Figure 6). Species can move either left or down in the matrix in order to move to a lower risk category, by reducing its score in either category. The nature of the protocol, the species, the vector, the level of risk of a species, and the risk aversion of the managers help determine the most appropriate management action. In other words, either prevention or control may be more feasible depending on the cost and effectiveness of a protocol, which varies by species and vector. Or it may depend on the probability that invasion will even occur. However, much of this information is necessarily qualitative and so decision making will greatly rely on priorities and risk tolerance of TNC and NPS. The decision that will be most effective depends on what other actions TNC and NPS plan to take. For example, implementing an early detection and rapid response plan is likely to make eradication a more feasible option, because it is meant to catch a species before it establishes extensively.

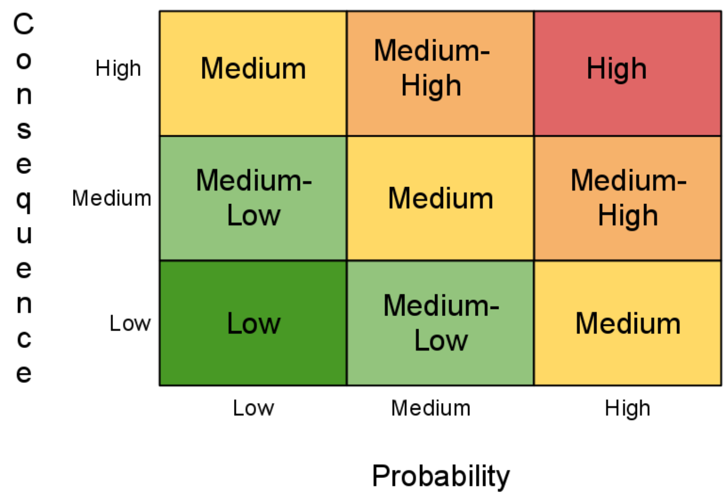

Figure 6. Risk categories as seen on a probability x consequence matrix

4 Results Based on Current Priorities

TNC provided us with species they believed to be risks to SCI, these species represent the current action priorities for the island managers. We used the above process to develop recommendations for managing the risk associated with these species of interest. It is important for TNC to regularly repeat this process to review and revise management decisions based on successes or failures, and new information and priorities.

4.1 Species & Vector Characterization

Selection

TNC created a list of species which have historically and recently become invasive in other areas, which they believe to be possible risk to SCI (Table 2). This list does not encompass every species that could threaten SCI biota or landscapes, but the process developed here can be expanded to incorporate new potential threatening agents of concern to both NPS and TNC in an ever changing ecological and climatic environment. The listed agents represent major categories of invaders including: Plants, invertebrates, mammals, and disease causing microorganisms.

Table 2. Target species derived from TNC and NPS priorities

Microorganisms/ Fungi	Terrestrial Plants	Terrestrial Animals
• Canine Diseases e.g. Distemper (*Morbillivirus Canine Distemper Virus*); Rabies (*Lyssavirus rabies*); Parvovirus • Earthworms • Planarians (*P. manokwari, B. Adventitum*) • Sudden Oak Death (*Phytophthora ramorum*) • West Nile Virus (*Flavivirus West Nile Virus)* • Chytrid fungus (*Batrachochytrium Dendrobatidis*)	• Cape Ivy (*Delairea odorata)* • Fountain Grass (*Pennisetum setaceum)* • Re-infestation of the 18 weeds targeted for eradication	• Argentine Ants (*Linepithema humile*) re-invasion • Red Imported Fire Ants (*Solenopsis invicta*) • Gold-spotted oak borer (*Agrilus coxalis)* • Cats (*felis catus)* • Raccoons (*Procyon lotor*) • Rats (*Rattus sp*) • House Mice (*mus musculus*) • NZ Mud Snail (*Potamopyrgus antipodarum*) • Squirrels (*Spermophilus beecheyi* and *Sciurus* sp)

Characterization
Species descriptions for the species of concern can be found in Appendix 11. As part of the characterization process, we identified the vectors to be used in the risk evaluation process.

4.2 Risk Prioritization

Using the risk evaluation worksheet, each of the vectors-species combination of concern was assigned a risk score (Table 3). The species of highest priority are those at the top of the list and will be the first to have management action determinations made for them (Figure 7).

4.3 Protocol Evaluation

Effectiveness
Two responses to the protocol evaluation questionnaire were received, from Chatham Islands Conservancy and from Secretary and Resolution Island in the Southland Conservancy. Both conservancies are part of the Department of Conservation in New Zealand. These evaluations are joined by comments on the Island Conservation biosecurity plan which qualitatively define the reviewers' confidence in the various

Table 3. Risk prioritization for each species vector combinations. Black rats and Norway rats are included in the rats category.

	Vector																		
Species	Aircraft	Animals	Bulk soil	Container	Dumpster	Firewood	Foodstuffs	IPCo Boat	Lumber	Miscellaneous equipment and supplies	NPS boat	Personal gear	Plants	Private boat	Staff and Contractor footwear	Vehicles	Visitor Footwear	Water	Wind
Argentine Ants	Medium risk		Medium risk	Medium risk	Medium risk	Medium risk			Medium risk	Medium risk		Medium risk	Medium risk			Medium risk			
Brown tree snake								No Risk			No Risk			No Risk					
Canine Distemper (Domestic)								No Risk			No Risk			Medium high risk					
Canine Distemper (Other wild)								No Risk			No Risk			No Risk					
Canine Distemper (Raccoons)								High risk			High risk			High risk					
Cape Ivy	High risk	High risk	High risk							High risk		High risk	No Risk			High risk		High risk	
Chytrid Fungus			No Risk							No Risk		No Risk	No Risk		No Risk	No Risk	No Risk		
Domestic cat					High risk			Low risk			Low risk			No Risk					
Earthworms			Medium risk							Medium risk			Medium low risk		Low risk	Medium low risk	Low risk		
Fountain grass	Medium low risk		Medium low risk							Medium low risk		Medium risk	Medium low risk		Medium risk	Medium low risk	Medium risk	Low risk	
Goldspotted Oak Borer						Medium high risk			Medium high risk										
House mouse								Medium high risk			Medium high risk	Medium high risk		Medium high risk					
New Zealand Mud Snail										High risk					High risk	High risk	Medium high risk		
Parvovirus (Domestic animals)								No Risk			No Risk			High risk					
Parvovirus (Other wild animals)								No Risk			No Risk			No Risk					
Parvovirus (Raccoons)								High risk			High risk			High risk					
Planarians			No Risk							No Risk			Low risk			No Risk			
Rabies (Domestic animals)								Medium high risk			Medium high risk			Medium high risk					
Rabies (Other wild animals)					High risk			No Risk			No Risk			No Risk					
Rabies (Raccoons)					Medium high risk			High risk			High risk			High risk					
Raccoon					High risk			Medium high risk			Medium high risk			Medium high risk					
Rats	High risk			High risk	High risk			High risk			High risk	High risk		High risk					
Rattlesnakes								Low risk			Low risk			Low risk					
Red imported fire ant	Medium high risk		Medium high risk	Medium high risk	No Risk	Medium high risk				Medium high risk		No Risk	No Risk			Medium high risk			
Sudden Oak Death Syndrome			Medium risk							Medium risk		Medium risk	Medium risk		Medium risk	Medium risk	Medium risk		
West Nile Virus		High risk																	
Western Gray Squirrel					Medium risk			Medium low risk			Medium low risk			Medium low risk					

● – High risk, ● – Medium high risk, ● – Medium risk, ● – Medium low risk, ● – Low risk, ○ – No Risk

High Risk

- Cape Ivy – Aircraft, animals, bulk soil, miscellaneous equipment and supplies, personal gear, vehicles, and water
- Domestic cat – Dumpster
- West Nile Virus – Animals
- Rabies (other wild animals) – Dumpster
- Rabies (raccoons) – IPCo, NPS, and private boats
- Canine Distemper (raccoons) – IPCo, NPS, and private boats
- Parvovirus (domestic animals) – Private boat
- Parvovirus (raccoons) – IPCo, NPS, and private boats
- New Zealand Mud Snail – Contractor Footwear, miscellaneous equipment and supplies, and vehicles
- Raccoon – Dumpster
- Rats – Aircraft, container, dinghy, dumpster, IPCo boat, NPS boat, personal gear, and private boat

Medium High Risk

- Canine Distemper (Other wild animals) – Private boat
- Goldspotted oak borer – Firewood and Lumber
- House mouse – IPCo boat, NPS boat, Private boat and personal gear
- Rabies (domestic animals) – IPCo, NPS, and private boats
- Rabies (raccoons) – Dumpster
- Canine Distemper (raccoons) – IPCo, NPS, and private boats
- Parvovirus (domestic animals) – Private boats
- Parvovirus (raccoons) – IPCo, NPS, and private boats
- New Zealand Mud Snail –Miscellaneous equipment and supplies, staff and contractor footwear, vehicles, and visitor footwear
- Raccoon – IPCo, NPS, and private boats
- Red imported fire ant – Aircraft, bulk soil, container, firewood, miscellaneous equipment and supplies, and vehicles

Medium Risk

- Argentine ants – Aircraft, bulk soil, container, dumpster, firewood, lumber, miscellaneous equipment and supplies, personal gear, plants, and vehicles
- Earthworms – Bulk soil and miscellaneous equipment and supplies
- Fountain grass –Personal gear, staff and contractor footwear, and visitor footwear
- Sudden oak death syndrome – Bulk soil, Miscellaneous equipment and supplies, personal gear, plants, Staff and contractor footwear, vehicles, and visitor footwear
- Western gray squirrel – Dumpster

Medium Low Risk

- Earthworms – Plants and vehicles
- Fountain grass – Aircraft, bulk soil, miscellaneous equipment and supplies, plants, and vehicles
- Western gray squirrel – Private boat, IPCo boat, and NPS boat

Low Risk

- Domestic cat – IPCo and NPS boats
- Earthworms – Staff and contractor footwear and visitor footwear
- Fountain grass – Water
- Planarians – Plants
- Rattlesnakes – IPCo, NPS, and private boats

Figure 7. Species-vector combinations categorized by risk can be used to inform management priorities

No Risk

- Brown tree snake – IPCo, NPS, and private boats
- Canine distemper (domestic animals) – IPCo and NPS boats
- Canine distemper (other wild animals) – IPCo, NPS, and private boats
- Cape ivy – Plants
- Chytrid fungus – Bulk soil, miscellaneous equipment and supplies, plants, personal gear, staff and contractor footwear, vehicles, and visitor footwear
- Domestic cat – Private boat
- House mouse – Private boat
- Parvovirus (domestic animals) – IPCo and NPS boats
- Parvovirus (other wild animals) – IPCo, NPS, and private boats
- Planarians – Bulk soil, miscellaneous equipment and supplies, and vehicles
- Rabies (other wild animals) – IPCo, NPS, and private boats
- Red imported fire ant – Dumpster, plants, and personal gear
- Western gray squirrel –Private boats

Figure 7 Continued

protocols. The effectiveness evaluations have been entered into the protocol database as effective, recommended, not effective, infeasible, or no information. An effective protocol is one which has been proven to be effective with monitoring, and is a rare designation to be given. A recommended protocol is one which experts in the field to be useful. A protocol labeled as not effective is one which experts believe will not be useful in reducing risk. It is different from an infeasible protocol, which would have legislative and regulatory barriers to implementation. Any protocol for which no opinion was gathered is noted as having no information.

Secretary and Resolution Island are visited very infrequently so there was little experience with how successful many of the protocols are. The reviewer, Peter McMurtrie, provided details about their protocols to indicate how commonly they are implemented. Most protocols in the biosecurity plan are implemented except for the following two exceptions: Cardboard boxes are allowed for transporting equipment, and high risk food waste is not removed from the islands.

The biosecurity manager of the Chatham Islands Conservancy completed the evaluation. The level of effort for several protocols was unknown because it was in the hands of contracted shippers, or relied on voluntary compliance by dockworkers. However, on-site monitoring and trapping are being implemented by the conservancy. Protocols from the plan not being implemented include putting biosecurity information on posters or on a website. Other educational protocols are being implemented such as staff training and the distribution of about 80 brochures per year. The Conservancy recognizes the importance of auditing and reviewing the biosecurity plan but has yet to do so.

Additionally, comments on biosecurity protocols have been incorporated into the protocol database. Protocols which were identified as ineffective or which were supported by an expert were identified as such in the database. In light of the lack of published or empirical protocol evaluations, expert opinion becomes very useful in gauging how effective a protocol may be. This highlights the importance of communication across agencies nationally and internationally that is necessary in developing biosecurity plans.

Cost

Preliminary cost estimates have been determined for 89 protocol recommendations. Feedback from both TNC and NPS was solicited to evaluate labor time estimations and their associated cost, as well as general feedback on the protocol suggestions developed by the group. Kate Faulkner of the National Park Service, and Coleen Cory and Christina Boser of The Nature Conservancy are currently in the process of reviewing preliminary cost estimates, including their applicable labor components to collaborate and confirm budgeted time estimations.

Database

The database has been populated to include information about all of the protocols initially gathered for this project. It currently includes some protocols which are not relevant to the current priorities of TNC and NPS. These protocols can be used in combination with future changes to management priorities. The database can also be updated with new information about protocols, species, and vectors.

4.4 Decision Making

Risk can be reduced either by either lowering the probability of invasion through prevention protocols or by decreasing the consequences through early detection, rapid response, control or eradication. Lowering the probability of introduction is chosen when available protocols are able to prevent species of high risk, are effective, and have a defensible cost. Decreasing consequences is a more feasible option when the vectors for introduction cannot be fully addressed through prevention protocols, or when the cost of effective control or eradication is lower than the cost of prevention.

Protocol Recommendations

The final protocol recommendations were selected from the protocol database for high risk species-vector combinations. As a way of selecting protocols which could be effective, a query was written to isolate protocols which were either recommended by experts or for which no effectiveness information was gathered. We did not want to exclude protocols just because no one had commented on them, though ultimately we still favored protocols which had been recommended by experts in biosecurity management. Only protocols which had been associated with these high risk combinations within the database would be chosen by the query.

From these query results, we selected which protocols would be the best choice for reducing the risk of each species-vector combination. In the hopes of increasing the cost effectiveness of the overall plan, we chose to favor protocols that were selected multiple times by the query and would therefore be effective at reducing the risk from multiple species at once. After selecting the most common protocols, we identified which species-vector combinations still needed to be covered by prevention protocols. When given a choice of multiple protocols, the least costly protocol was selected. Educational protocols were also selected but they were not considered to be adequate by themselves for controlling invasive species risk. The final recommendations can be found in Appendix 8. Included in these recommendations is which species-vector risks these protocols are intended to manage. Even though these protocols were selected based on their ability to reduce risk from high risk species-vectors, we also indicated what other combinations were impacted by the protocols.

Inherent in many of the recommended protocols is the need for either a responsible staff member or a designated biosecurity manager to implement or enforce them. The success of selected protocols will be contingent upon the experience and knowledge of those carrying them out and the degree of accountability to which those parties are held. We therefore recommend that the island managers institute a training program for staff and designate parties responsible for ensuring compliance with each protocol.

Staff will need to be trained on a range of materials including how to use the decision process, which protocols to implement and the method of implementation, as well as general knowledge about invasive species threats. Training should be performed by those who were involved with the creation of the decision process, are knowledgeable about invasive species, as well as the structure of SCI management. Who will be trained and to what degree will depend on how biosecurity responsibilities are distributed. Biosecurity related responsibilities can be centralized in one position or spread more diffusely across organizations and departments. The responsibility structure chosen should be one which accomplishes successful protocol implementation at an efficient cost, promotes interagency collaboration, and can be most smoothly integrated with existing practices and institutional structures.

The most centralized mechanism would be the hiring of a new staff member as a biosecurity manager, a practice that appears commonly in the management plans for islands in New Zealand. The biosecurity manger would be responsible for creating a training manual for staff, running training sessions, keeping up biosecurity infrastructure such as rodent traps, inspecting shipments and equipment being sent to the island, developing early detection and rapid response plans (described in Section 5), monitoring the success of protocols, responding to potential breaches in biosecurity, enforcing protocols where necessary, and monitoring for new threats to be evaluated and integrated into the existing plan. In this case, training and additional responsibilities for other staff members would be minimal. Staff training would focus on the importance of biosecurity to the island's ecological integrity, explain the role of the new manager, and tell staff members what to look out for and how to report any incidents.

If a biosecurity manager is not hired, all staff members could receive a more in depth training and each department would be responsible for carrying out all relevant biosecurity duties. The way responsibilities would be distributed across staff can vary, though it may be most reasonable to make staff members accountable for the area in which they work. For example, personnel on the ships themselves would be responsible for checking and maintaining on board rodent traps and reporting any incidents threatening island biosecurity. Loading and dock personnel would be responsible for keeping the dock area weed and rodent free and inspecting equipment or other materials headed to the island. In this case, training would focus on those topics mentioned above as well as a detailed department-specific description of what biosecurity related duties are expected and how to accomplish them. An individual in each department could be assigned to double check compliance, receive incident reports, and hold staff members accountable for carrying out protocols. This mode of implementation still requires the creation of a manual to facilitate employee training and a central figure to provide training, collect incident reports, field questions.

Whichever action is taken, the goal should be to keep staff members informed of biosecurity concerns and hold them accountable to carrying out the accepted protocols at the lowest cost and in a way that can function smoothly within the existing institutional structures of TNC and NPS. Since group members lack an in-depth knowledge of TNC and NPS's organizational structures, it is possible that neither of these scenarios are the optimal method for accomplishing this goal. We currently recommend the strategy of training staff in biosecurity practices and theories because of the lower cost it would incur. However, TNC or NPS may determine that it is not feasible to distribute these responsibilities among all staff. In this case, they can either choose to identify a select number of responsible staff or hire an employee with the sole purpose of implementing biosecurity.

Control & Eradication

Gathering information about control and eradication options was part of the species description process. The goal when performing this review was to be able to compare the expense and effectiveness of control with prevention. However, a direct comparison prevention and control is difficult. One reason for this difficulty is that the descriptions of cost are inexact for Santa Cruz Island, sometimes greatly so, and descriptions of effectiveness are qualitative. This makes it difficult to produce a straight forward result. Another reason is that control costs must be weighted by the probability that control will be necessary. A long term prevention protocol may not necessarily be wise when there is a very low probability of invasion or a low consequence of establishment. However, actions are prioritized toward the highest risk species where it can more easily be assumed that control will be necessary. The lack of accuracy in the assessment of control and prevention makes it difficult to identify the proper decision in every situation. However, features of some control and eradication options make them clearly undesirable compared with implementing prevention protocols.

Control methods can also be exorbitantly expensive. When non-target species are likely to be impacted, especially when they are listed or otherwise sensitive species, mitigation against these impacts greatly increases the cost of control. Eradication of feral cats on San Nicolas Island cost $3 million, in part due to the mitigation to ensure no harm came to the island fox populations (Barlow 2010), Kate Faulkner, NPS, personal communication, October 12, 2010). There are likely to be similar cost issues mitigating against impacts to the island fox on Santa Cruz Island. Members of the Montrose Settlements Restoration Program have determined that impacts to native species make rat eradication on San Miguel Island impossible (Montrose Settlement Restoration Program 2010). This does not make control ineffective, as eradication has been carried out while protecting sensitive species, but it does make prevention more favorable.

There are some species for which no well tested control methods exist, or methods that do exist are not likely to be effective. For example, no control methods exist yet for planarians or earthworms (Kawakami & Okochi 2010, MN DNR 2003). The effectiveness of a protocol depends on the degree of infestation. A small patch of cape ivy was removed from Santa Cruz Island in the 1970s soon after detection (Knapp et al. 2007). Removal of larger areas of cape ivy is much more difficult and many areas have only reached the control stage rather than complete eradication (Alvarez 1997). Therefore, a more successful eradication effort will occur if an invasive species is detected before it spreads to an unmanageable area. In the following section, the process of developing early detection plans for high risk species is discussed. Early detection allows managers to respond rapidly to invasions before they reach unmanageable sizes.

5 Early Detection & Rapid Response

EDRR planning is a way of reducing the consequence of an invasion. Focusing on reducing consequence is most appropriate for cases where the probability of introduction for an organism cannot or will not be reduced through biosecurity protocols. This is often the case for species vectored by private boaters, the actions of which are not subject to oversight by the island managers. Within the group of species for which preventative action cannot or does not address threats, magnitude of consequences can be used to prioritize which species are most appropriate for the development of EDRR plans and the implementation of early detection monitoring.

The development of species-specific management plans included extensive literature review and use of expert opinion to qualitatively describe the likelihood of establishment, magnitude of potential consequences, detection methods and materials, available eradication options, and regulatory processes necessary to enact the plan.

Likelihood of establishment
Factors under consideration included: species ability to stow away on vectors reaching the island, reproductive system, dispersal characteristics, natural enemies

or predators in new environment, ability to sequester underused resources, suitable habitats.

Magnitude of potential consequences
Factors considered included: reproductive system, rate and extent of a potential invasion given dispersal characteristics and habitat suitability, natural enemies or predators in new environment, native species that may be affected, and evidence of impacts on native species on other islands.

Detection and Eradication options
This included a summary and evaluation of existing methods for detecting and removing each of the three species including: supplies, permits, and personnel required under each rapid response plan, and provide a brief summary of the cost associated with supplies and staff for the particular rapid response plan in question. This information was gathered from published literature, estimates from TNC or NPS, market research into various pest control cost measures in the Ventura County area, and consultation with experts, including staff at Island Conservation.

Permitting and Regulation
Regulatory and permitting processes can be a significant impediment to rapid action. Multiple regulatory bodies are likely to be involved in any major action that takes place on the island due to the sensitivity of island wildlife and stringency of California's environmental regulations. State and federal permitting and regulatory processes were determined for the relevant detection and eradication methods. Agencies from which compliance action was most frequently required include: California Coastal Commission, California Department of Pesticide Regulation, and California Department of Fish and Game, Environmental Protection Agency, and US Fish and Wildlife Service.

Species Selection
EDRR plans were developed over a summer internship, before the group developed the risk evaluation methodology. As such, it was not possible to complete risk evaluations for all species before selecting those for which EDRR plans would be developed. Three species were initially selected by client priorities - Rats (*Rattus* spp), gold-spotted oak borer (*Agrilus coxalis)* (GSOB), and the amphibian pathogen chytrid fungus (*Batrachochytrium dendrobatidis*). After initial investigation, chytrid fungus was replaced by *Phytophthora ramorum*, the causal agent of the disease known as Sudden Oak Death. Having now completed the risk evaluation, we reflect on which the chosen species were best suited for an EDRR plan, and ways in which methodology of species selection can be improved in the future.

Rats - Rats can reach the island by multiple vectors, not all of which can be adequately addressed through prevention protocols, particularly private boats. Private boats are considered a high probability vector for rats, which are considered a high consequence invader. Island managers have no ability to insure that private citizens maintain rodent free vessels. Monitoring and preparing for an incursion by rats, particularly at popular anchorages, is an appropriate action.

Gold-spotted oak borer - GSOB adults and larvae can reach the island under the bark of firewood. Existing prevention protocols already prohibit the transportation of firewood to the island. This prohibition is well enforced by IPCO and the NPS. Managers prohibit but cannot control firewood brought to the island by private boaters. Firewood is considered a medium probability vector for GSOB, which are considered a high consequence invader. Monitoring and preparing for an invasion by the GSOB is an appropriate action, but a preparing EDRR for a species with a high probability uncontrolled vector would take priority.

Chytrid fungus - Fungal spores can be transported by a myriad of vectors that reach the island. At least two high probability vectors, footwear and personal gear, can be transported to the island by private boaters, an uncontrolled vector. Additionally, it is not possible to visually detect spores on the clothing and gear of visitors or disinfect them before passage to the island. However, it was determined through expert consultation that chytrid did not pose a threat to the amphibian species on SCI. Since the magnitude of consequences is low to none, so this is not a species for which EDRR is appropriate. This conclusion was reached over the summer, and an EDRR plan was not developed.

P. ramorum **-** Similarly to chytrid fungus, the spores of *P. ramorum* can arrive through multiple high probability uncontrolled vectors. Risk evaluation revealed that the magnitude of consequence associated with establishment of *P. ramorum* is medium.
In this case, as with the GSOB, the development of an EDRR plan is warranted, but is a lower priority than a species with high probability uncontrolled vectors AND high magnitude of consequence.

In the future, be advised that the preparation of an EDRR plan be undertaken after a risk evaluation has been completed and managers have determined that EDRR is the most appropriate way to address that risk.

The EDRR Plans are stand-alone documents and have already been delivered to TNC.

6 Education

TNC hopes to develop a public education campaign for all island visitors, particularly the recreational boating community, advocating the importance of the preventing invasive species introductions. We drew on literature from the marketing field and from studies that examine the efficacy of public education campaigns to provide a review of recommended techniques to assist in this effort.

A literature review and analysis of comprehensive survey design was also performed during a summer internship. A survey was developed in an effort to measure attitudes of the private boating community towards island preservation, as well as participation in and opinions of current permitting programs and regulations. One aspect key to effective survey design is the incorporation of effective question structuring that allows the administrator to obtain effective answers and data from the survey population. The survey developed for TNC incorporates feedback and ideas from several different managers from within TNC in order to address question phrasing that combines several key concerns. Survey question construction was also reviewed by Dr. Sarah Anderson of the BREN school. A determination was made by TNC to launch the survey questionnaire primarily on-line via their website strictly for budgetary reasons, even though the response rate for on-line surveys has been observed to be between roughly 10 and 12% (Rea & Parker 2005). The survey is currently open and being administered by TNC staff. This survey can be found in Appendix 8.

Additional educational material developed for TNC includes, a calendar of events for the year end 2010 and beginning of 2011, a list of relevant research outlets, and a poster advertising both the survey and the permitting process. The calendar of events was started to identify appropriate occasions for TNC and NPS to present educational outreach materials. There were some limitations to filling the calendar through year end 2011 as many event dates seem to be solidified in their scheduling times closer to the actual event occurrence, as well as some that can be weather permitting. The poster design was aimed to attract the attention of prior island visitors by depicting common private boating anchorages with this outreach advertisement, and marketing the poster at several appropriate outlets such as West Marine stores across California, yacht clubs, and marinas.

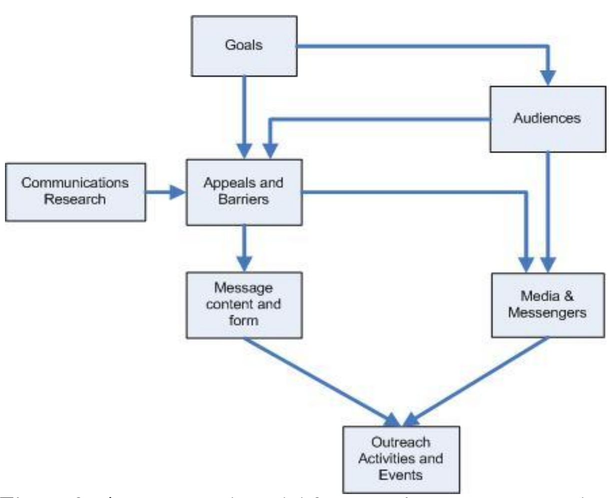

Figure 8. A conceptual model for targeting messages to the private boating community, adapted from Sandman (2000).

We propose that TNC use the framework shown in Figure 8 as a guide toward a message and mode of delivery that will be effective at accomplishing education goals with the recreational boating community (Sandman 2000). To this end, we have described the steps and completed some work toward the development and dissemination of messages to promote biosecurity.

Goals

The first step is to define the goals of the educational campaign. Environmental education campaigns frequently state that the goal is education or awareness, but we believe that the true goal of educating private boaters and other park visitors is to encourage them to voluntarily change their behavior in a way that promotes island biosecurity goals. In other words, the ultimate goal is for people to change their behavior. Awareness of a problem, as discussed below, is just one part of accomplishing this. This is an important distinction to make due to a concept known as the "value action gap." Sociological research of environmental behavior shows that a gap exists between the knowledge and values held by individuals, and the actions that they take. Research on the "value-action gap" reveals that knowing and caring about an environmental issue are not typically enough to get people to act in a way that will contribute to solving it (Chung & Leung 2007, Flynn et al. 2010, Kollmuss & Agyeman 2002). This implies that an education campaign such as this one, which seeks to encourage voluntary participation from island visitors, will need to do more than simply make people aware of the ecological consequences of invasive species. This is not to say that awareness is not important, simply that it is not enough to accomplish TNC's goals and that messages should be crafted in such a way that individuals are more likely to act on the information, to overcome the gap.

Audiences

The next step in the conceptual model is to determine the most appropriate audience or audiences that need to be reached in order to accomplish the goal. In this case, the most appropriate audience is the private boaters who visit SCI. Due in part to limited enforcement capacity, TNC and NPS have little control over the actions of this group. Any biosecurity action that is to occur within this community will need to be of a voluntary nature. Determining how best to reach and influence this audience requires an in depth understanding of them. In the same way that companies use market research to understand how best to sell a product, so too must the organizers of a public education campaign do research to understand how to sell their ideas and promote environmental behavior. Important characteristics of a target include: their current and past involvement with the topic, current knowledge of the topic, expectations, social norms, culture and values- both complimentary and competing (Maibach 1993). Information gathering on the private boating community has recently begun through the use of an online survey, as discussed in Section 3.7. Conducting personal interviews and recording information from casual encounters may further inform TNCs understanding of boater ideas, needs, culture, and values.

Appeals and Barriers

This information, in addition to sociological research, can be used to identify the appeals and barriers that the audience has toward accepting new ideas, changing behavior, and helping to accomplish goals. Appeals can also be thought of as benefits or incentives, barriers can also be thought of as costs. Ideas will be more readily accepted if the appeals are articulated in terms that the audience will appreciate and relevant barriers can be removed or reduced. Appeals and barriers can be put into three general categories: monetary, personal, and social. All are important in promoting the new ideas, but between the three, sociological research tells us that normative and social factors are by far the most powerful in promoting environmental behavior (Folz & Hazlett 1991, Chung & Leung 2007). An initial assessment of appeals and barriers relevant to changing behavior amongst the boating community to promote biosecurity are shown below.

Appeals

- Personal
  - When environmental action is normative, people gain satisfaction from doing what they perceive to be a good thing.
- Social incentives
  - Creating a positively reinforcing mechanism that rewards compliance with status/societal recognition for their "good deed," typically involves a highly visible indication of compliance (Chung & Leung 2007, Maibach 1993).
  - Tie the message to respected figures, organizations. Most effective if the information comes from them and is supported by them (Blake 1999).
- Monetary Incentives
  - Avoiding enforcement tickets (Chung & Leung 2007).

Barriers

- Personal
  - Convenience - changing habits can require an initial input of time and energy
  - Tradition
  - Disapproval of island management
- Social barriers
  - Traditions amongst family and friends
  - Culture of entitlement to anchorage and landing spots
  - Culture of resistance to island management
- Monetary barriers
  - Other locations with similar appeal may be further away and require more off time and resources to reach.
  - Cost of boarding pets

It is critical to note that those items listed above that do not include citations are, at this point, based purely on speculation and should serve as a hypothesis to be tested rather than the basis for moving forward to develop messages. Information gathered through the online survey will be a more accurate representation of the audience in question and will lead to the confirmation or rebuttal of these initial guesses.

Messages

Messages should emphasize appeals and reduce or remove barriers to the adoption of new ideas and new behaviors based on information gathered through audience research.

Media and Messengers

Messages can be delivered in multiple ways. The appropriate communication channel can be chosen based on the number of people that can be reached, the kind of people that can be reached, and the rate of influence/the kind of impact (Maibach 1993). Interpersonal channels have low reach, high specificity, and a high potential rate of influence. Mediated channels, such as public service announcements, fliers, posters and signage, have higher reach, lower specificity and lower rate of influence. Utilizing multiple channels allow the message to be communicated on multiple levels of that spectrum.

Summer research produced contact information for organizations within the boating community as well as a calendar of events describing relevant information about outlets through which information could be disseminated. The poster to market the survey and advertise the existing permitting and regulation program on SCI for private boat visitation is included in Appendix 9.

7 Discussion

7.1 Next Steps

Going forward, TNC and NPS will be responsible for deciding which protocols to implement and how to compliment them with other aspects of biosecurity. We recommend that island managers implement an overarching passive adaptive management program with an internal audit and review process, using the tools presented here to incorporate new information and updating the plan based on the observed effectiveness of protocols.

Holistic Biosecurity

The actions that TNC and NPS ultimately take will depend on their priorities, risk aversion, and budget in addition to the recommendations that have resulted from this analysis. The usefulness of the risk prioritization and the prevention plan would be improved if other aspects of a holistic biosecurity plan are incorporated, particularly research and education. For example, managers for SCI have a history of researching and developing methods for mitigating for non-target effects associated with eradication efforts. It would benefit both the island and conservation efforts worldwide if that research were to continue. As another example, successful messaging and education of island visitors and the recreational boating community may increase compliance and reduce uncontrolled vector arrival, reducing the chance of an incursion and reducing the need to implement early detection monitoring.

Internal Auditing & Adaptive Management

To continually improve the biosecurity plan, it is recommended that an annual or biennial review of the plan's effectiveness and an internal audit of stakeholder performance are performed. The primary goal of an internal audit and review process is to have an effective tool for identifying changes that should be made to the biosecurity plan. Identifying changes which need to be made arises from assessing new threats, evaluating efficacy of the existing program, and ensuring the plan is being properly implemented. This system involves establishing an internal audit and review team with clearly defined goals and responsibilities, requiring documentation of decisions, protocols, implementation, results, and modifications, and then incorporating results of audit and review into plan updates and implementation (Hathaway & Fisher 2010).

There is a certain degree of uncertainty involved in developing a biosecurity plan; choosing which species are risks to the island and which protocols will be effective at reducing this risk is done on the best available knowledge, which is typically incomplete. This uncertainty can be reduced by implementing an adaptive management program, a systematic process for continually improving management policies and practices by learning from the outcomes of previously employed policies and practices (Hassan et al. 2005). Within the field, there are two types of adaptive management: active and passive adaptive management. Active adaptive management relies on managers simultaneously enacting alternative practices and policies as an experiment to see which option reveals itself as the best management action. Passive adaptive management relies on managers to pick the optimal management option based on the best available information and monitor its success to determine if conservation goals are being met. Inherent in both active and passive adaptive management is careful implementation, monitoring, evaluation of results, and subsequent adjustments of objectives and practices (Hassan et al. 2005). Passive adaptive management is preferred in this scenario because it does not require the capacity to implement multiple policies at one time and requires less time and structure for managers who are already spread thin. Passive adaptive management is also preferred because creation of a robust experiment requires testing similar management options in the same or similar conditions simultaneously, preferably with replication. This is far more easily accomplished when testing landscape treatments than here, where the majority of trips to the island leave from just one harbor on only a few boats.

A passive adaptive management program is useful for monitoring or tracking the ability of protocols to intercept target species, and will greatly improve the ability of managers to improve or replace ineffective protocols and justify spending on effective protocols. Tracking agents intercepted through biosecurity protocols is the first step. However, if a protocol does not intercept target species, this could indicate either that it is ineffective or that the species is not present at that vector. Ideally, the monitoring design would be able to tease apart this difference. This will be difficult to accomplish, doubling detection effort for a period of time to see if additional agents are intercepted would be one option, another would be to periodically monitor high use areas on the island to see if targeted organisms are getting through. In this framework, the implementation of each protocol is essentially a trial period. Managers may find that a given protocol can be more effective, in which case spending on that protocol is justified. Conversely, they may find it to be ineffective and choose to discontinue implementation, reducing spending that does not contribute to biosecurity goals.

New information should also be incorporated throughout the adaptive management process. This review process can identify new threats, which are certain to arise, and incorporate new information on existing threats, including new techniques for preventing, monitoring, and controlling individual species. Knowledge about these topics should be continually improved upon through literature review and communication with experts. The tools presented in this report can continue to be used to evaluate new threats and make decisions when circumstances change. It is important to note that the output of any future analysis using this method will be only as good as the information that goes into it. The outlined steps are meant to identify the information that must be made explicit in biosecurity plan development, not to act as a perfect recipe. Those utilizing these tools will need to conduct the necessary research about species biology and ecology, determine cost and effectiveness of potential actions as accurately as possible, and think critically about the results.

Improving the biosecurity plan will also rely upon an internal audit of the compliance with and proper execution of implemented protocols, identifying successes and difficulties with implementation. By nature, biosecurity plans need cooperation and agreement from many parties to be effective. They necessitate acceptance of new policies, and most importantly, they require changes to current behavior. In this situation, an internal audit and review process can bolster implementation and efficacy by providing an opportunity to discuss the degree to which protocols are being accepted and followed, brainstorm ways to improve compliance, and integrate new biosecurity detection and response methods as they are developed (Hathaway & Fisher 2010).

7.2 Uncertainty & Data Limitations

Many aspects of this project and biosecurity planning in general could benefit from more information. The high degree of uncertainty surrounding many aspects of biosecurity is the reason these qualitative processes were developed to guide analysis using relevant and existing information. Uncertainty can come in the form of both epistemic uncertainty from a lack of knowledge, and linguistic uncertainty resulting from ambiguous meanings (Benke et al. 2011). Epistemic uncertainty leads to the inability to get an exact answer or quantification. Alternate interpretations from person to person of the criteria that have been developed can lead to more uncertainty in the results of this process. Communicating these sources of uncertainty, and where they impact the results is important if management decisions are to be based on this information (Morgan et al. 1990). The specific instances of uncertainty are dealt with below, along with actions taken to deal with them.

The first step in the risk evaluation process was to develop descriptions of the biology and ecology of the target species, but many of these important factors are difficult to know. For example, information about the probability that a species is likely to be associated with a particular vector us very hard to come by. An incomplete knowledge about each species ultimately hinders the ability to do an accurate risk evaluation. Additionally, lack of information about Santa Cruz Island also leads to uncertainty in risk evaluation. For example, the New Zealand mud snail may out-compete other invertebrates, yet the diversity of invertebrates on Santa Cruz Island is unknown so the impact of the snail is also unknown. Generally, a precautionary approach was taken in the risk evaluation, where a species was assumed to meet a certain risk criteria if the actual answer was unknown.

Even with the information gathered about the target species, the variability of nature makes it difficult to use this information to accurately predict what might occur on Santa Cruz Island (Benke et al. 2011, (Bierbaum & Baker 1999). This is a big issue when it comes to determining what the cost and effectiveness of control and eradication measures might be on Santa Cruz Island. This makes control estimates very rough, making a direct comparison between prevention and control difficult. Therefore, major issues with implementing control measures were identified to determine if a control measure is infeasible or ineffective.

Uncertainty in criterion weights leads to reduced confidence in the result of the risk evaluation. Benke et al (2011) dealt with uncertainty in the weights of the multi criteria decision analysis in the Victorian Weed Risk Assessment by performing a Monte Carlo analysis using a range of possible weights. All criteria were weighted equally in this project. This may not accurately reflect the actual weights of each criterion but there is no scientific consensus otherwise regarding what traits best define an invasive species, especially across species types. This is especially difficult because indicators of species risk varies across species types (Kolar & Lodge 2001)(Hayes & Barry 2008). Several similar risk evaluation worksheets use equal weighting to deal with this issue (Drucker et al. 2008)(Campbell & Kriesch 2003).

It was difficult to find reasons why authors of biosecurity plans had chosen their respective protocols, and whether these protocols were effective. There is no evidence that there have been reviews of existing biosecurity plans. Therefore, it is difficult to see why plans continue to use the same protocols. To change this, the opinion of people with experience using these protocols was elicited to begin gathering information on protocol effectiveness. Carefully recording this information and sharing it across agencies would greatly improve existing information sources.

The decision process developed throughout this project may not be interpreted the same way by all users. This linguistic uncertainty is the result of vagueness, ambiguity, context dependence, lack of specificity, or the time indeterminacy of theoretical terms used in the framework (Benke et al. 2011). For this reason, this decision process is not recommended as a recipe. Instead, this process was developed as a way to highlight what information is important to consider when developing a biosecurity plan, and how to use this information.

7.3 Conclusions

Several lessons were learned about the development of a biosecurity plan throughout this process. They are the key concepts which should be kept in mind when trying to manage invasive species risk.

1. Risk assessment provides a logical framework for analyzing potential species threats on Santa Cruz Island and can serve as a method for prioritizing management action. Biosecurity plans developed without support from a risk prioritization process are less likely to result in an efficient allocation of resources. They also lack the ability to convince participants that biosecurity measures are necessary.

2. Data regarding the effectiveness of individual prevention protocols, the synergistic effectiveness of complete biosecurity plans, and the costs associated with eradication and control is rare. This information would greatly improve managers' ability to make cost effective decisions about managing risky species. Effectiveness information comes as a result of monitoring and reviewing prevention and control protocol success. Cost information is most helpful when the labor, administrative, and equipment costs are reported, as well the associated process and areal extent of the project. This data should be collected and shared between agencies to improve future management decisions.

3. Biosecurity is a holistic and continuous effort to reduce the likelihood of ecological damage by invasive species. It includes research, prioritization of risk, prevention protocols, early detection, rapid response, education, eradication, and review. A biosecurity plan is incomplete without each of these components. This biosecurity plan includes research and prioritization of risk for each of the species of concern, recommended prevention protocols, three early detection and rapid response plans, known methods of eradication for each species, and an outline of potential procedures for educational outreach.

4. Biosecurity plans must be adaptive to change. New information about invasive species, biosecurity technologies and techniques, and risk assessment is likely to become available in the future. It is important to build upon the current plan with these additions or to reassess the plan according to these innovations. Biosecurity plans should also change as a result of regular assessment of the success and necessity of its protocols.

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Appendix 1 – Existing Biosecurity Measures & Attitudes

Methods

The Non-Native Species Prevention Plan for Channel Island National Park, California was written by Island Conservation in 2004, but little progress has been made on its implementation. In order to identify what barriers currently exist to implementation of this plan, feedback was solicited from several park service employees responsible for carrying out the existing protocols. Comments included opinions regarding the feasibility of protocol implementation within the park. Remarks from five NPS employees were solicited; responses were received from Paula Power, Restoration Ecologist, and Kent Bullard, Maintenance Supervisor. Additionally, an in-person interview with Paula Power was conducted. Feedback from David Chang, Agricultural Program Specialist with the Santa Barbara County Agricultural Commissioner's office, was also considered in this process. Identifying strengths and weaknesses of the current plan serves to indicate what gaps need to be addressed and what changes need to be made in the creation of the new plan.

Current island operations were also visually observed to identify and highlight ongoing practices of the main agencies interacting with the SCI environment. The group conducted an initial island visitation to observe TNC, NPS, and IPCO practices, infrastructure, and staff. The trip included time spent on both TNC and NPS owned land, as well as island travel on both an IPCO and an NPS boat. We observed a large-scale loading at the NPS dock and interviewed staff involved in the loading to understand the organizational and individual attitudes toward biosecurity. The group also attended various meetings to speak to TNC, NPS, and IPCO about actions they were currently undertaking and actions they would be willing to take.

Results

Issues with protocols fell into several categories. The first category includes those cases in which institutional or regulatory barriers prevent protocol implementation. For example, fumigation of cargo is infeasible because a permit to use a fumigant would not be issued by the Agricultural Commissioner's Office (David Chang, personal communication, April 15, 2010). Secondly, some protocols were believed to be ineffective. Protocols identified as ineffective included buffer zones at island landing points or insect sticky traps (David Chang, personal communication, April 15, 2010). Lastly, many protocols were seen as too costly to be implemented. This includes not allowing multi-island boat and aircraft trips (Paula Power, personal communication, November 5, 2010). Identification of a protocol as too costly indicates a lack of budgetary prioritization. The purpose of this project is to identify risks which justify this high cost, though. Therefore, a prevention protocol which is identified as too costly is not necessarily infeasible. In addition to comments on individual protocols, there was an identification of a lack of emphasis on biosecurity and therefore a lack prioritization of it for employees (Paula Power, personal communication, November 5, 2010).

Staff and expert interviews also identified protocols that are already accepted by NPS and the degree of effort with which they are implemented. NPS specifies that dumpsters must be power washed by suppliers, although they have no enforcement over this. NPS currently power washes vehicles and large equipment, inspects the dock area for non-native weeds or cover for non-native species, and places bait stations on boats. However, the regularity of these practices is unknown, and could probably be improved (Kent Bullard, personal communication, November 10, 2010). On the island, airstrips are mowed to reduce weed growth, but probably on an infrequent basis (Kent Bullard, personal communication, November 10, 2010).

Though TNC does not transport anyone on its own boats, their contract with IPCO allows them to direct them to implement a variety of protocols. As such, IPCO is on board with implementing biosecurity protocols. IPCO believes contractors are the group that most frequently tries to bring prohibited materials to the island (Alex Brodie, personal communication, December 29, 2010). TNC has developed a list of prohibitions for contractors, which IPCO must enforce:

- No animals, including pets, companion animals or research animals.
- No plants, including live potted plants, cuttings, bulbs, sorms, seeds, or freshly cut or dried flowers or plants.
- No potting soil (unless soilless Sun Gro Sunshine mix #4, original package with no tears/holes)
- No wooden planters, plastic must be new, no used pots
- No fire wood or wood with bark
- No corrugated cardboard boxes (banana boxes). Clean plastic containers, original manufacture packing allowed if inspected for insect hitchhikers and found to be clean.
- No recycled wooden crates
- No transportation vehicles
- No firearms, bows and arrows, or compressed air guns
- No fireworks

IPCO and TNC agree that notification about what is being transported to the island can be better between organizations. IPCO also currently implements several biosecurity protocols. Visitors are not allowed to bring dogs, and any dogs caught on the boat are prevented from disembarking. IPCO also maintains bait stations on their boat for non-biosecurity reasons.

NPS, TNC, and IPCO all include educational material for visitors on their websites (NPS 2011)(TNC 2010)(IPCO n.d.). This information includes the value of the island ecosystem, the impact of invasive species, and materials which visitors are not permitted to bring to the island. The TNC information is contained in an FAQ section about visiting the islands, which mainly indicates the prohibition of dogs and the restriction of access to the island. This page also includes information about obtaining a landing permit. IPCO hopes to develop an online ticket reservation system with information disseminated to visitors during purchase (Alex Brodie, personal communication, December 29, 2010). However, a lot of non-biosecurity information is already necessary during this process and they believe that additional biosecurity information will overwhelm the visitor. Similarly, there is a limited amount of time which can be spent on orientation for visitors before boarding the boat. The IPCO page links to the NPS page with a list of prohibited items, and highlights the fact that dogs are not allowed on the island, visitors should check their gear for seeds, and visitors should not throw organic waste out on the island. The NPS site includes a clear list of items prohibited by on the island. These include:

- Pets or any animal
- Service animals, except by permit from the superintendent
- Live or Potted Plants
- Soil
- Cut Flowers
- Firewood or any untreated, unfinished wood (including hiking sticks)
- Corrugated boxes
- Tools or equipment with attached soil
- Motorized vehicles
- Bicycles

Appendix 2 – Species Characterization Template

The following appendix describes the steps used to characterize the target invasive species of concern for Santa Cruz Island. Characterizing species is an essential step in ecological risk analysis (Stolgren & Schnase). Gathering information about a species' traits such as suitable habitats, estimates of potential distribution and abundance, potential rate of spread, and possible deleterious effects is essential to determining species invasiveness potential on SCI. The importance and methods of creating species characterizations is further described in section 3.1 of the main report.

The steps taken to characterize the target species are presented in outline format below. The elements of the outline are to be used as a guide for a land manager to find the pertinent information regarding the invasion process for potential alien species. Ultimately, the information gathered during the species characterization process is instrumental for defining the potential risk and consequence posed by that species to the Island.

Appendix 11 contains the completed species descriptions that were used to inform our risk evaluation. Information in the species descriptions may deviate what is outlined below based on what information was available and special characteristics of the organism which it was useful to note.

Species Description Outline:

I. **Physical Description**: A description of the physical properties and structure of an alien species (including pictures if available)

II. **Range**
   - A. **Native Range**: A description of the species indigenous environment, including country of origin and native habitat characteristics.
   - B. **Invasive Range:** A description of the known location and distribution of the species in its non-native territory (including maps). This information is important when determining if a vector originates or passes through an area where the invasive species exists.

III. **Introduction pathways**:
   - A. **Associated Vectors and Pathways:** A list of possible pathways and vectors that an invasive species may utilize to arrive at the island.

IV. **Invasion Ecology**
   - A. **Preferred Habitat:** A description of the species preferred habitat. Including possible habitat suitability maps in the area of concern for the species. Identify whether or not the species is a generalist or specific.
   - B. **Dispersal Mechanism:** Identify the primary methods of dispersal for the species. This information will feed into introduction pathways and vectors above.

C. **Reproduction Rate:** A description of the rate at which an agent reproduces.
D. **Home Range:** A description of a species potential home range.
E. **Speed / Rate of Range Expansion:** A description of the speed or rate at which an agent can disperse through a system or habitat.

V. **General Impacts:** A description of possible impacts to Santa Cruz Island. Special emphasis on whether or not sensitive island species such as the island fox or bald eagle will be affected.

VI. **Potential on Santa Cruz Island**: An analysis of the potential for this species on Santa Cruz Island given the above information and known characteristics. With particular attention to factors that may make the species more or less susceptible to invasion of SCI.

VII. **Control & Eradication**

A. **Management:** A description of management options for dealing with an invasion of the species, including costs and success rates.
B. **Known Treatments:** A description of known control or eradication measures.

VIII. **Additional Resources:** Links and descriptions of available important resources on the subject of the given invasive species.

IX. **Works Cited**

Appendix 3 – Risk Evaluation Tool

SCI Risk Evaluation Worksheet		
Species -		
Vector -		
Probability of Establishment		
Are initial criteria met? (yes or no)		
Initial criteria - If the agent/vector combination does not meet these criteria, the probability of introduction is none.		
Vector originates or passes through an area where the species is found (OR unknown) and species could stow away on this vector.		
Vector must reach the island (relative to species dispersal cabailities).		
1. Propagule Pressure (Yes=1 or No=0)	**Weight**	
a. Vector frequently reaches the island AND agent is likely to be associated with the vector (OR unknown)	1	
b. Number of agents likely to be associated with vector undetected is enough to potentially establish.	1	
c. Agent is likely to gain access to the island upon arrival.	1	
2. Suitability (Yes=1 or No=0)		
a. Habitat and climate on SCI are highly suitable.	2	
b. Habitat and climate on SCI are only potentially suitable.	1	
c. Species has a known history of invasiveness.	1	
propagule pressure* probability of establishment		0
Probability of Establishment Rating (6-9=High , 3-4= Medium, 1-2=Low, 0=Very low)		**VERY LOW**
Probability of Establishment Score (High = 3, Medium = 2, Low=1, Very low = 0)		0

Probability of Establishment worksheet of the risk evaluation scoresheet. This score is combined with the Magnitude of Consequence score to get an overall risk evaluation.

SCI Risk Evaluation Worksheet

Species -		
Consequence		**Yes or No**
Are the initial criteria met? (yes or no)		
Initial Criteria for Analysis: Invasive will cause a decrease in individual fitness of native species or changes in community composition or ecosystem proc		
Impacts may come in the form of		
• Changing disturbance regimes, nutrient cycling, hydrology, geomorphology, or microclimate (weeds)		
• Predation, competition, or grazing (vertebrates, invertebrates, weeds)		
• Disease (fungus/disease)		
3. Value of the impacted resource(s)	**Weight**	
a. Potential impact to sensitive, protected, rare, keystone species (fox, jay, eagles etc) large or unique areas (oak woodlands, freshwater systems)	3	
b. Widespread or resilient endemics (mice), many native species	2	
c. Native species	1	
4. Rate of spread - Often associated with fecundity, dispersal capabilities, or ecological resilience of the impacted system or species. Relative to casual de		
a. Rapid	3	
b. Moderate	2	
c. Slow	1	
5. Degree of impact - Related to the impact on an individual and the proportion of the population or system that may be affected. Factors to consider inclu		
a. Threat to population viability or system integrity- Impacts reduce survival of a large proportion of native species, reducing population viability across the island. Alteration of island-wide ecosystem processes may indirectly reduce population viability.	3	
b. Some threat to population viability or system integrity- Impacts reduce survival of a portion of native species population(s), enough to reduce its range. Localized changes to ecosystem processes may also contribute to range reduction	2	
c. Little to no threat to population viability or system integrity- Impacts to individual health are not likely to result in reduced population viability. Changes to system are not likely to interfere with existing ecosystem process.	1	
value*rate*degree		0
Magnitude of consequence rating (≥12 = High, 9≥x≥6 = Medium, ≤4 = Low)		**LOW**
Magnitude of consequence score (High = 3, Medium = 2, Low=1, Very low = 0)		1

Magnitude of consequence worksheet

Appendix 4 - Risk Evaluation Worksheet Instructions

The risk evaluation worksheet is an Excel spreadsheet with built-in formulas used to describe and prioritize the threats to island biosecurity. A new spreadsheet file is meant to be created to evaluate the risk posed by each species. The first tab of the Excel spreadsheet is a summary score sheet. The second tab is the evaluation of the magnitude of consequences that could occur as a result of an invasion by that species. The remaining tabs are evaluations of the introduction and establishment probability at each vector. Because the magnitude of consequence rating will be the same for every vector, those criteria do not need to be re-evaluated each time, but instead, are linked through built-in formulas to the score from the "consequence" tab. When re-evaluating consequence information, it is only necessary to update the "consequence" tab and the summary spreadsheet and the vector pages will update automatically. The logical structure of the evaluation and justification for the included criteria can be found in Section 3.3.

This worksheet is not meant to be used to define the likelihood of rare events and the results of ecological interactions in absolute terms, but instead, is meant to identify which factors are most important to consider in order to compare risks to each other. The evaluator will need to make decisions based on the combination of multiple factors, each with its own level of detail and certainty. In order to perform this evaluation in an informed manner, the evaluator should first gather and synthesize available information on the target organism through the species characterization process outlined in Section 3.1 and Appendix 2. Detailed criteria definitions and the biological and ecological factors which should be considered to complete the REW are described below. It is highly advised that the "Notes" section adjacent to each response be used to identify what factors led to each response and that questions answered under uncertainty be denoted by shading their response cell. This will allow evaluators to visually assess the level of uncertainty associated with the REW overall, as well as inform investigations of how the score and priority of that threat would change if uncertain responses were different. It also indicates areas that should be researched and reassessed if new information becomes available.

Probability of Establishment -

Preliminary criteria - Preliminary criteria for evaluation in this section are that (1) a vector must originate from or pass through an area where the species in question is present, (2) that the species can stow away on the vector, and (3) that vector must reach Santa Cruz Island. If any of these criteria is not met, the vector is not a threat and the risk evaluation does not proceed. For these criteria, uncertainty is handled with the precautionary approach, meaning the evaluator is to assume a risk does exist if the answer is unknown.

Vector and agent origin - The origin of a vector can often be obtained by inspecting product labels or direct inquiry of product owner or provider. Current distribution of the target species can be obtained through literature review and contacting resource managers actively involved in managing the species' spread. The exact distribution may not be known, particularly for species undergoing rapid range expansion. In this case, we recommend using the precautionary approach - if the species could reasonably be present in a given location, we assume that it is present there. The same principle applies when the origin and path of the vector cannot be obtained; if the vector could have reasonably originated from or come in contact with the species range, we assume that it has.

Agent can stow away - The ability of an agent to stow away on a vector is related to its size, dispersal characteristics, life history, and history of accidental introductions. These characteristics can help determine whether it is physically possible and probable that an agent will find its way on to a given vector. If a material could harbor agents from the organism's dispersal modes, it may be a vector. If the material is habitat or food for the agent at some point in its life cycle, it is also considered a vector. If the material has been the known or suspected vector of the species elsewhere, it is considered a vector.

Vector reaches the island - Whether or not the vector effectively reaches the island is both intuitive and relative to the dispersal capabilities of the agent in question. If people transport the vector onto the island, this criterion is met. If the vector comes near the island, the dispersal capabilities of the given species are used to determine whether the criterion is met. For example, a private boat that anchors off shore effectively reaches the island for an individual Norway rat or raccoon because they are capable swimmers, but not for house mice, which are not known to swim. Similarly, a docked boat has effectively reached the island for any agent that will either be offloaded within a vector by people or can actively offload itself, but for passively dispersed agents, the docked boat does not reach the island and the criterion is not met.

1. **Propagule Pressure**
    a. **Vector frequently reaches the island AND agent is likely to be associated with the vector (or unknown).**
        i. **Frequency -** Vectors that are considered to "frequently" reach the island are those that are transported more than ~15-20 times per year, such as material transported on a daily, weekly, or biweekly basis. Frequency with which private, contractor, and agency vessels arrive at the island's various anchorages and harbors was gathered from NPS and SAMSAP visitation data (Appendix 3). Frequency with which other vectors are transported to the island was attained through consultation with TNC and NPS staff.
        ii. **Reaches the island** - Same as above.
        iii. **Likelihood of association -** An agent is likely to be associated with a vector when the vector can act as habitat, host, or food for

the agent. Likely association may also be indicated by expert testimonial or historical examples of agent introduction through that vector. Lastly, likely association can occur when dispersal mechanisms are conducive, such as plant propagules that are small, numerous, and/or likely to stick on clothing, shoes, etc. Again, a combination of logic and the precautionary approach is typically employed when dealing with reasonable but uncertain pairings.

b. **Number of agents likely to be associated with vector undetected upon casual observation is enough to potentially establish.**
   i. **Agent size -** Very small agents, such as fungal spores, can be impossible to detect upon casual or visual observation. Similarly, small seeds are difficult to detect without deliberate inspection. Larger agents, such as individual mammals, may be more easily detected depending on their behavioral tendencies.
   ii. **Agent behavior -** Reclusive, nocturnal, or commensal species can still be difficult to detect even if they are relatively large because they have a tendency to remain hidden.
   iii. **Size of the vector relative to the agent –** If the ratio of vector size to agent size is larger, it will be more difficult to detect because the agent will have more places to hide and casual observation of the entire vector will be less likely. For example, rats could be difficult to detect casually on the NPS boat but would be far easier to detect in someone's personal gear. Comparatively, hundreds of seeds or thousands of fungal spores can stow away on a boot or within personal gear because of the size of these agents is so small relative to the vector.
   iv. **Establishment potential of individual agents -** This is related to the survival and reproductive potential of a given agent. Individual adult plants or animals will be more likely to survive than seeds or larvae/juveniles. Within seeds, larvae, and juveniles, survival potential can depend on the level of parental investment characteristic for that species. Where possible, information about the number of individuals that can feasibly establish a population should be gathered from research into past accidental introductions or species biology. For example, genetic research documents multiple instances where rat population establishment has resulted from the introduction of a single individual. Any assumptions or uncertainty about the number of individuals considered capable of founding a population should be explicit in the "Notes" sections.

c. **Agent is likely to gain access to the island upon arrival**.

i. **Vector access to the island -** If the vector is physically transported onto the island, such as a dumpster or personal gear offloaded from the boat, this criterion is met. If the vector is the boat or aircraft itself, it depends on the species ability to offload itself.

ii. **Species dispersal capabilities and behavioral tendencies -** Species that are highly likely crawl along mooring lines, swim, or fly will be able to gain access to the island even if they are not offloaded from the boat or aircraft by people. For example, a flying insect such as a honey bee would probably fly from the boat as soon as it stopped moving. A rodent would be likely to crawl off a boat if it were moored overnight, but much less likely to expose itself during a short docking period when people and equipment are moving around. This is a relatively subjective decision to make; assumptions should be documented in the "Notes" section.

2. Establishment

a. Habitat and climate on SCI are highly suitable

i. Climate - Minimum and maximum temperature and precipitation tolerance of the species relative to the conditions on the islands should be considered, as should the seasonality of temperature and precipitation as it relates to the species life history. In many cases, tolerance levels are not distinct or well characterized**.** In these cases, the native and exotic range will be the most useful and widely available information to determine suitability of climatic conditions on the island.

ii. **Habitat -** The quality, quantity and distribution of the potential habitat is considered. Habitat includes the physical conditions required by a population of individuals including food source or host range for all life stages, availability of water relative to species needs, presence/absence of predators or diseases, and any physical or chemical requirements for reproduction. Quality of habitat can be estimate by comparing known preferences and habitat in the species native and exotic range and through the use of habitat suitability models. Distribution of available habitat is important as it relates to the location of likely introduction points and species dispersal capabilities. Because of the island size and rugged topography, not all locations containing suitable habitat may be accessible to the organism.

iii. **Modeling** - Habitat suitability modeling, a discipline for which a large and longstanding literature exists, contains many methods for modeling potential habitat.

b. **Habitat and climate on SCI are only potentially suitable** - Using the analytical considerations above, one may find that the conditions on SCI are tolerable for the target species but not ideal or not particularly conducive to survival and reproduction. In this case, only 1 point is awarded in the REW compared with 2 point for when the habitat and climate are highly suitable.

c. **History of Invasiveness** - Information on a species history of invasiveness can be obtained from literature review.

Formulas embedded within the spreadsheet will sum the scores within each category and then multiply the sums for these two categories together. Possible point values are equally distributed among High (9 - 6), Medium (4, 3), and Low (2,1), and Very Low (0) categories and scaled down to fall within a range of 0-3 for later analysis.

Magnitude of Consequences

Preliminary criteria -

Here, we define "impact" to be a decrease in fitness of native species or changes to community composition or ecosystem processes in the form of changing disturbance regimes, nutrient cycling, hydrology, geomorphology, or microclimate (weeds); predation, competition, or grazing (vertebrates, invertebrates, weeds); or disease. If establishment of the target organism will not result in these consequences, the magnitude of consequences is zero.

1. **Value of the impacted resource -** Predicting which species, habitats, or ecosystem processes will be impacted by the target organism will require knowledge about its impacts in other areas; areas with similar species and food web interactions will be most useful. Historical information about the impacts of similar exotic organisms on SCI or the Channel Islands could also inform this prediction. If the determination of which resources will be impacted is dependent on other factors including invasion size, density, or rate, these assumptions should be made explicit in the "notes" section. For example, whether or not a weed impacts a rare native plant may depend on where the weed was able to establish relative to the rare plant, particularly if the suitable habitat and climate range of either is restricted. If we have reason to believe the ranges would not overlap but are not certain, we would note that and shade the cell as uncertain.

2. **Rate of Spread -** Information on the species rate of spread can often be found in published literature or through consultation with resource managers responsible for control of that species elsewhere. Rate of spread may be associated with fecundity and reproductive rate, dispersal capabilities, habitat and climate match (defined above in 2a), or ecological resistance of the impacted system or species.

We do not define exact cut-offs in area per unit time by which to differentiate rapid, moderate, and slow spread of impact because it can be relative to the type of species and the mode in which it impacts native species or systems and the ability of management to respond and contain the invasion. For plants or territorial species, slow spread is on the order of meters per year, moderate spread would be on the order of tens of meters per year, and rapid spread is on the order of hundreds of meters per year. The rate of spread for a disease may be dictated by its mechanism of spread and behavior of the native species. For example, a sexually transmitted disease would spread slowly amongst individuals of a species that are monogamous. These rate descriptions may require review as more information is learned about threatening species.

Assumptions or predictions about ecological interactions that impact rate of spread should be clearly noted. For example, a small mammal species may expected to spread more slowly on SCI than has been observed elsewhere because two species of native mice are well established throughout the island and would compete with the invading individuals for resources. Conversely, if the invasive organism will be able to take advantage of a previously unoccupied niche, it may be expected to spread more quickly on SCI than has been observed elsewhere.

3. **Degree of Impact** - These questions include two major concepts: 1) the degree to which the target organism impacts individual native species and 2) the proportion of the native population that is likely to be impacted. Impacts to native species, as described in preliminary criteria can be direct or indirect. Direct impacts will typically be associated with the target organism's host range, food source, or territoriality. Indirect impacts will result when the habitat and climate range of the target organism overlaps with that of the given native species resulting in alteration of or competition for resources.

    a. **Degree of impacts to individuals** - Predicting the impact expected to occur to individual organisms can be based on impacts elsewhere, as defined in published literature or through consultation with resource managers.

    This question considers not only whether an impact will occur, but also the degree to which individuals are affected. The most severe impact is sudden mortality, with impacts decreasing in severity with decreasing degrees of decline in reproductive fitness. This can be influenced by the nature of the impact as well as the ability of the native species to fend off or otherwise avoid this pressure. For example, the fungal pathogen *P. ramorum* can infect many plant species to a limited extent, resulting in a fitness gain comparable to the numerous native pathogens that exist in forests. In this case, the degree of impact is low. Or, an organism that depredates bird nests would be expected to have strong influence on reproductive fitness for bird species that do not actively defend nests and a lesser influence on species that do.

b. **Impacted proportion of the native population** - Factors influencing the proportion of the native population that will be impacted by the target organism include the range and distribution of the native species relative to the predicted range and distribution of target organism and predicted resistance of the native species to impact by the target organism. If the ranges of the target and native species overlap entirely, we might expect that as much as all of the native population could be impacted. If the overlap area is small, we might expect a small proportion of the native population to be impacted. If the native species has demonstrated the ability to outcompete or otherwise resist the impacts of the target species, again we expect the proportion impacted to be less. Distribution models described above can inform this prediction, as can information about invasions elsewhere.

Similar to the probability section, formulas embedded within the spreadsheet will multiply the scores from the questions together. Possible point values are equally distributed among High (27, 18, 12), Medium (9, 8, 6), and Low (4, 2, 1) categories and scaled down to fall within a range of 0-3.

Both sections of the worksheet have been scaled to a range of 0-3 so that they can be combined with equal weighting. To calculate overall risk, which we define as probability * consequence, formulas embedded in the spreadsheet will multiply the "Probability of Establishment" score with the "Magnitude of Consequences" score to get a score ranging 0-9. Risk rating is derived from this score, giving a risk evaluation rating of high (9), medium high (6), Medium (3, 4), Medium Low (2), Low (1), Very Low (0).

Appendix 5 – Visitation Statistics

The group analyzed data from the NPS visitation statistics and the Sanctuary Aerial Monitoring and Spatial Analysis Program (SAMSAP) to understand the temporal and spatial visitation trends for Santa Cruz Island. NPS began collecting the visitation data in 1995, while the SAMSAP observations began in 1997. Both datasets include visitation through August of 2010. The NPS visitation statistics included information from all of the concessionaires for the Channel Islands, however only the concessionaires for Santa Cruz Island were included in this analysis: Island Packers Company, Truth Aquatics, and Channel Islands Aviation. The data for Channel Islands Aviation did not specify the destination for any trips to any islands.

SAMSAP is an aerial survey program at the Channel Islands National Marine Sanctuary designed to gain a better understanding of visitor use in the sanctuary, record migration patterns and seasonal use of sanctuary waters by marine mammals, and characterize physical conditions (Natalie Senyk, Channel Islands National Marine Sanctuary, personal communication, August 23, 2010). Scientific observers document the precise locations of the vessels using a Global Positioning System (GPS) and distinguish between different types of vessels during aerial surveys. Vessels are identified according to the activity that they are participating in when the observation occurrs; activity is classified into four general groups including (1) recreational consumptive (Commercial Passenger Fishing Vessels as well as private boaters that are actively fishing), (2) recreational nonconsumptive (sailboats, private boats that are not observed actively fishing), (3) commercial consumptive (commercial fishing activities), and (4) commercial nonconsumptive (island concessionaire vessels, whale watch vessels, cargo ships, tankers) (Natalie Senyk, Channel Islands National Marine Sanctuary, personal communication, August 23, 2010). There are gaps in the SAMSAP database due mainly to aircraft availability and weather. Observations cover the region encompassing the sanctuary boundary which includes the 6 nautical miles of water surrounding San Miguel, Santa Rosa, Santa Cruz, Anacapa, and Santa Barbara Islands, however only observations for Santa Cruz Island were used in this analysis.

Visitation to the island tends to peak in late summer during July or August and drops off considerably from December through February 9 (Figure 1). This data does not include the weekly NPS trips out to the island or the associated passengers. Generally, visitation is increasing every year (Figure 2). This may continue in 2010, but the visitation data was only available through August.

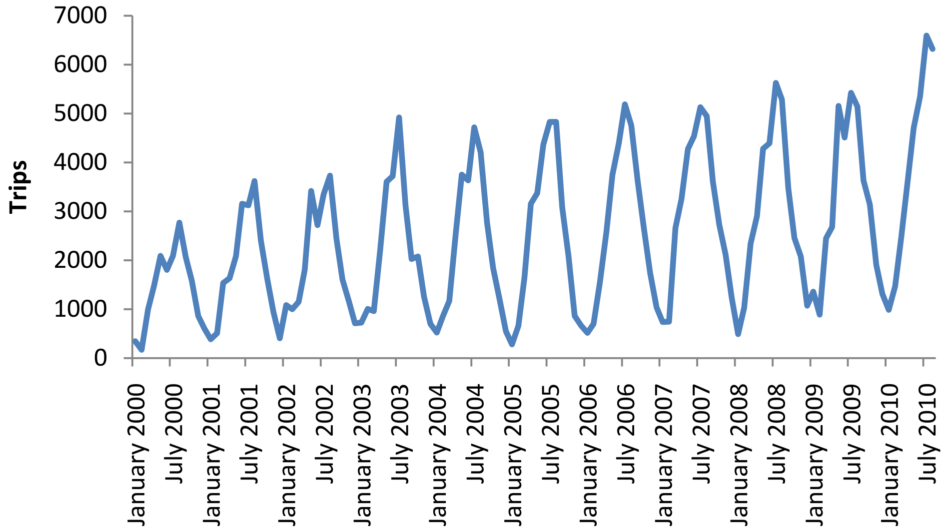


Figure 1. The seasonal change in trips to the island. (NPS and SAMSAP)

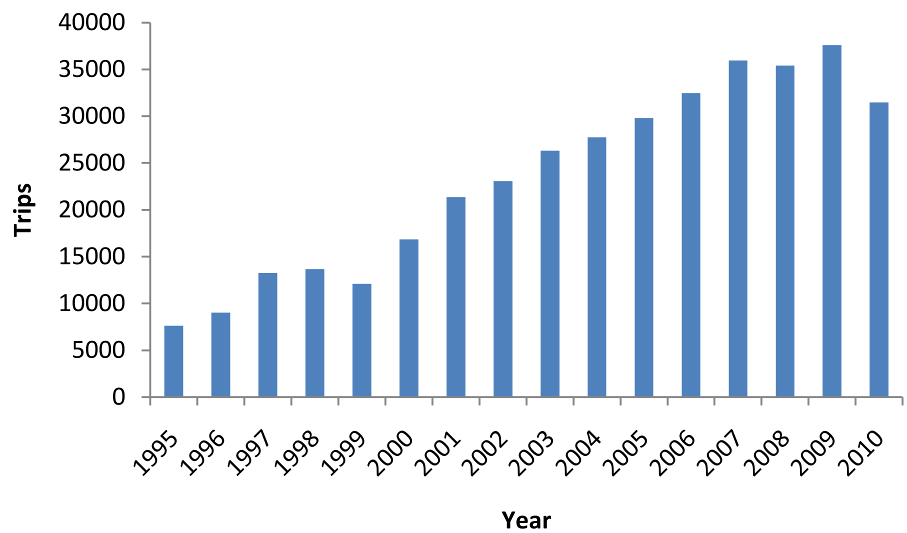


Figure 2. The total number of trips per year. (NPS and SAMSAP)

Private boat destinations were defined by proximity to an anchorage, cove, or point at the time of observation. San Pedro and Sand stone are the most popular destinations for private boaters (Figure 3); however these boats may have been en route to other locations. Furthermore, SAMSAP data was only collected up to six times in one month and each boat may have a different number of passengers.

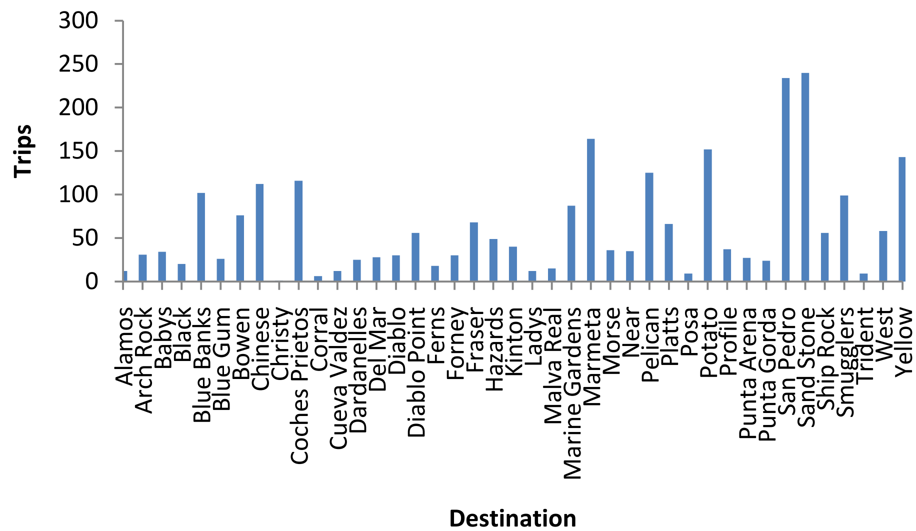


Figure 3. The number of private boat trips to each anchorage, cove, and point on the island. (SAMSAP)

When all types of boats are included, Scorpion and Prisoners Harbors are the most popular destinations on SCI (Figure 4). Given that the SAMSAP data was collected at maximum six times per month, there may be more trips to other destinations. However it is unlikely that the SAMSAP data is biased by three orders of magnitude. Moreover, it is unlikely that many private boats carry close to the same amount of passengers as IPCo boats.

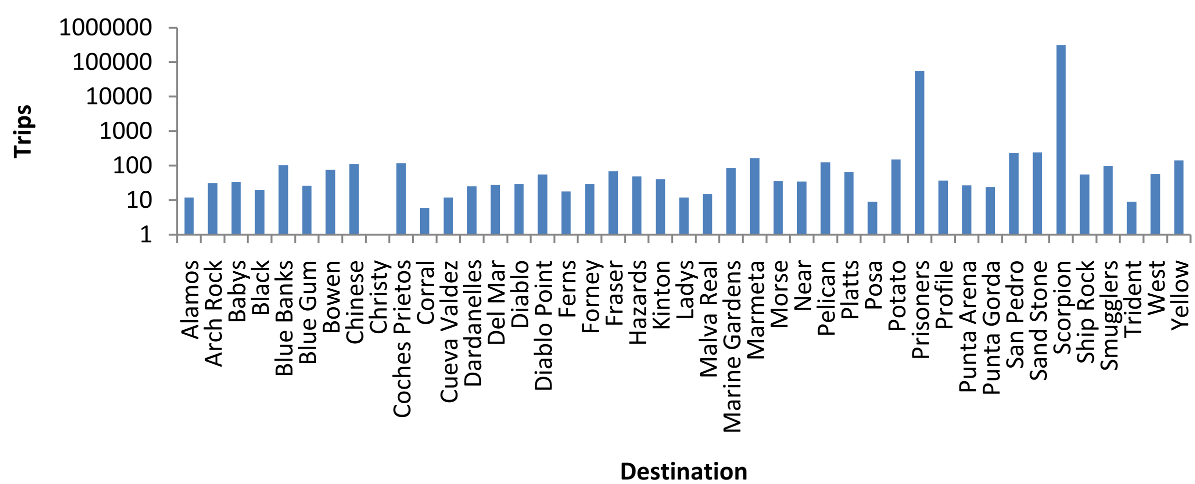


Figure 4. The number of trips to all destinations on the island from every source, except for Channel Islands Aviation (the destination is not given). The y-axis is shown in logarithmic scale. (NPS and SAMSAP)

Figure 5 illustrates the organization or method by which visitors arrive on the island. Recreation boaters include sport fishing, recreational boater, sailboat, kayak, and jet ski. Commercial boaters include commercial fishing, urchin boat, squid light boat, lobster boat, squid harvest boat, Gill Netter, trawler, and head fishing boat. Dive boats are commercial dive boats. Support boats include research vessels and support vehicles. Freighters include all tankers, freighters, and coastal freighters. Islands Packers has the most trips to the islands by two orders of magnitude (Figure 5). Truth Aquatics (10019 trips) and Channels Islands Aviation (4443 trips) appear to have a similar number of trips (Figure 5); however they differ by almost an order of magnitude.

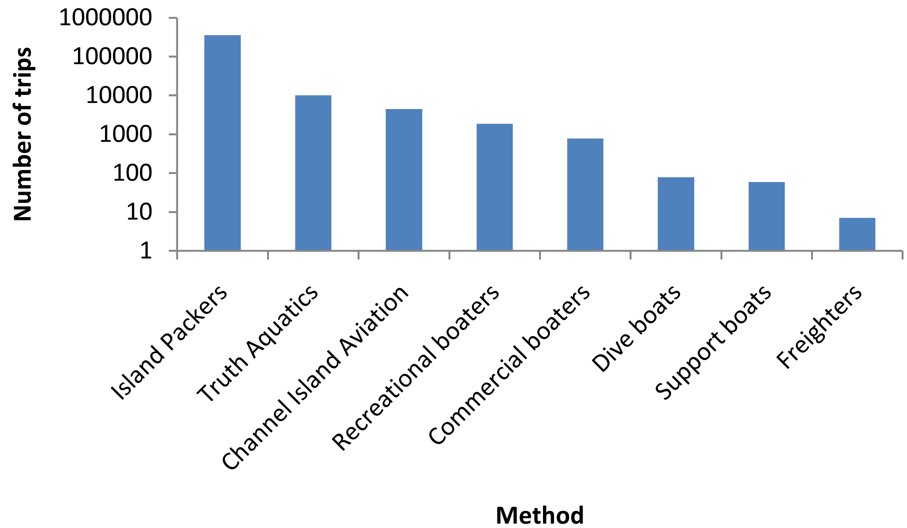


Figure 5. The number of trips for each method. The y-axis is shown in logarithmic scale. (NPS and SAMSAP)

Appendix 6 – Effectiveness Evaluation

Criteria for High Risk Vectors

1. Vector originates or passes through an area where the species is found (OR unknown) and species could stow away on this vector.
2. Vector frequently reaches the island AND agent is likely to be associated with the vector (OR unknown)
3. Number of agents likely to be associated with vector undetected is enough to potentially establish.
4. Agent is likely to gain access to the island upon arrival.

		Contributes to addressing the following criteria				Implementation		Comments and Clarifications
Description		#1	#2	#3	#4			
Interpretive signs at departure and landing points								
	Mammals						Hours spent on maintenance per year	
	Weeds							
	Invertebrates						number or density of signs	
	Fungus/Disease							
Biosecurity information on website								
	Mammals						Hours spent on maintenance per year	
	Weeds							
	Invertebrates							
	Fungus/Disease							
Rangers will use all public interactions with private boaters to promote biosecurity messages								
	Mammals						Hours spent on information dissemination per week	
	Weeds							
	Invertebrates							
	Fungus/Disease							
Visitors that present a risk will be confronted and may be asked to leave								
	Mammals						Hours spent on enforcement per week	
	Weeds							
	Invertebrates							
	Fungus/Disease							
Staff will use all media opportunities to promote key messages								
	Mammals						Hours spent delivering messages through the media per year	
	Weeds							
	Invertebrates							
	Fungus/Disease							
Specific proactive advocacy to raise awareness like Xray machines or sniffer dogs esp at the early phase								
	Mammals						Hours spent on proactive advocay per week	
	Weeds							
	Invertebrates						number or density of dogs and machines	
	Fungus/Disease							

Appendix 7 – Database Instructions

Information Storage

Information added to the database must be in the same format as the information already stored in the database, or the database will not accept the information.

Table 1. The information formats for information stored within the database.

Species	
Common_name	Text
Genus_species	Text
Type	Text
Species_Type	
Type	Text
Vectors	
Vector	Text
Description	Text
Protocols	
ID	Number
Description	Text
Type	Text
Equipment_Cost	Currency
Labor_Cost	Currency
Total_Cost	Currency
Effectiveness	Text
Contact	Text
Notes	Memo
Effectiveness	
Level	Text
Description	Text
Effectiveness_Sources	
Source	Text
Organization	Text
Location	Text
Contact Information	Text
Protocol_Type	
Type	Text
Description	Text
Species_Vector	
Vector	Text
Genus_Species	Text
Risk	Text
Risk	

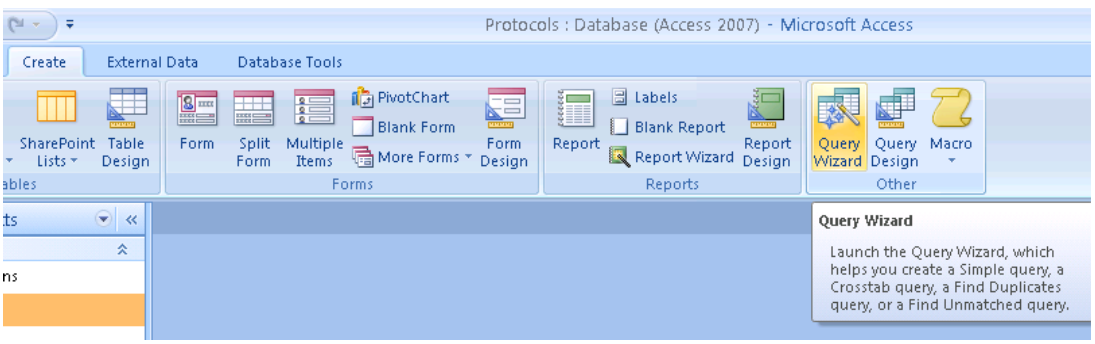
Level	Text
Species_Protocol_Vector	
ID	Number
Protocol	Text
Species	Text
Vector	Text

Query Design

Queries in the database allow for information selection. The database contains sample queries for high risk species, invertebrates, and low risk species. There are two common methods for creating a query: SQL and design view.

By Query Wizard

To create a query using the query wizard, select Query Wizard under the Create tab in the main menu.



A window will appear with four options: Simple Query Wizard, Crosstab Query Wizard, Find Duplicates Query Wizard, and Find Unmatched Query Wizard. The Simple Query Wizard returns a select query, the Crosstab Query Wizard creates a spreadsheet based on the selected information, the Find Duplicates Query Wizard selects values within a given field that are duplicated, and the Find Unmatched Query Wizard selects values that are unique within a given field. Select the Simple Query Wizard.

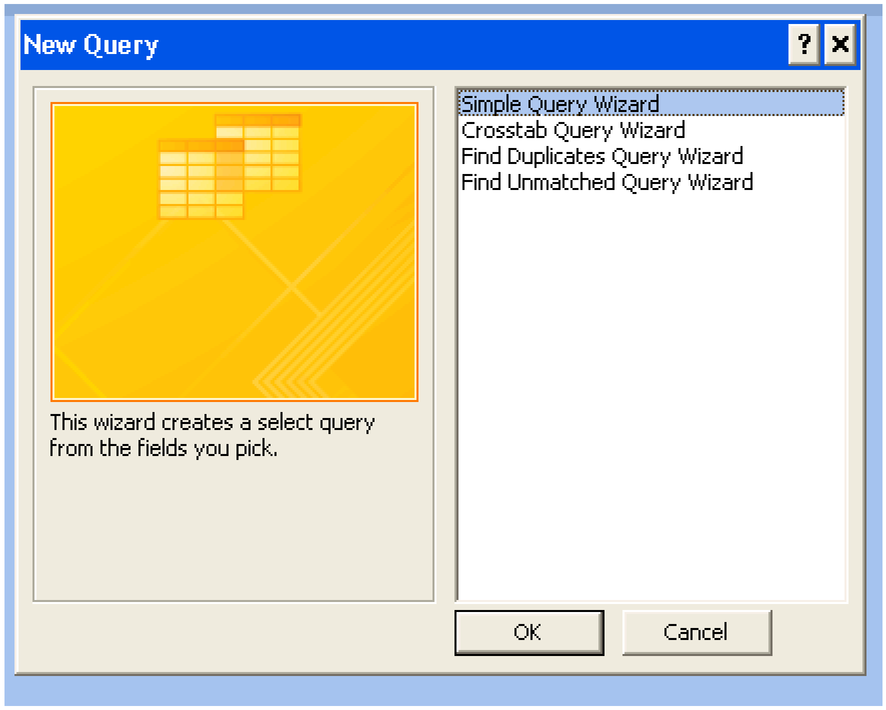
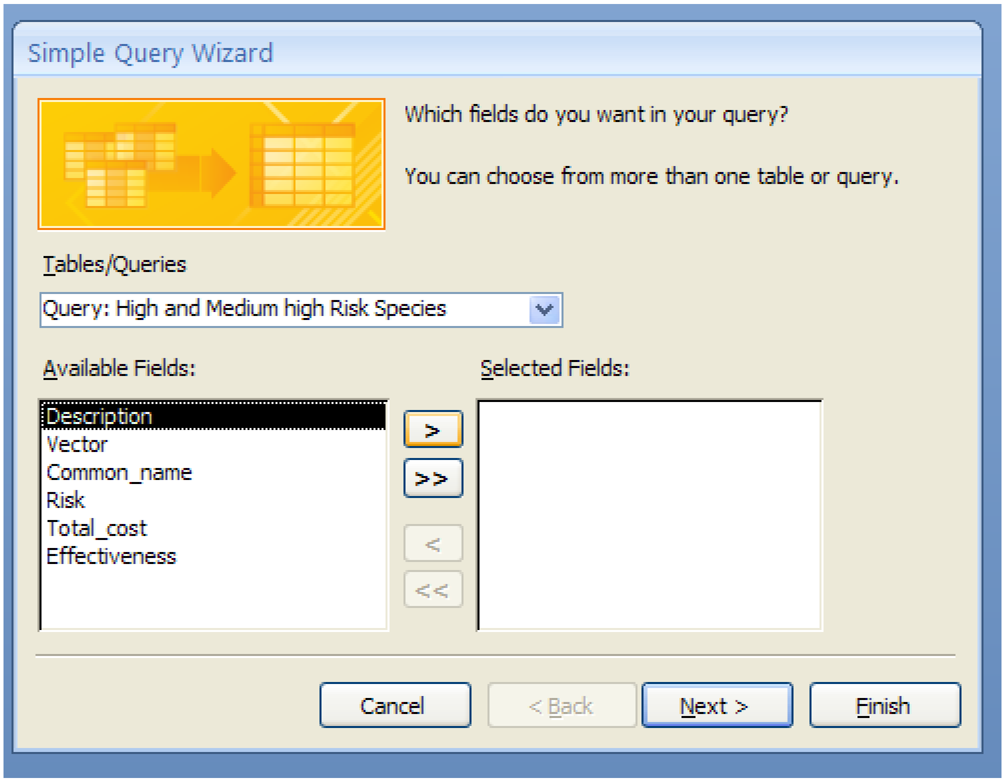
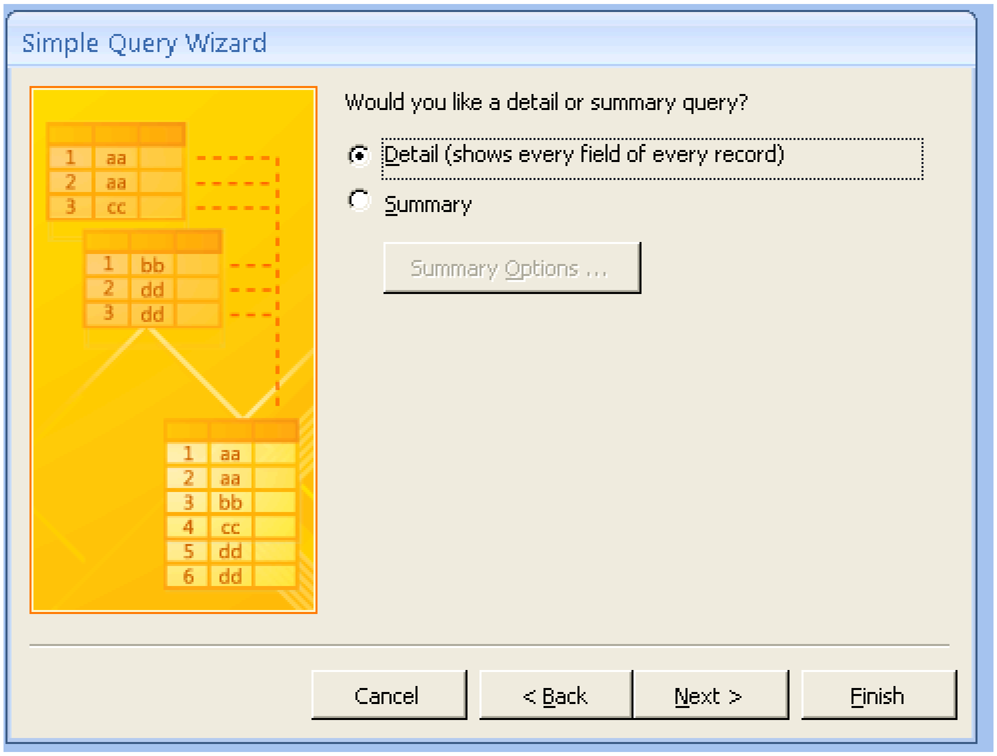


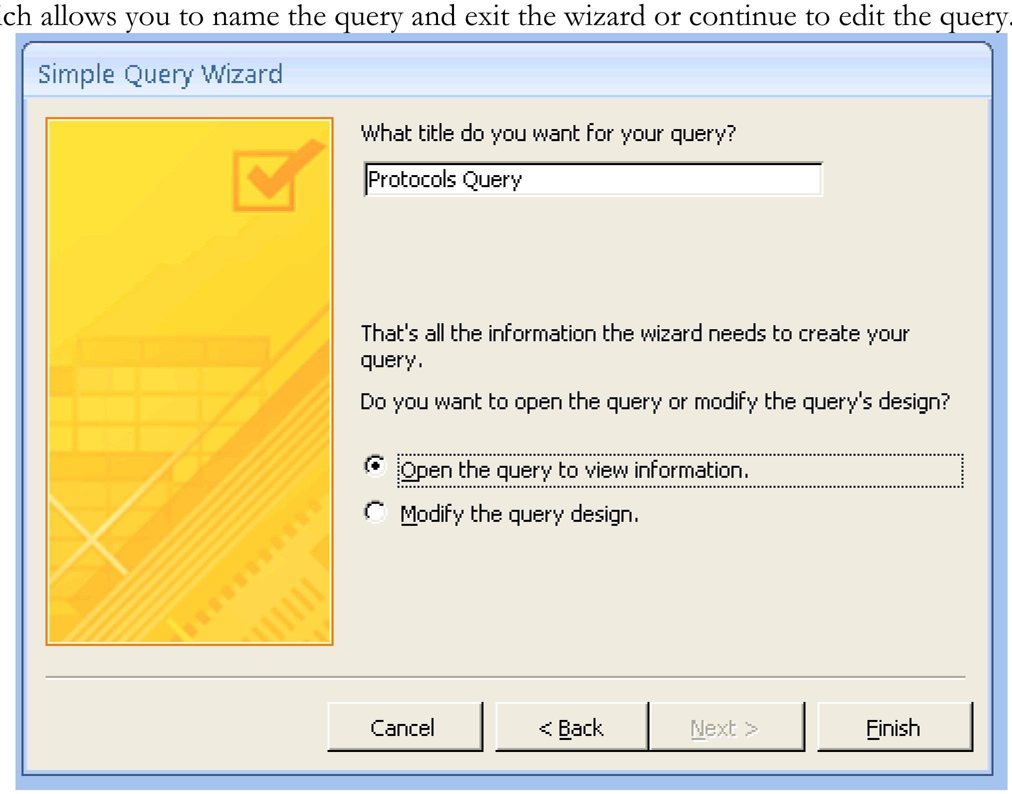
Figure 1.
In the Query dropdown menu select the table of interest then select the field (or column) of interest. Press the > button to select the field. To select fields from multiple tables, repeat the process with the correct table selected in the Query dropdown menu. When the correct information is selected, press next >.



The window shown below will appear with two options: Detail or Summary. The Summary option allows for statistical analysis of the resulting information (i.e. average, sum, maximum, count, etc.), while the detail information gives every value. Detail allows for more information and also will likely be of more assistance for selecting management actions.



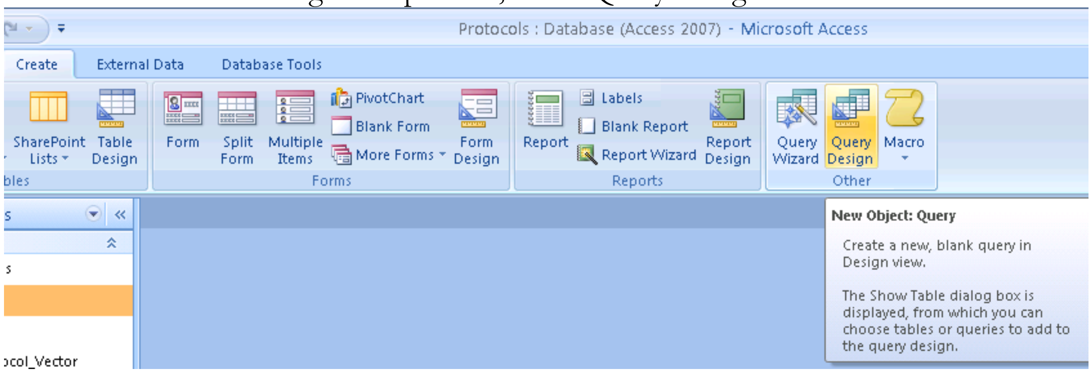
Once you select the correct option, select Next >. The window below will appear, which allows you to name the query and exit the wizard or continue to edit the query.



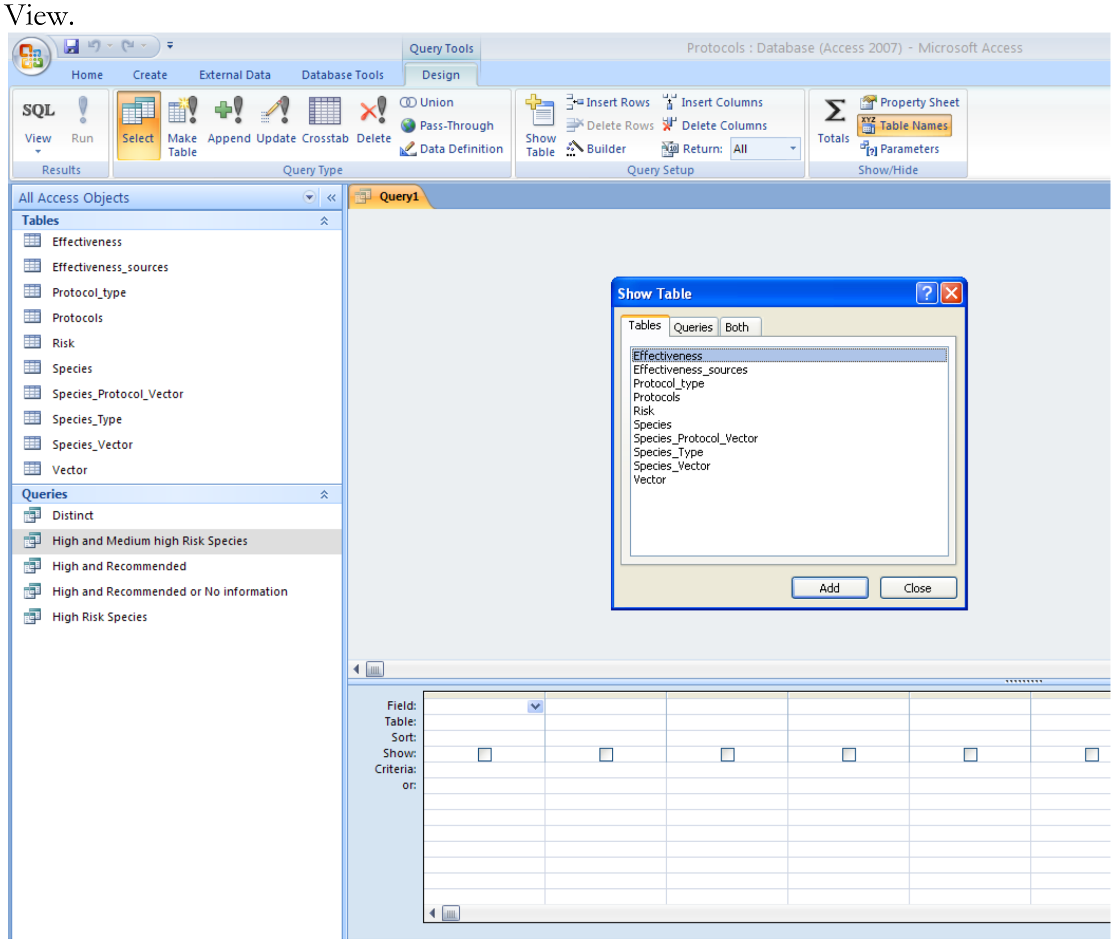
Once a query has been created with the Query Wizard or through any other means, the query must be edited in either Design View or SQL View.

By Design View

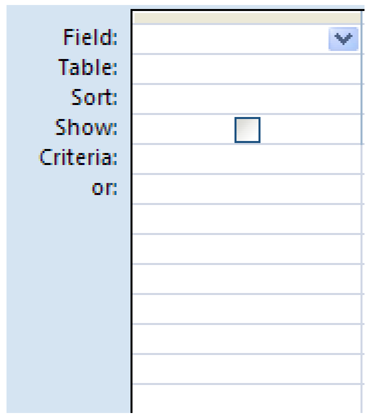
In design view, information selection is more visual. To create a query in Design View, under the Create tab along the top menu, select Query Design.



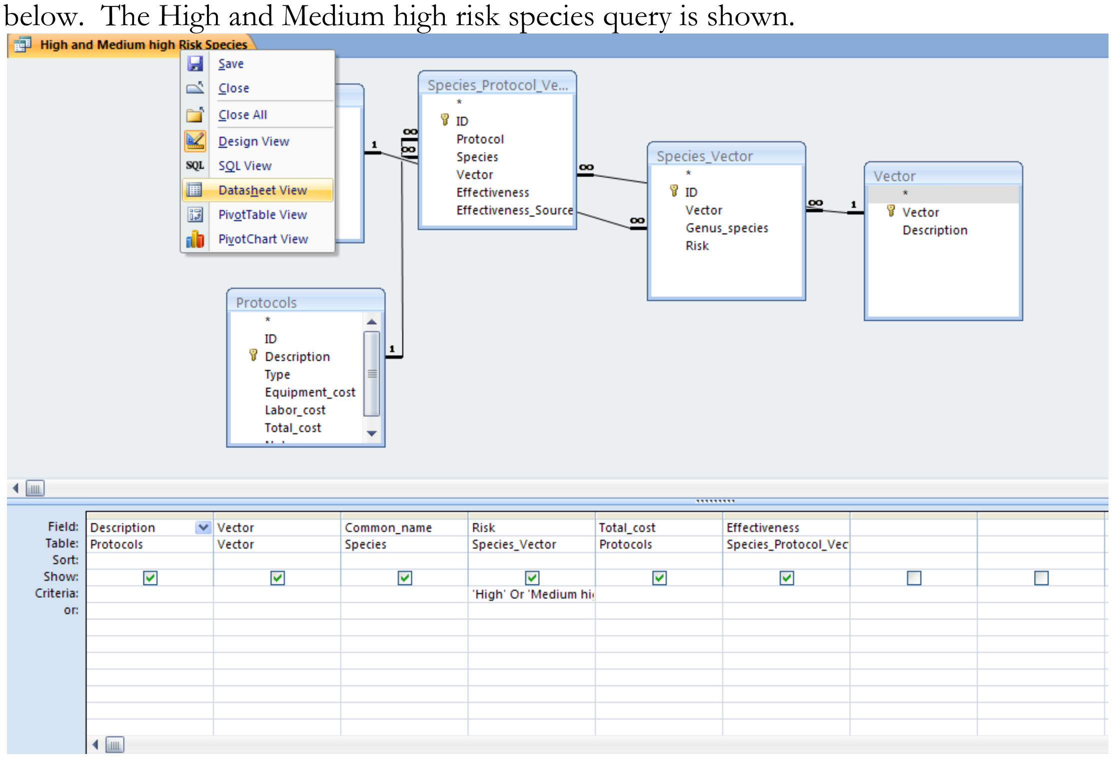
A new query will appear in the window, as shown below. This view is known as Design View.



Field is the column you wish to select, table is the table you are selecting it from, sort is the order you would like the information within the column to be in, show is whether it is visible or not, and criteria are the given criteria you are selecting. The criteria will depend on the column in question and may include many options from within the column's domain. Both the field and table sections include a scroll down menu to allow for easier selection. Sort has three options: ascending, descending, and not sorted. The show option allows you to select many columns and toggle them on or off depending on your needs.



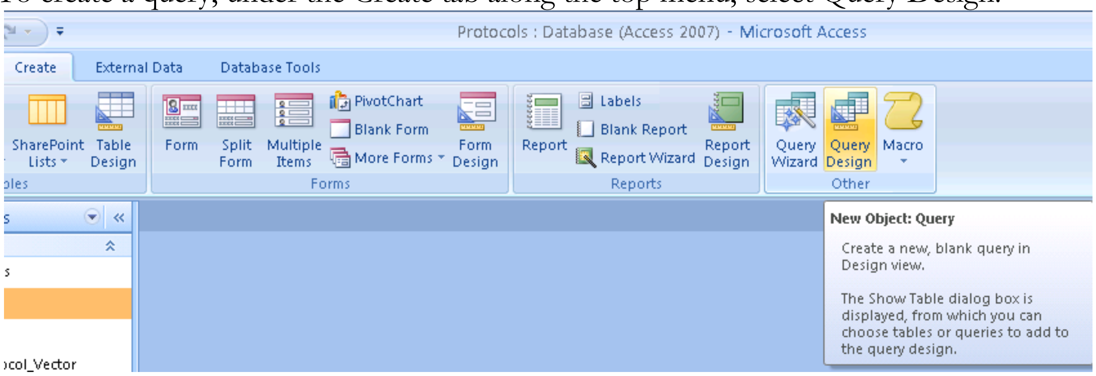
Once you have filled in each of these to your satisfaction, you can view the results of your query, by right-clicking on the query tab and selecting Datasheet View as shown below. The High and Medium high risk species query is shown.



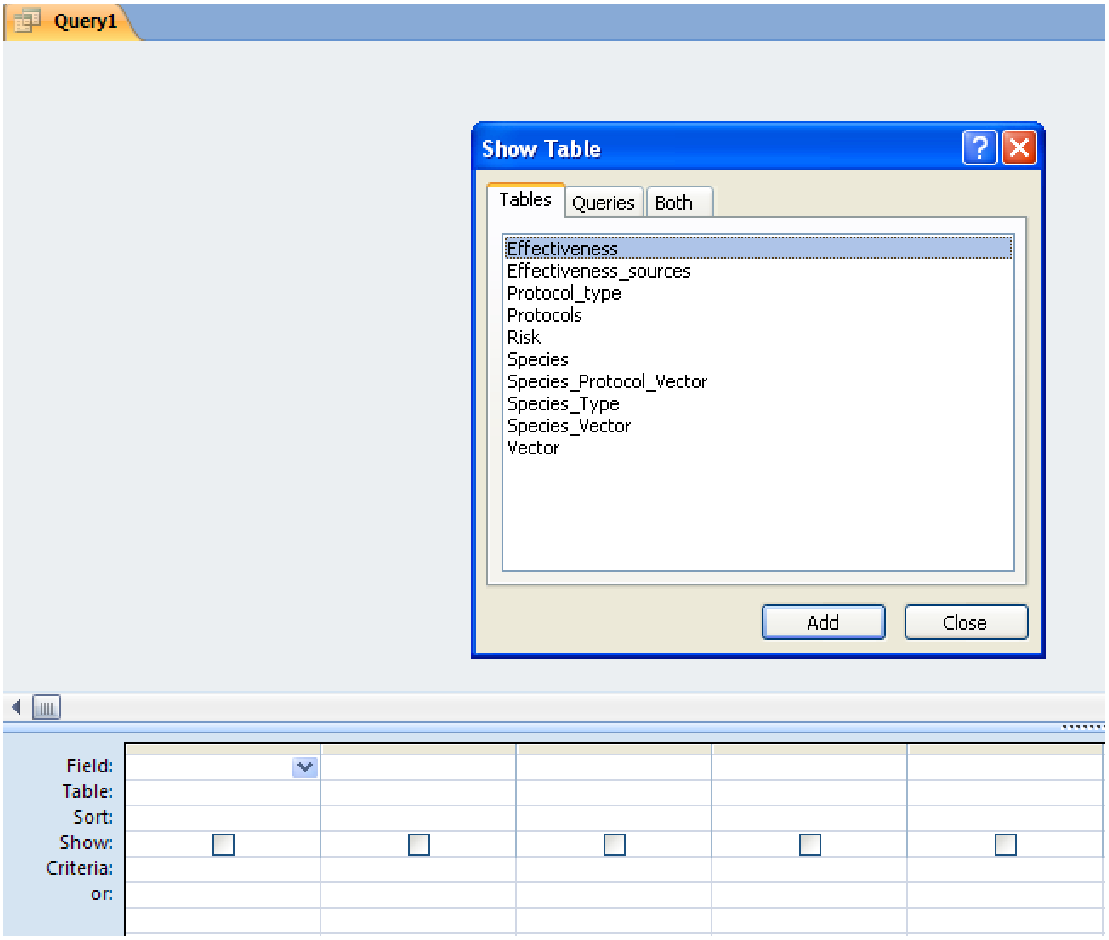
By SQL

Structured Query Language (SQL) allows for database creation, information addition, and editing. SQL requires more structure than other query creation within Access and allows for greater user control of queries. However, SQL will not inform a user about problems in syntax until the user attempts to save the query or change the view. Below is an example of an SQL query within the database, which selects for high, medium high, and medium risk species, and instructions for how to recreate this query. This query returns the protocol, protocol cost, protocol effectiveness, species by common name, vector, and the associated species-vector risk. Each query within the database returns the same columns of information with different values selected. To select different information, different columns can be specified within the query in the appropriate section.

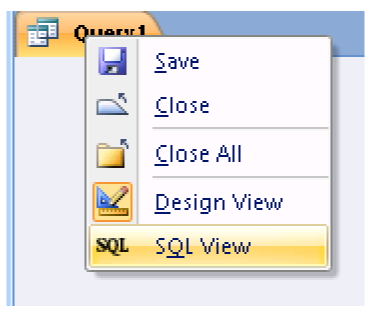
To create a query, under the Create tab along the top menu, select Query Design.



A new query will appear in the window, as shown below.



Close the Show Table window and right-click on the query title, in this case Query 1. Select SQL View.

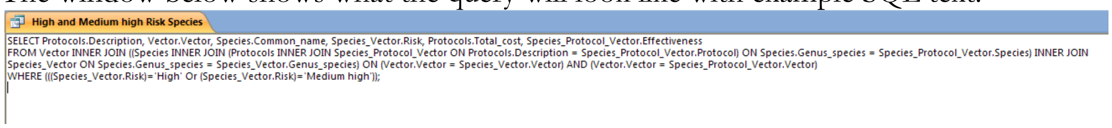


In this view, enter SQL text to form the query. Below is the text for the High and Medium high risk species sample query.

SELECT Protocols.Description, Vector.Vector, Species.Common_name, Species_Vector.Risk, Protocols.Total_cost, Species_Protocol_Vector.Effectiveness
FROM Vector INNER JOIN ((Species INNER JOIN (Protocols INNER JOIN Species_Protocol_Vector ON Protocols.Description =

Species_Protocol_Vector.Protocol) ON Species.Genus_species = Species_Protocol_Vector.Species) INNER JOIN Species_Vector ON Species.Genus_species = Species_Vector.Genus_species) ON (Vector.Vector = Species_Vector.Vector) AND (Vector.Vector = Species_Protocol_Vector.Vector)
WHERE (((Species_Vector.Risk)='High' Or (Species_Vector.Risk)='Medium high'));

The window below shows what the query will look like with example SQL text.

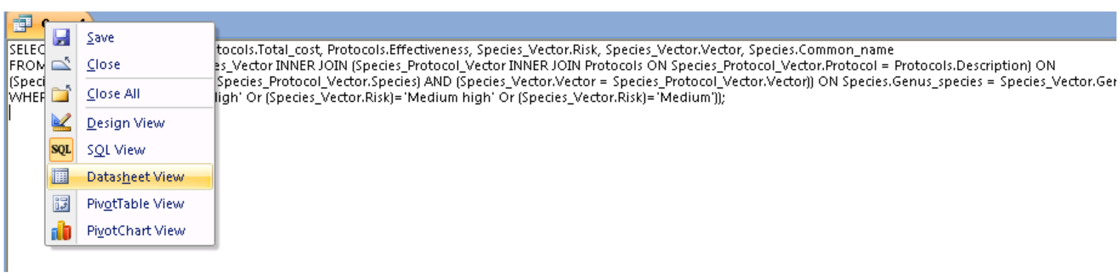


"SELECT" should be followed by the columns that you wish to view. These columns may be from any tables that are related. The structure for specifying the column is the "table_name.column_name". Columns and table names should not include spaces, because spaces will prevent a query from using that column or table. Each column or table name must exactly resemble the name assigned to it, or the query will not save or will not return any results.

"FROM" should be a list of tables where you select the columns.

"WHERE" should be followed by the criteria you are interested in. If you do not have any criteria that you are interested in and you want every response from those columns, you should delete this statement.

Once you have finished typing the SQL into the query, right click on the query and select Datasheet View to preview the results. This will show you a table with the information for the criteria you specified.



Once the query is correct, right-click and save the query.

Appendix 8 – Recommended Protocols

Table 1. The species-vector combinations the recommended protocols apply to. High risk species are in bold.

Protocol	Vector	Species	Risk	Cost	Effectiveness
Aggregate should be weed free and sterile. Aggregate does not include lumber.	Bulk soil	Cape Ivy	**High**		Recommended
	Bulk soil	Fountain grass	Medium low		
Bulk items that have not been approved must not be loaded. Biosecurity ranger must be notified if passenger arrives with such material.	Bulk soil	Cape Ivy	**High**	63.75	No information
		Argentine Ant	Medium		
		Earthworms	Medium		
		Earthworms	Medium		
		Sudden Oak Death Syndrome	Medium		
		Red imported fire ant	Medium high		
		Fountain grass	Medium low		
		Chytrid fungus	N/A		
		Planarian	N/A		

	Firewood	Argentine Ant	Medium		
		Gold spotted oak borer	Medium high		
		Red imported fire ant	Medium high		
	Lumber	Argentine Ant	Medium		
		Gold spotted oak borer	Medium high		
	Miscellaneous equipment and supplies	Cape Ivy	**High**		
		New Zealand Mud Snail	**High**		
		Argentine Ant	Medium		
		Sudden Oak Death Syndrome	Medium		
		Red imported fire ant	Medium high		
		Fountain grass	Medium low		
		Chytrid fungus	N/A		
Commercial vessels, passenger ferries, transport vessels cannot stay	IPCo boat	Rats	**High**		No information
		House mouse	Medium high		
	NPS boat	Rats	**High**		

at the wharfs except for shipping goods or passengers.		House mouse	Medium high		
Equipment cleaned and free of soil, invertebrates, and plant material.	Container	Argentine Ant	Medium	4362.64	Recommended
		Red imported fire ant	Medium high		
	Miscellaneous equipment and supplies	Cape Ivy	**High**		
		New Zealand Mud Snail	**High**		
		Argentine Ant	Medium		
		Sudden Oak Death Syndrome	Medium		
		Red imported fire ant	Medium high		
		Fountain grass	Medium low		
		Chytrid fungus	N/A		
Equipment transport manifest checklist filled out prior to departure by contractor, submit to TNC or	Firewood	Argentine Ant	Medium	414.38	No information
		Gold spotted oak borer	Medium high		
		Red imported fire ant	Medium high		
	Footwear	Fountain grass	Medium		

NPS upon loading and/or arrival.		Sudden Oak Death Syndrome	Medium		
		New Zealand Mud Snail	Medium high		
		Earthworms	Medium low		
		Chytrid fungus	N/A		
	Lumber	Argentine Ant	Medium		
		Gold spotted oak borer	Medium high		
	Miscellaneous equipment and supplies	Cape Ivy	**High**		
		New Zealand Mud Snail	**High**		
		Argentine Ant	Medium		
		Red imported fire ant	Medium high		
		Fountain grass	Medium low		
	Personal gear	Cape Ivy	**High**		
		Argentine Ant	Medium		
	Plants	Planarian	Low		
		Argentine Ant	Medium		

		Earthworms	Medium low		
		Earthworms	Medium low		
		Fountain grass	Medium low		
		Cape Ivy	N/A		
		Red imported fire ant	N/A		
	Vehicles	Cape Ivy	**High**		
		New Zealand Mud Snail	**High**		
		Argentine Ant	Medium		
		Sudden Oak Death Syndrome	Medium		
		Red imported fire ant	Medium high		
		Earthworms	Medium low		
		Earthworms	Medium low		
		Fountain grass	Medium low		
		Chytrid fungus	N/A		
		Planarian	N/A		

If any pest is detected during travel to, or on arrival at an island, than the planned visit must not proceed until that pest has been killed and pest free status of the stores or vessel is confirmed.	Footwear	New Zealand Mud Snail	Medium high		Recommended
	IPCo boat	Cape Ivy	**High**		
		Rats	**High**		
		Domestic Cat	Low		
		Western rattlesnake	Low		
		House mouse	Medium high		
		Raccoon	Medium high		
		Western Gray Squirrel	Medium low		
		Brown tree snake	N/A		
	NPS boat	Cape Ivy	**High**		
		Rats	**High**		
		Domestic Cat	Low		
		Western rattlesnake	Low		
		House mouse	Medium high		
		Raccoon	Medium high		

		Western Gray Squirrel	Medium low		
		Brown tree snake	N/A		
Implement an education program that targets private boating community, encourage voluntary participation in ensuring boats are clean and no species are inadvertently transported to the island, in particular, dogs are prohibited from landing.	Private boat	Canine Distemper – Raccoons	**High**	10056.5	No information
		Parvo - Domestic animals	**High**		
		Parvo - Raccoons	**High**		
		Rabies - Raccoons	**High**		
		Rats	**High**		
		Canine Distemper - Domestic animals	Medium high		
		Rabies - Domestic animals	Medium high		
		Raccoon	Medium high		
		Canine Distemper - Other wild animals	N/A		
		Domestic Cat	N/A		
		Parvo - Other wild animals	N/A		
		Rabies - Other wild animals	N/A		

		Western Gray Squirrel	N/A		
Inspection of vehicles to be transported to island, pressure wash if necessary and not completed by contractor.	Vehicles	Cape Ivy	**High**	492.29	No information
		New Zealand Mud Snail	**High**		
		Argentine Ant	Medium		
		Sudden Oak Death Syndrome	Medium		
		Red imported fire ant	Medium high		
		Earthworms	Medium low		
		Earthworms	Medium low		
		Fountain grass	Medium low		
		Chytrid fungus	N/A		
		Planarian	N/A		
No open bags or unsealed cardboard. Rodent proof containers for gear.	Container	Rats	**High**	505.83	No information
		Argentine Ant	Medium		
		House mouse	Medium high		
		Red imported fire ant	Medium high		

No trash can remain onboard the vessel at the end of each day.	IPCo boat	Rats	**High**	1275	No information
		House mouse	Medium high		
	NPS boat	Rats	**High**		
		House mouse	Medium high		
Ranger must be notified of bulk shipments 2 weeks in advance.	Bulk soil	Cape Ivy	**High**	159.38	No information
		Argentine Ant	Medium		
		Earthworms	Medium		
		Earthworms	Medium		
		Sudden Oak Death Syndrome	Medium		
		Red imported fire ant	Medium high		
		Fountain grass	Medium low		
		Chytrid fungus	N/A		
		Planarian	N/A		
	Firewood	Argentine Ant	Medium		
		Gold spotted oak borer	Medium high		

		Red imported fire ant	Medium high		
	Lumber	Argentine Ant	Medium		
		Gold spotted oak borer	Medium high		
	Miscellaneous equipment and supplies	Cape Ivy	**High**		
		New Zealand Mud Snail	**High**		
		Argentine Ant	Medium		
		Red imported fire ant	Medium high		
		Fountain grass	Medium low		
	Vehicles	Cape Ivy	**High**		
		New Zealand Mud Snail	**High**		
		Argentine Ant	Medium		
		Sudden Oak Death Syndrome	Medium		
		Red imported fire ant	Medium high		
		Red imported fire ant	Medium high		
		Earthworms	Medium low		

		Earthworms	Medium low		
		Fountain grass	Medium low		
		Chytrid fungus	N/A		
		Planarian	N/A		
Setting traps to control small mammals on vessels, and at departure and arrival points.	IPCo boat	Rats	**High**		Recommended
		Domestic Cat	Low		No information
		House mouse	Medium high		Recommended
		Raccoon	Medium high		No information
		Western Gray Squirrel	Medium low		No information
	NPS boat	Rats	**High**		Recommended
		Domestic Cat	Low		No information
		House mouse	Medium high		Recommended
		Raccoon	Medium high		No

					information
		Western Gray Squirrel	Medium low		No information
Signage at departure points	Aircraft	Cape Ivy	**High**	472.5	Recommended
		Rats	**High**		
		Rats	**High**		
		Argentine Ant	Medium		
		House mouse	Medium high		
		Red imported fire ant	Medium high		
		Fountain grass	Medium low		
	IPCo boat	Rats	**High**	472.5	Recommended
		Domestic Cat	Low		
		Western rattlesnake	Low		
		House mouse	Medium high		
		Raccoon	Medium high		
		Western Gray Squirrel	Medium low		

		Brown tree snake	N/A		
	NPS boat	Rats	**High**		
		Domestic Cat	Low		
		Western rattlesnake	Low		
		House mouse	Medium high		
		Raccoon	Medium high		
		Western Gray Squirrel	Medium low		
		Brown tree snake	N/A		
Signage at landing points	Aircraft	Cape Ivy	**High**	472.5	Recommended
		Rats	**High**		
		Rats	**High**		
		Argentine Ant	Medium		
		House mouse	Medium high		
		Red imported fire ant	Medium high		
		Fountain grass	Medium low		

	IPCo boat	Rats	**High**	472.5	Recommended
		Domestic Cat	Low		
		Western rattlesnake	Low		
		House mouse	Medium high		
		Raccoon	Medium high		
		Western Gray Squirrel	Medium low		
		Brown tree snake	N/A		
	NPS boat	Rats	**High**		
		Domestic Cat	Low		
		Western rattlesnake	Low		
		House mouse	Medium high		
		Raccoon	Medium high		
		Western Gray Squirrel	Medium low		
		Brown tree snake	N/A		
Steam-cleaning of	Vehicles	Cape Ivy	**High**	999	Recommended

vehicles and machinery with particular attention to areas where seed and soil can gather to prevent unintentional further weed/argentine ant spread.		New Zealand Mud Snail	**High**		No information
		Argentine Ant	Medium		No information
		Sudden Oak Death Syndrome	Medium		Recommended
		Fountain grass	Medium high		Recommended
		Red imported fire ant	Medium high		No information
		Earthworms	Medium low		No information
		Earthworms	Medium low		No information
		Chytrid fungus	N/A		Recommended
		Planarian	N/A		No information
Supervision on all IPCO trips to island, including manual inspection	Bulk soil	Cape Ivy	**High**	392	Recommended
		Argentine Ant	Medium		
		Earthworms	Medium		

of all gear and belongings of 1 out of every 10 passengers on each arrival trip.		Earthworms	Medium		
		Sudden Oak Death Syndrome	Medium		
		Red imported fire ant	Medium high		
		Fountain grass	Medium low		
		Chytrid fungus	N/A		
		Planarian	N/A		
	IPCo boat	Rats	**High**		
		Domestic Cat	Low		
		Western rattlesnake	Low		
		House mouse	Medium high		
		Raccoon	Medium high		
		Western Gray Squirrel	Medium low		
		Brown tree snake	N/A		
	Miscellaneous equipment and	Cape Ivy	**High**		
		New Zealand Mud Snail	**High**		

	supplies	Argentine Ant	Medium		
		Earthworms	Medium		
		Earthworms	Medium		
		Sudden Oak Death Syndrome	Medium		
		Red imported fire ant	Medium high		
		Fountain grass	Medium low		
		Chytrid fungus	N/A		
		Planarian	N/A		
	Personal gear	Cape Ivy	**High**		
		Rats	**High**		
		Argentine Ant	Medium		
		Fountain grass	Medium		
		Sudden Oak Death Syndrome	Medium		
		House mouse	Medium high		
		New Zealand Mud Snail	Medium high		

		Chytrid fungus	N/A		
		Red imported fire ant	N/A		
Training of staff in biosecurity procedures by a managerial facilitator.	All except private boats	All	**Variable**	392	No Information
Trash storage should be pest proof	Dumpster	Domestic Cat	**High**	89.94	Recommended
		Rats	**High**		
		House mouse	Medium high		
		Raccoon	Medium high		
		Western Gray Squirrel	Medium high		
Vessels and aircraft cleaned, does not include ranch vehicles.	Aircraft	Cape Ivy	**High**	659	No information
		Rats	**High**		
		Argentine Ant	Medium		
		House mouse	Medium high		
		Red imported fire ant	Medium high		

		Fountain grass	Medium low		
	IPCO boat	Canine Distemper - Raccoons	**High**		
		Parvo - Raccoons	**High**		
		Rabies - Raccoons	**High**		
		Rats	**High**		
		Domestic Cat	Low		
		Western rattlesnake	Low		
		House mouse	Medium high		
		Rabies - Domestic animals	Medium high		
		Raccoon	Medium high		
		Western Gray Squirrel	Medium low		
		Brown tree snake	N/A		
		Canine Distemper - Domestic animals	N/A		
		Canine Distemper - Other wild animals	N/A		

		Parvo - Domestic animals	N/A		
		Parvo - Other wild animals	N/A		
		Rabies - Other wild animals	N/A		
	NPS boat	Canine Distemper - Raccoons	**High**		
		Parvo - Raccoons	**High**		
		Rabies - Raccoons	**High**		
		Rats	**High**		
		Domestic Cat	Low		
		Western rattlesnake	Low		
		House mouse	Medium high		
		Rabies - Domestic animals	Medium high		
		Raccoon	Medium high		
		Western Gray Squirrel	Medium low		
		Brown tree snake	N/A		
		Canine Distemper - Domestic animals	N/A		

		Canine Distemper - Other wild animals	N/A		
		Parvo - Domestic animals	N/A		
		Parvo - Other wild animals	N/A		
		Rabies - Other wild animals	N/A		
Visitors who refuse to comply with biosecurity procedures will be prohibited from transporting their personal gear to the island.	Footwear	Fountain grass	Medium	1360	No information
		Sudden Oak Death Syndrome	Medium		
		New Zealand Mud Snail	Medium high		
		Earthworms	Medium low		
		Chytrid fungus	N/A		
		Chytrid fungus	N/A		
	Personal gear	Cape Ivy	**High**		
		Rats	**High**		
		Argentine Ant	Medium		
		Fountain grass	Medium		
		House mouse	Medium high		

		New Zealand Mud Snail	Medium high		
		Red imported fire ant	N/A		
Visitors will use a checklist to perform self-checks in a designated area.	Footwear	Fountain grass	Medium		Recommended
		Sudden Oak Death Syndrome	Medium		
		New Zealand Mud Snail	Medium high		
		Earthworms	Medium low		
		Earthworms	Medium low		
		Chytrid fungus	N/A		
	Personal gear	Cape Ivy	**High**		
		Rats	**High**		
		Argentine Ant	Medium		
		Fountain grass	Medium		
		House mouse	Medium high		
		New Zealand Mud Snail	Medium high		
		Red imported fire ant	N/A		

Visitors, staff, contractors should be told that gear should be cleaned and free of soil, invertebrates, and plant material at ticket purchase		Cape Ivy	**High**		Recommended
		Argentine Ant	Medium		
		Fountain grass	Medium		
		New Zealand Mud Snail	Medium high		
		Red imported fire ant	N/A		
Visual detection of footprints; droppings, prey remains, chews, wallows, rooting, feathers, etc. Employee walk through of designated dock and vessel areas of concern once daily.	IPCo boat	Rats	**High**	2210	No information
		Domestic Cat	Low		
		House mouse	Medium high		
		Raccoon	Medium high		
		Western Gray Squirrel	Medium low		
	NPS boat	Rats	**High**	2210	No information
		Domestic Cat	Low		
		House mouse	Medium high		
		Raccoon	Medium high		
		Western Gray Squirrel	Medium low		

Where visits between islands (of different pest status) within the same island group occur, biosecurity standards must be applied as if moving from the mainland to that island and/or back again.	Aircraft	Cape Ivy	**High**	doubles cost of all recommended protocols	Recommended
		Rats	**High**		
		Argentine Ant	Medium		
		Red imported fire ant	Medium high		
		Fountain grass	Medium low		
	IPCo boat	Rats	**High**		
		House mouse	Medium high		
	NPS boat	Rats	**High**		
		House mouse	Medium high		

Appendix 9 – Private Boating Community Survey

Santa Cruz Island Boater Survey

Ahoy!

The Nature Conservancy would like to learn more about boaters who visit Santa Cruz Island. This survey will help The Nature Conservancy enhance public awareness and education about Santa Cruz Island. Your identity will not be recorded during the survey and therefore can not be revealed when responses are analyzed. Anonymous responses and survey summaries may be distributed to Nature Conservancy staff and partners.

Thank you very much for taking the time to participate!

~The Nature Conservancy

1. How many years have you been boating to the northern Channel Islands?

- ◯ Less than one year
- ◯ 1-5 years
- ◯ 6-10 years
- ◯ Over 10 years

2. How often do you anchor at or near Santa Cruz Island?

- ◯ Less than one time a year
- ◯ One time a year
- ◯ 2-6 times a year
- ◯ More than six times a year

3. Please select up to five anchorages/areas you frequent the most when you boat out to Santa Cruz Island.

- ☐ Alamos
- ☐ Albert's
- ☐ Chinese
- ☐ Christy
- ☐ Coches Prietos
- ☐ Cueva Valdez
- ☐ Diablo
- ☐ Forney's
- ☐ Fry's
- ☐ Hazards
- ☐ Lady's and Baby's
- ☐ Laguna
- ☐ Little Scorpion
- ☐ Marmetta Reef
- ☐ Orizaba
- ☐ Painted Cave
- ☐ Pelican Bay/Tinkers
- ☐ Platts
- ☐ Potato Harbor/Potato Bay
- ☐ Pozo
- ☐ Prisoner's
- ☐ Sauces
- ☐ Scorpion
- ☐ Smuggler's
- ☐ Twin
- ☐ Valley
- ☐ Willow's
- ☐ Yellowbanks

Other (please specify)

Santa Cruz Island Boater Survey

4. What activities do you enjoy during your visits to Santa Cruz Island and the surrounding waters? Please select all that apply.

- [ ] Walking and expoloring on the beach
- [ ] Exercising my pets on the beach
- [ ] Running or Hiking
- [ ] Bird or marine mammal watching
- [ ] Exploring using a dinghy or kayak
- [ ] Fishing or Diving
- [ ] Surfing or Swimming
- [ ] Camping
- [ ] Beach barbecues or campfires
- [ ] Spiritual endeavors
- [ ] Absorbing the peaceful solitude

Other (please specify)

5. How often do you come ashore during your trips out to Santa Cruz Island?

- ○ Every time
- ○ Sometimes
- ○ Rarely
- ○ Never

6. Have you ever seen pets brought ashore by boaters on Santa Cruz Island?

- ○ Yes
- ○ No

7. Have you ever brought your own firewood when traveling to Santa Cruz Island?

- ○ Yes
- ○ No

8. Have you noticed changes in the landscape of Santa Cruz Island since you have been visiting the island?

- ○ The island landscape has significantly improved since I started frequenting the island.
- ○ I have noticed slight improvements in the last few years.
- ○ I have noticed some changes although I preferred the island as it was in the past.
- ○ I have not been visiting Santa Cruz Island long enough to notice any changes in the landscape.

9. Please tell us if you preferred the island as it was in the past and why.

10. The protection of native island species and restoration of native plants and vegetation is important to the preservation of Santa Cruz Island.

	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
A.	○	○	○	○	○

Santa Cruz Island Boater Survey

11. Increasing my knowledge about native island species will enhance my experience while visiting Santa Cruz Island.

	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
A.	◯	◯	◯	◯	◯

12. The Nature Conservancy's policies which prohibit dogs, fires and overnight camping on Santa Cruz Island are necessary for the future preservation of Santa Cruz Island.

	Strongly Agree	Agree	Unsure	Disagree	Strongly Disagree
A.	◯	◯	◯	◯	◯

13. Did you know that landing permits are required to come ashore on the western portion of Santa Cruz Island that is owned by The Nature Conservancy?

◯ Yes ◯ No

14. When you plan to go ashore, do you buy a landing permit for your visits to Santa Cruz Island?

◯ Yes ◯ No

15. If you do not purchase landing permits, please tell us why.

____

16. Do you think the landing permits are reasonably priced?

◯ Yes ◯ No ◯ Unsure

17. Do you think the landing permits are easy to obtain?

◯ Yes ◯ No ◯ Unsure

18. What would make the permit application and renewal process easier for you to access? Please select any that apply.

- ☐ The current process is fine.
- ☐ Send a reminder email when the permits expire.
- ☐ Make the permit application link easier to find.
- ☐ I do not know anything about the current process.

Please provide suggestions as to how the landing permit application process could be more accessible to you:

____

Santa Cruz Island Boater Survey

19. In which mainland harbor do you keep your boat, or if trailered, which boat launch do you use most frequently when going out to the Channel Islands?

- ◯ Channel Islands
- ◯ Santa Barbara
- ◯ Point Hueneme
- ◯ Ventura
- ◯ Other

20. Does your boat have a marine waste holding tank?

- ◯ Yes
- ◯ No

21. Are you a member of a boating organization such as a yacht club, charter club, cruise club, or fishing club?

- ◯ Yes
- ◯ No

If yes, Please tell us what organization:

Appendix 10 – Marketing Flyer for Survey & Permit Program

The Nature Conservancy
Protecting nature. Preserving life.™
nature.org

Visiting Santa Cruz Island?

Photo © Stephen Francis Photography

Please take our boater survey:
www.surveymonkey.com/s/cruzsurvey

Thanks for your support!

Appendix 11 – Invasive Species Characterizations

Table of Contents

Microorganisms / Fungi

Canine Distemper

Physical Description

Canine infected with Canine Distemper.

Initial symptoms include gooey discharge from eyes and nose, fever, poor appetite coughing and development of pneumonia. Eventually vomiting and diarrhea occur as well as callusing of the nose and footpads. This stage is known as the mucosal stage because the virus is attacking the body's interfaces with the environment. Next the virus proceeds to the neurological phase where virus attacks the central nervous system, resulting in seizures that begin as "snapping" or "tremors" of the jaws that eventually leads to full body seizures as well as imbalance and limb weakness (marvistavet.com 2011).

Canine distemper (CDV) is made of a single strand of RNA, encased in a protein coat which is encased in a fatty envelope. This is important to note, because the fatty envelope makes the virus easily disrupted in the environment which means it is difficult for the virus to persist in the environment. This also means that transmission of the virus must happen with dog to dog contact (marvistavet.com 2011).

Introduction Pathways

- Domestic Dogs on private sail boats
- Raccoons stowed away on private sail boats
- Raccoons stowed away in dumpsters

Invasion Ecology/Transmission

Transmission of CDV occurs when an infected dog comes in close contact with an uninfected dog and the virus is spread via coughing of infected respiratory secretions. Other bodily secretions such as urine also spread it; however, once the virus enters the environment, it does not last long. The virus enters the new host via the nose or mouth and begins to replicate (marvistavet.com 2011).

The virus acts quickly, within 24 of ingestion, the virus begins to replicate and travels to the lymph nodes. By day 6 the virus has migrated to the spleen, stomach, small intestine and liver. The host shows signs of fever at this point. By day 8 or 9 the host's body launches an intensive immune response. A healthy host with a strong immune system will clear the virus by day 14. A host with a weak immune system will allow the virus to reach the epithelia cells (cells that line the interface with the outside world) including the lining of the chamber of the brain. At this point the host begins to get sick and display the range of symptoms described above.

General Impacts
Young puppies or individuals with weak immunity often die during the mucosal phase while strong individuals may have relatively mild mucosal signs and not appear ill until the neurological phase strikes (marvistavet.com 2011).

Potential on Santa Cruz Island
Potential threats from domestic dogs are minimal because most domestic dogs receive vaccines for CDV. Dogs most likely to be infected with CDV would be stray dogs, which would be highly unlikely to make it to SCI.

Wild hosts such as raccoons pose a higher risk because they are not actively vaccinated, they are located at harbors up and down the coast of California, and they are inherently curious natured animals that would be likely to stow away on a boat or dumpster bound for SCI.

Control & Eradication
Treatments for infected animals involves supportive care for the animal while it builds its own immune response. Neurological distemper is difficult, while it is possible for dogs to recover from neurological distemper, euthanasia is recommended when incapacitating neurological symptoms are evident.

Effective distemper vaccinations exist for canines. On Catalina Island, an experimental canine distemper virus vaccine was successfully used on the island fox (Institute For Wildlife Studies 2011).

Resources
Canine Distemper
http://www.marvistavet.com/html/canine_distemper.html

Works Cited
INSTITUTE FOR WILDLIFE STUDIES, 2011. Island Fox. Available at: http://www.iws.org/island_fox_studies_Santa_Catalina_Island.htm [Accessed March 18, 2011].

MARVISTAVET.COM, 2011. Canine Distemper. Available at: http://www.marvistavet.com/html/canine_distemper.html [Accessed March 17, 2011].

Canine Parvovirus

Physical Description and Background

Canine Parvovirus. (Source: Canine Parvovirus Info Center 2011)

Parvoviruses are smaller than most viruses and consist of a protein coat (a "capsid") and a single strand of DNA inside, which is a relatively simple construction compared to many other viruses. Parvovirus is not enveloped in fat the way many other viruses are, making it especially hardy in the environment and difficult to disinfect away. The simple construction has also proved especially effective at infecting and rapidly dividing host cells such as intestinal cells, bone marrow cells, cells of the lymph system, and fetal cells (Canine Parvovirus Info Center 2011).

Compared to other viruses, the Dog Parvovirus is quite small, but it is resilient. While some viruses are destroyed by sunlight or moisture, the parvovirus can survive almost all climatic conditions. A parvovirus has basically two parts, the capsid and the nucleic acid. The capsid is a protein that protects the nucleic acid inside. The nucleic acid of the parvovirus is the DNA (deoxyribonucleic acid) (B19virus 2011).

CPV-1, the original canine parvovirus, also known as the canine minute virus was discovered in 1967 and only threatened newborn puppies. The CPV-2 variant appeared in the US in 1978. It is considered a mutation of the feline distemper virus. The virus is shed in such large magnitudes and is especially hardy in the environment; ultimately, CPV-2 is ubiquitous or present everywhere in the world in the environment. Compared to CPV-1, CPV-2 is tougher and poses more of a threat for domestic dogs and wild canines (Canine Parvovirus Info Center 2011).

There are variants of CPV type 2 called CPV-2a, CPV-2b and CPV-2c. The antigenic (a toxin or other foreign substance that causes and immune response in the body) patterns of 2a and 2b are quite similar to the original CPV type 2. CPV-2b is the most common form of CPV-2 today (Canine Parvovirus Info Center 2011). Variant 2c emerged in 2000 and has quickly become the second most common form of CPV. CPV-2c is able to infect cats(Canine Parvovirus Info Center 2011).

According to the European Association of Zoos and Aquariums (EAZA), speces from six familes are suceptable to CPV-2. Those families are: Felidae (cats), Canidae (dogs), Procyonidae (raccoons), Mustelidae (weasel), Ursidae (bears), and Viverridae (old world mammals such as genets) (Frolich 2002).

Range
The CPV-2 viruses are spread so rapidly that it has been considered "ubiquitous," in other words, canine parvovirus can be found anywhere in the world (B19virus 2011).

Associated Vectors and Pathways

- Dogs: feces from infected dogs
- Bedding or other material that has been in contact with an in infected dog
- Raccoons: It is uncertain whether or not raccoons are a vector of CPV. Raccoons do not develop clinical disease when exposed to canine parvovirus, yet the can be affected by a unique raccoon parvovirus that is most antigenically similar to feline parvovirus (Purdue Animal Disease Diagnotic Laboratory 1997) However, recent research has identified a mutated strain of canine parvovirus that can infect raccoons (Bailey 2011)

Invasion Ecology

- The interaction of three things determine the ability for infection. 1) host vitality: including immune experience / vaccination status). 2) virulence of the virus: the number of viral particles a host is exposed to. 3) environmental factors. These three aspects interplay in such a way that a stressful environment will reduce host vitality and a dry environment will reduce the number of viral particles (Canine Parvovirus Info Center 2011).
- The virus is essentially everywhere, on every carpet, every floor, in every yard and park. The disease is highly contagious and is often spread from dog to dog by direct or indirect contact with their feces (Canine Parvovirus Info Center 2011)
- The virus is shed in the stool for the first two weeks or less after the initial infection. Only a tiny portion of infected stool is necessary to infect a non-immune dog. The infected stool from a host can remain viral for months depending on the environmental temperature and humidity (Canine Parvovirus Info Center 2011).
- Following the ingestion, the virus replicates in the lymphoid tissue in the throat, and then spreads to the bloodstream. From there the virus attacks rapidly dividing cells, notably those in the lymph nodes, intestinal crypts, and the bone marrow (Canine Parvovirus Info Center 2011).
- Immunology: one of the most important factors in whether parvovirus infection occurs is the experience the dog's immune system has had with the virus plus the number of viral particles the host is exposed to. When

the virus first emerged in the 1970's all dogs young and old were susceptible. Now, because the virus is ubiquitous, it is likely that a dog has had at least some immunology experience with the virus. Any exposure, no matter how small, is likely to generate some antibodies. The younger the canine, the less immunologic experience and more susceptible to infection. (Canine Parvovirus Info Center 2011).

- When puppies are born they are completely unable to make antibodies against any infectious invader. They rely on their mother's post birth milk, known as colostrum, which contains the antibodies of the mother dog, thus giving her own immune experience to her off-spring.
- Speed / Rate: CPV-2 first made its appearance in 1978 and within 1-2 years it spread worldwide (Carmichael 2005).
- **Susceptibility:** risk for infection with CPV-2c (and other variants) is highest when large numbers of dogs are housed together in close confinement such as boarding / training kennels, shelter facilities, dog shows, and racing kennels. Dogs of all ages and breeds are susceptible to infection. Puppies and unvaccinated or improperly vaccinated dogs are at high risk of infection and illness (Canine Parvovirus Info Center 2011).

General Impacts

- Skunks are not susceptible to canine or feline parvo (Burgess 2011)
- CPV2 can be especially severe in puppies that are not protected by maternal antibodies or vaccinations. Incubation in puppies is 3-7 days before there are obvious ill symptoms (Canine Parvovirus Info Center 2011).
- Two distinct presentations of CPV-2. Intestinal and cardiac. 1) Common signs of the intestinal from are severe vomiting and dysentery. The cardiac form causes respritory or cardiovascular failure in young puppies (Canine Parvovirus Info Center 2011).
- Parvovirus kills one of two ways (Canine Parvovirus Info Center 2011):
    - Diarrhea and vomiting lead to extreme fluid loss and dehydration until shock and death result
    - Loss of the intestinal barrier allows bacterial invasion of potentially the entire body. Septic toxins from bacteria result in death.
- When parvovirus enters the body it seeks out the nearest rapidly dividing group of cells. It generally begins replicating in the lymph nodes where itreplicates in large quantities. After a couple days, so much of the virus has been produced that the virus is released into the blood stream. From there, the virus seeks new organs containing rapidly dividing cells: the bone marrow and the delicate intestinal cells. This process takes place in 3 to 4 days.

  In the bone marrow, the virus destroys the cells of the immune system, effectively knocking out the body's defenses. Thus, all parvoviral infections are associated with a drop in white blood cells. The gastrointestinal tract is where the heaviest damage occurs. Parvovirus strikes the crypts of liberkuhn, which is the rapidly dividing area where new cells and microvilli are produced in the intestine. The microvilli are tiny finger like projections in the intestine that increase surface area for absorption of fluids and nutrients.

Without new cells being created from the crypt, the villi of the intestine become blunted and unable to absorb nutrients. Diarrhea occurs in large quantities. Additionally, the barrier separating the digestive bacteria from the blood stream breaks down. Diarrhea becomes bloody and bacteria can enter the body causing widespread infection (Canine Parvovirus Info Center 2011).

Potential on Santa Cruz Island

Island foxes have not been vaccinated for CPV and are considered to be at risk of CPV. There are also no tested vaccines available for foxes. It is uncertain whether or not CPV has made it to the Island in the past. Given the ubiquitous state of CPV it is not out of the question. It may be possible that foxes have natural antibodies built up in their system against CPV.

Risk for infection with CPV-2c (and other variants) is highest when large numbers of dogs are housed together in close confinement such as boarding / training kennels, shelter facilities, dog shows, and racing kennels. Captive breeding on Santa Cruz Island has been discontinued; therefore the risk of an outbreak of CPV in the breeding facility is unlikely.

Additionally the relatively hot and dry environmental conditions on SCI coupled with the low quantities of viral agents makes transmission of CPV by Island foxes a low potential.

Control & Eradication

- Currently available vaccines for domestic dogs cover all variants of CPV, including CPV-2c. So do all commercially available diagnostic test kits. Treatment often involves veterinary hospitalization (Canine Parvovirus Info Center 2011). However, the these vaccines have not been tested on wild foxes.
- Most often, transmission is through the fecal-oral route, probably mainly through ingestion of virus from the environment, rather than by direct contact with infected animals. Because of this, free-ranging wild carnivores, even if solitary, widely dispersed, and at low density, may be exposed at marking sites, latrines, or other areas contaminated by feces deposited by a virus shedder (Williams & Barker 2001).
- Abundant inactiveated-adjuvanted or modified live vaccines (MLVs) are registered for use against parvovirus in cats, dogs, and mink. These vaccines are recommended in captive wild carnivores that may be susceptible to

parvovirus infection. The vaccine selected should be based on similarity of the hosts or known or probable virus susceptibility of the host to be vaccinated. There is no warranty of safety or efficacy for use of these vaccines in wild carnivores. The few studies of parvovirus vaccination in wild animals suggest that the response is comparable to domestic animals(Williams & Barker 2001).

- Vaccination programs should mirror the principles applied to vaccination of domestic carnivores in the face of maternal antibody. Begin vaccinations at 6-9 weeks of age, and continue to vaccinate at 2 – 4 week intervals through 20 weeks of age.

Resources

Parvovirus
http://www.b19virus.com/canine-parvovirus.html

Canine Parvovirus Info Center:
http://www.marvistavet.com/html/body_canine_parvovirus.html

American Veterinary Medical Association:
http://www.avma.org/animal_health/canine_parvovirus_faq.asp

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Chytrid Fungus (*Batrachochytrium dendrobatidis*)

Physical Description

B. dendrobatidis is the only chytrid fungus which causes chytridiomycosis in amphibians (Berger et al. 2002). Frogs infected by the fungus have discolored skin which sloughs off, are lethargic, and will sit unprotected in the daytime (Berger et al. 1999). Identification of the fungus in skin samples can be performed histologically (Berger et al. 2000). The zoosporangia are spherical with a discharge papilla through which zoospores are released. After zoospores are released, the empty zoosporangia can fill with bacteria. The zoosporangia can be seen in four growth stages. The zoosporangia are less than 15 µm in diameter.

Frog infected with chytrid fungus. (Source: Gewin 2008)

Range

Chytrid fungus probably originated in southern Africa, as no cases of chytridiomycosis were known in amphibians from outside this area for 23 years after the first case (Weldon et al. 2004). It has been found on every continent except Asia. In California, *B. dendrobatidis* has been identified along the coast, particularly in the San Francisco Bay area, and in the Sierra Nevada Mountains (CCADC 2007).

Introduction Pathways

It is though that chytridiomycosis first spread from southern Africa through trade of *Xenopus spp* (Weldon et al. 2004). The fungus can also be spread via equipment which has been used in areas of infection, such as boots, nets, measuring instruments, and husbandry supplies (Johnson et al. 2003).

Invasion Ecology

Habitat

B. dendrobatidis is a water-borne pathogen. Mortality can occur within 3 hours of desiccation. The fungus can survive in sterile water for 7 weeks. Amphibians that breed in water bodies, especially permanent streams are most at risk to infection (Kriger & Hero 2007). The fungus prefers the cooler temperatures found in the running water of streams.

Dispersal

Zoospores, the life stage produced via clonal reproduction of *B. dendrobatidis,* disperse through moving water. They swim an average of only 2 cm before encysting and therefore rely on flowing water to disperse downstream (Kriger & Hero 2007). The fungus can also be spread from infected frogs (Morgan et al. 2007). Infection of more terrestrial amphibians indicates that the sloughed skin from infected species may also spread the fungus (Kriger & Hero 2007). Infection sites with genotypic variability indicate that sexual reproduction and genetic recombination may possibly be occurring. Sexual reproduction results in the creation of a less vulnerable meiosporangia which can act as a long-range dispersal agent (Morgan et al. 2007). It can also persist in the absence of a host for longer periods of time. In addition to persistence in the environment, the fungus can use tadpoles and some adults as reservoirs by maintaining low levels of infection (Skerratt et al. 2007).

General Impacts
Chytrid fungus causes the disease chytridiomycosis which has led to the decline of amphibians in Ecuador, Venezuela, New Zealand, and Spain (Weldon et al. 2004). It has caused the decline of yellow-legged frogs (*Rana muscosa*) all over the Sierra Nevada Mountains (Briggs et al. 2005). It is not known to have caused declines in frogs in Africa (Weldon et al. 2004). The disease infects the skin of adults, causing sloughing of the epidermis (Bosch et al. 2001). Tadpoles can carry the fungus but are not affected by it, creating a reservoir for the disease (Briggs et al. 2005). These physiological changes lead to mortality; however, the exact mechanism by which this occurs is not known (Morgan et al. 2007). Two possible explanations are that the fungus releases proteolytic enzymes into the organism or that the disruption of the skin leads to osmoregulatory imbalances (Berger et al. 1999).

Potential on Santa Cruz Island
The amphibians present on Santa Cruz Island which could potentially be infected by chytrid fungus are the Pacific tree frog (*Pseudacris regilla*), the Channel islands Slender Salamander (*Batrachoseps pacificus pacificus*), and the Black-bellied Slender Salamander (*Batrachoseps nigriventris*). Cherie Briggs, a professor at UCSB, has studied chytrid fungus and frogs in the Sierra Nevada Mountains and believes the risk to the species on Santa Cruz Island is minimal (personal communication, July 7, 2010). Members of the *Pseudacrus* genus are often infected by the fungus, but rarely die from it. *Batrachoseps spp* are also frequently infected by the fungus, and have been known to die as a result in the laboratory setting. It is unknown how fatal the fungus is in the field.

Control & Eradication
Disinfectants can kill zoospores and zoosporangia to prevent the spread of chytrid fungus on contaminated equipment and in quarantined husbandry facilities (Johnson et al. 2003). Successful disinfectants include sodium chloride, bleach, potassium permanganate, formaldehyde, Path-X™, full strength quaternary ammonia compound 128, Virkon, ethanol, and benzalkonim chloride. Desiccation for at least 3 hours and heating to 32ºC are also effective in killing 100% of the fungus. However, heating to 32ºC requires 96 hours of heating, while heating to 100ºC only requires 1 minute to attain 100% mortality. Banning the sale of frogs through the pet trade would also

prevent introduction of the disease, however, this is not relevant to SCI (Kriger & Hero 2009).

Eradication of the fungus from infected sites is not possible, and methods for eradication are not likely to become known in the near future (Kriger & Hero 2009). At sites where a rare or endangered species is affected, it may be necessary to capture individuals and cure them on a case by case basis until eradication measures are discovered. In areas where the fungus is expected to invade, individuals should be tested periodically to identify when invasion has occurred. Captive breeding programs can maintain healthy individuals in the event of introduction of the fungus.

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Earthworms

Literature on nonnative and invasive earthworms typically refers to lumbricids, *Amynthas* spp., and *Pontoscolex corethrurus*, which are now widespread and abundant in many ecosystems.

Range

The worm species discussed here are European in origin.

Introduction Pathways

Soil containing earthworms is most frequently transported as potting medium, ballast fill, and in the treads of vehicles or shoes. Worms are also introduced as fishing bait or through vermiculture (Lilleskov et al. 2009, ISSG 2009).

Bold lines represent the Pliestocene glaciation boundary. Hash marks denote areas with native earthworms (Source: Callaham et al 2006).

Invasion Ecology

Predicting Invasion

The physiological and ecological conditions under which earthworm invasion can be successful are not well understood. The majority of impacts are found in areas that were historically free of earthworms, such as north of the Pleistocene glacial margins (fig. 1) or chronically disturbed areas, such as agricultural systems. Exotic earthworms have, however, also successfully invaded undisturbed ecosystems with pre-existing native earthworms (Hendrix et al. 2006, Callaham et al. 2006). Invasion success is thought to be more a product of the physical and chemical composition of the habitat than competitive interaction with native earthworms, but a reliable set of predictive criteria has not yet been developed (Hendrix et al. 2006).

Dispersal/Rate of spread

Dispersal is slow, approximately 10-15 meters per year in the absence of human transport. Reproduction is also relatively slow, considering the rate at which many invasive species are able to multiply. It can take years to decades for an exotic population to proliferate to high abundances after introduction (Hendrix et al. 2006).

General Impacts

Earthworms mix soil strata and consume organic matter in the soil column. Nonnative earthworms can cause a fundamental shift in the soil properties of areas without native earthworms, transforming historically unmixed soils with distinct horizons into well-mixed soil horizons (Lilleskov et al. 2009). This mixing and the worms' consumption of organic matter can then cause significant changes in nutrient availability, plant litter decomposition rates, soil aggregation and porosity, dynamics of nutrient cycling, water and solute transportation, and the composition of resident plant and soil organism communities (Hendrix et al. 2006 and references therein). Negative effects from direct competition with native earthworm have not been demonstrated, but are considered a possibility. Frequently, native and exotic earthworms are able to coexist, possibly because the nonnative species are able to exploit resources that are not fully utilized by natives (Hendrix et al. 2006).

Potential on Santa Cruz Island

Earthworms could be transported to the island in soil in the treads of vehicle tires or as bait from recreational fishermen. Earthworms are currently present on SCI, though it is not known whether they are native (Lyndal Laughrin, UC Reserve director, person. Com., 11/01/10). Introduced earthworms may compete with those worms populations currently on the island, however since worms are already widespread on the island, any additional changes to soil properties would likely be minimal.

Control & Eradication

There are currently no economically feasible methods for eradicating earthworms (MN DNR 2003).

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Gold Spotted Oak Borer (*Agrilus auroguttatus*)

The gold spotted oak borer (*Agrilus auroguttatus*) is a new pest to California oak woodlands. It was not detected until 2004 and was not associated with ongoing oak mortality until 2008 (Coleman & Seybold 2008b). Research on the life history and dispersal capabilities of *A. auroguttatus* is limited but on going. *A. auroguttatus* is not known to be a pest elsewhere and has not been described in detail, but many other *Agrilus* species are well understood and can provide information to guide management decisions until more information is available. Other North American *Agrilus* pest species include the emerald ash borer (*A. planipennis*), bronze birch borer (*A. anxius*), and twolined chestnut borer (*A. bilineatus*).

Figure 1. *Agrilus auroguttatus* adults from dorsal (top) and lateral (middle) views, larvae (bottom) from Coleman and Seybold (2008)

Physical Description

A. auroguttatus may be observed in one of three life forms - adult, larval, and pupae - described below and shown in Figure 1. The symptoms displayed in the bark and canopy of infected trees are shown in Figure 2 (Davis et al. 2010).

Adults

A. auroguttatus adults found in California are a bullet shaped and dull metallic green with six spots of prominent golden yellow pubescence on the elytra. Adult beetles average 9.5mm long and 1.5mm wide (Coleman & Seybold 2008b, Baez 2009). The U.S. form and the southern Mexican and Guatemalan forms differ in the shape of the prehumeral carina, and during pubescence. U.S. specimens show larger and more golden-colored elytral spots (Hespenheide 1979, Coleman & Seybold 2008b).

Larvae and larval galleries

Mature larvae average 18 mm long, 3 mm wide. They are white and legless with an elongated slender shape and two pincher-like spines located at the tip of the abdomen (Coleman & Seybold 2008a). Larval galleries occur most extensively in sapwood but can extend into the inner and outer bark as well, though typically at lower densities. Galleries are black in color, 3-4mm wide, packed with frass, and in a pattern that is meandering but with a general vertical orientation. They are present at the base of trees and extending upward along the main stem and larger branches (Coleman & Seybold 2008b). Larvae and galleries of the related Emerald Ash Borer (*Agrilus* plannipenis) are more common on the south and east sides of trees, this may also be the case for *A.auroguttatus* (Francese et al. 2008)

Pupae
Pupae are found in the outer bark, observed from mid- to late- June through early October (Coleman & Seybold 2008b). Pupae appear similar to adults but white in color (Baez 2009).

Bark
Larval feeding creates dead portions of cambium and bark staining on the main stem and larger branches. Staining is black or red blisters with oozing sap (Baez 2009). Larval galleries, as described above, will be present when dead or blistered bark is removed. Adult emerge from the outer bark leaving D-shaped holes about 1/8"wide (IAWG 2010). Infested trees also commonly show signs of woodpeckers foraging, such as the removal of outer bark to eat larva and pupae. *Q. Agrifolia* and *Q. kelloggii* show similar external symptoms from *A.auroguttatus* feeding but evidence is not as apparent on *Q. kelloggii*. It could be that host suitability differs between the two species or that signs are less apparent on the darker and more deeply fissured bark of *Q. kelloggii* (Coleman & Seybold 2008b).

Canopy
The first sign of infestation in the canopy is premature leaf drop. Crown thinning will then begin, starting at the end of twigs and progressing down branches. Canopy die back may not be evident during the first year of infestation, mortality occurs after several years of larval feeding (IAWG 2010). *Q. agrifolia* may retain a large amount of foliage all the way up until mortality occurs. This is not the case with *Q. kelloggii*, which loses leaves in the fall.

Range
The native range of the goldspotted oak borer is relatively uncertain. It is nearly identical to *Agrilus coxalis*, which is native to Arizona, Mexico, and Guatemala. So far, exotic range of *A. auroguttatus* is contained within San Diego Co. California (Smith et al. 2010). It is expected that the insect's range and associated tree mortality will continue to expand and move north through natural dispersal and the transportation of infested firewood (Smith et al. 2010).

Introduction Pathways
It is likely that the goldspotted oak borer (*Agrilus auroguttatus*) was introduced to San Diego Co. between 1996-2002 through the movement of infested firewood and continues to spread by this mechanism. Insects can emerge from cut wood for at least two seasons if the bark remains intact (Smith et al. 2010). It is not known whether lumber can harbor larvae, but it seems unlikely because wood is debarked and processed.

BEETLE IMPACTS

Feeding galleries of the goldspotted oak borer larvae are often black in color with no specific pattern. Larvae feed under the bark primarily on the wood surface.

High densities of larval galleries can patch kill areas of inner bark and lead to tree death. Patches of dense galleries are often indicated by dark, wet staining on the bark exterior.

Black or red staining on the main stem or larger branches can signify injury from the goldspotted oak borer.

EVIDENCE OF INJURY

Woodpeckers chip away outer bark to forage on goldspotted oak borer larvae. Woodpecker foraging in coast live oak exposes the dark larval galleries and inner bark .

When new adult beetles emerge, they create D-shaped exit holes about 3/16 of an inch (4 mm) in diameter. These exit holes indicate that tree damage is extensive.

Twig die-back and crown thinning can be symptoms of goldspotted oak borer injury.

Figure 2 - Beetle impacts to bark and crown. From USFS identification flier and IAWG (2010)

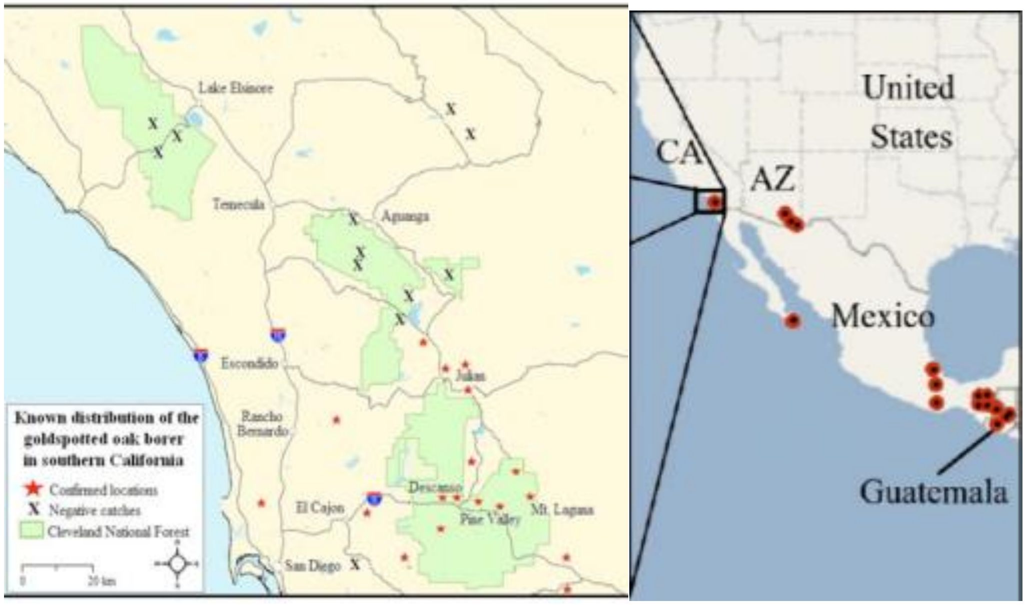

Figure 3. The total known range of the *A. auroguttatus* is shown on the right. *A. auroguttatus* is native to Arizona, Mexico, and Guatemala but invasive in California (left, as of Nov 11, 2009) (IAWG 2010).

Invasion Ecology

Habitat

A.auroguttatus are known to infest Coast Live Oak (*Quercus agrifolia*), Canyon Live Oak (*Quercus chrysolepis*), and the California Black Oak (*Quercus kelloggii*) in California. It cannot be ruled out that other oak species may be susceptible as well. Infestation occurs typically, but not exclusively, in old and mature trees. Attacks have not been observed in small diameter oaks (<12 cm DBH).

Reproduction and Dispersal

A.auroguttatus produce one generation per year (Figure 4). Adult beetles emerge and mate from late May through September, but may begin earlier in temperate coastal climates. It is likely that adults feed on foliage and mate shortly after emerging, like other wood-boring *Agrilus* species (Wawrzynski 2009, Haack &

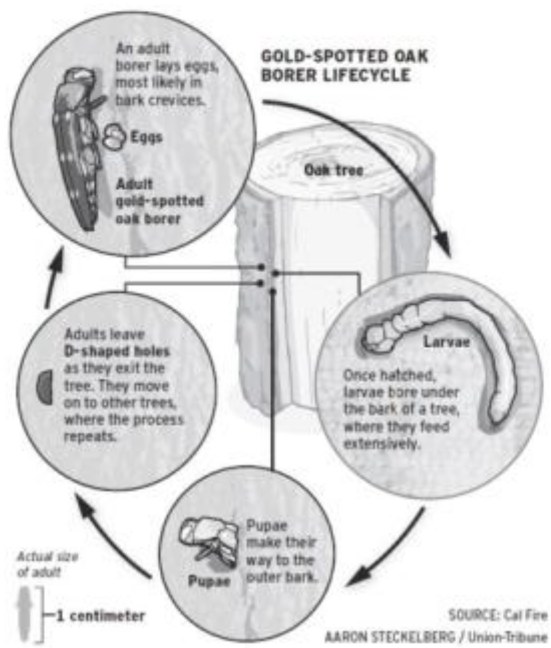

Figure 4. *A. auroguttatus* life cycle. (Image source: CalFire)

Acciavatti 1992). *Agrilus* lay eggs on or in tree bark. Larvae hatch within 1-2 weeks and burrow through the bark to enter the tree's cambium where they feed and overwinter before emerging the following year as adults (Wawrzynski 2009, Haack & Acciavatti 1992)

Agrilus species are known to be good fliers, tethered flights in laboratory conditions suggest that mated EAB females may fly as far as 20 km per day to find a suitable host (Taylor et al. 2007). The USDA Animal and Plant Inspections Service developed control protocols for the emerald ash borer that recommend trees be treated or removed within 0.8km of a known infestation, which is the average dispersal distance of a female emerald ash borer (Hausman et al. 2010). Currently, 0.8km is the best available estimate for average *A. auroguttatus* dispersal as well. More research will begin this year (Tom Coleman, USFS, pers. comm., 07/15/10).

General Impacts

A.auroguttatus larvae kill trees by extensive feeding in the cambium layer at the xylem-phloem interface and is thought responsible for the loss of more than 20,000 oak trees across 620,000 acres in San Diego County over just seven years (Coleman & Seybold 2008b, Smith 2009). Oak infestation rates on Cleveland National Forest average 65% with some areas approaching 100% (Smith et al. 2010).

The consequences of this rapid change in vegetation are still unknown, but drastic changes to the structure and composition of the ecological community are likely. Oak trees are a beautiful and iconic part of the landscape in California. Oaks protect and stabilize watersheds and provide high quality habitat and food for wildlife. Loss of oak trees will result in the loss of these ecological and aesthetic values. Oaks are long-lived and slow to mature trees; it may take decades before they will return to the landscape there.

Potential on Santa Cruz Island

Introduction

SCI is beyond even this liberal estimate of natural dispersal range, so under average conditions, the *A. auroguttatus* is not likely to be introduced by adult flight. It is possible that during strong westward Santa Ana wind events, *A. auroguttatus* individuals could be blown to the island from the coast. This will be more important to consider if the mainland infestation reaches the coast near SCI, but given the current distribution of *A. auroguttatus* in San Diego Co., for now natural dispersal is an unlikely vector for introduction.

A.auroguttatus could be introduced to the island through the movement of infested firewood, though the frequency and volume of firewood brought to the island is probably minimal. Island Packers Company (IPCo) passengers are possible but unlikely vectors for *A. auroguttatus* infested firewood because fires are not allowed at public campgrounds. TNC and University of California (UC) field station staff and visitors are also unlikely vectors because bringing firewood from off-island is prohibited and locally sourced wood is available. Private boaters or fishermen landing on SCI are prohibited from having fires, but are known to do so. It is unknown whether boaters use firewood from the mainland, but if they do, this is a potential vector of *A. auroguttatus*.

Invasion
All of the oak species known to be susceptible to *A. auroguttatus* infestation occur on SCI. Six other oak species and two hybrids are also present on the island, but it is not known at this time whether they may also be susceptible to the *A. auroguttatus*. Oak trees are a beautiful and iconic part of the landscape in California and on SCI Oak trees protect and stabilize watersheds and provide high quality habitat and food for wildlife, helping to sustain the island's rich collection of native species. If oak mortality were to occur on SCI at rates comparable to that observed on the mainland, the ecological implications would be devastating. The distribution of oak communities on SCI that may be at risk are shown in Figure 5.

Eradication and Control
Infected oak trees, and oaks with DBH greater than 12cm within a 0.8km radius of a known infestation, should be treated with systemic or cover-spray insecticides, depending on the level of infection in the tree (Hausman et al. 2010). Dead, downed or significantly weakened trees should be felled and the resulting wood treated by chipping, tarping, or debarking and drying.

Systemic Insecticide Effectiveness
Systemic insecticides are recommended for trees infested but not yet weakened by infection. Systemic insecticides are applied through soil injection, basal drenching, and trunk injection. These compounds get transported throughout the tree and make all parts of the plant toxic when ingested by insects (Frazier 2008). Systemics are recommended for use in oaks that are uninfested or newly infested. Unlike topical insecticides, systemics can kill larvae before they emerge (Frazier 2008). Systemics are not as effective in trees with significant (>20%) crown thinning and dieback because the compound may not be adequately transported throughout the tree. They can however, be helpful for protecting high-value unhealthy trees if used in conjunction with cover sprays (Coleman 2010). Preliminary results from Tom Coleman (USFS) suggest that trunk injections of imidacloprid, a neonicotinoid compound, in the late winter to early spring are the most effective way of delivering insecticides to the foliage (Coleman 2010). The longevity of its effects are unknown, so it is recommended that treatments be reapplied yearly until additional research is complete (Herms et al. 2009, Coleman 2010). It is best to apply systemics in the late winter to early spring because precipitation is most abundant and insecticide is thought to move best within well-watered trees.

	Area	
	ha	% of the island
Santa Cruz Island	26,000.00	100%
Coast Live Oak and Canyon Oak	718.71	2.76%
Island Oak*	610.71	2.35%
Island Scrub Oak* (not shown)	4,801.35	18.47%
*Host compatability unknown		

Coast live oak and canyon oak are known to be susceptible to infestation by the goldspotted oak borer (GSOB). It is not known whether the island oak and island scrub oak commuities are susceptible.Dense stands of mature oak near popular harbors and anchorages should be monitored yearly for GSOB presence.

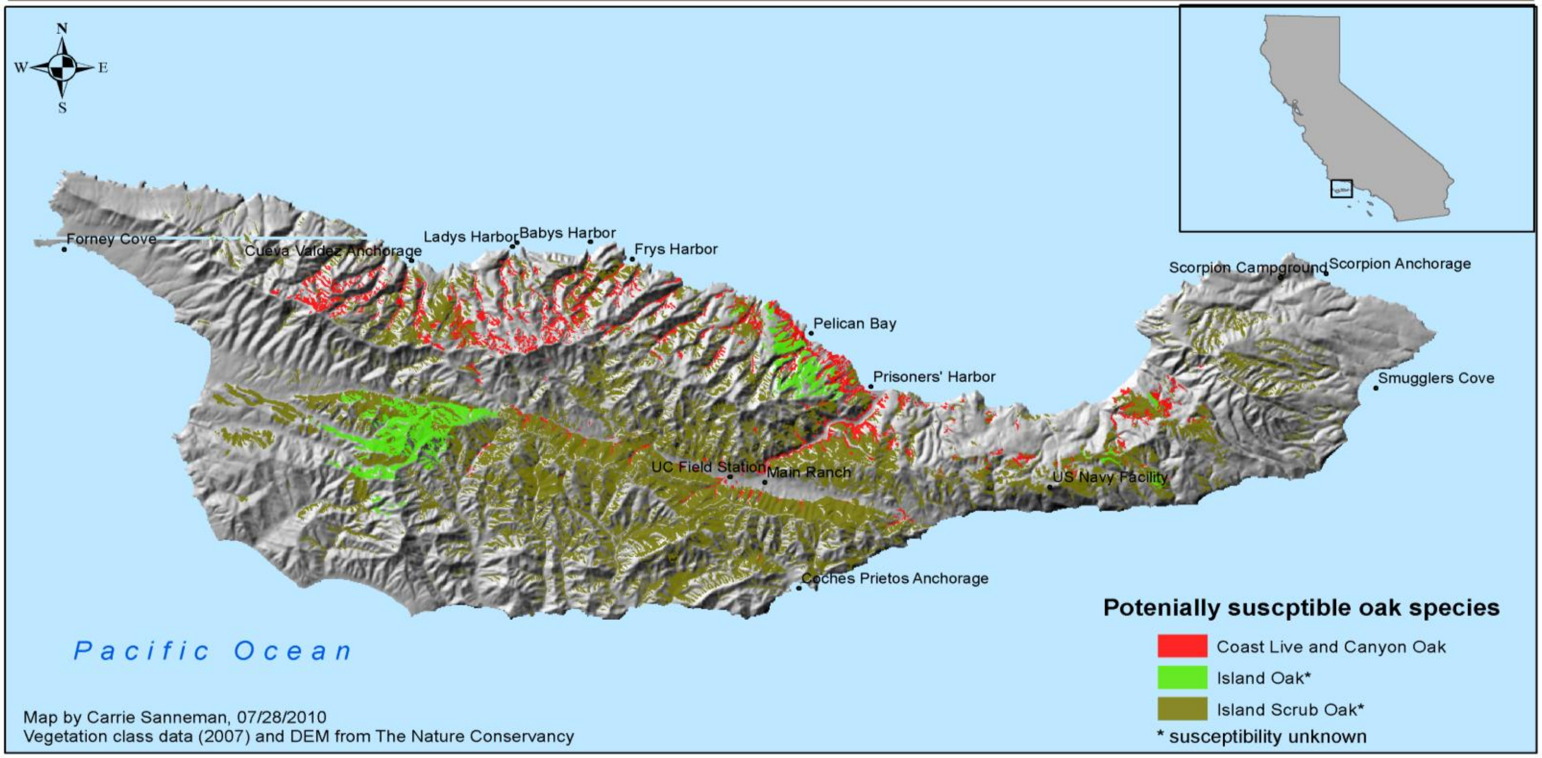

Figure 5. Potentially susceptible oak species on SCI. Coast Live and Canyon Oaks (red) are known to be susceptible to infestation.

Cover Sprays

Cover-sprays are recommended for infested trees with >20% canopy dieback because the ability of these weakened trees to transport systemic insecticides to branches and foliage may be impaired. Cover sprays are also an effective preventative measure; though again, the duration of their efficacy in this capacity is unknown (Coleman 2010). A licensed professional should be contracted to apply insecticides; formulations available over the counter may not be strong enough to kill all larvae (Coleman 2010).

Secondary Effects of Insecticide Use

Systemic compounds can be taken up by any organism that ingests parts of the tree; cover sprays can drift even under the best conditions; and soil applications can be absorbed by other plants, leach downward, or volatilize (El-Hamady et al. 2008). It is important to recognize potential impacts so that monitoring of sensitive non-target organisms can be incorporated into the pest management plan; however, secondary effects and the potential for accumulation are typically considered to be of less concern in short term use than in long term control programs.

Neonicotinoid and pyrethoid compounds are highly selective. They typically require low doses to kill insects and have low toxicity to mammals (Table 1 & 2) (Gentz 2009, Tomizawa & Casida 2005, Tomizawa et al. 2000). They are also relatively stable biochemically, readily biodegradable, and have low environmental persistence (Gentz 2009, Tomizawa et al. 2000, 2008). Pyrethoids have a soil half-life of 12 days and will be 94% degraded within 5 weeks (NPTN 1998). Neonicotinoid compounds have been shown to suppress some non-target soil arthropods in and around agricultural fields for an average of two weeks after application, but populations quickly rebounded to pre-application levels after that (Sanchez-Bayo et al. 2007).

Neonicotinoids are, however, known to negatively affect the foraging behavior of honeybees and also some wild bees (Mommaerts et al. 2010). This systemic insecticide is translocated throughout the plant, including the pollen. It is the ingestion of contaminated pollen that is most harmful to honey bees and has been linked to the disruption of honey bee learning and foraging activity by creating movement, coordination and orientation difficulties (Decourtye et al. 2003, 2004, Suchail et al. 2001). Honeybees (*Apis mellifera*) are not native to SCI and there are no known honeybees on the island at this time. It is unknown whether this compound could affect SCI's more than 100 species of native bees and, by extension, the pollination of island flora.

Tree Removal

Trees that show >50% canopy decline are unlikely to recover and should be cut down. It is advised that dead, downed, and thoroughly infested trees be cut down. The wood should be properly stored and treated onsite to avoid spreading the larvae outside the area of infestation. Trees killed by *A.auroguttatus* should be considered infected through the end of the next full breeding season (Coleman 2010). Untreated wood from felled trees should not be moved outside of the infested area in order to avoid spreading larvae

(Coleman 2010). Preliminary results from (Coleman 2010) suggest the following methods for treating wood from infested trees:

- Chipping wood into 1" or smaller pieces is considered the best way to ensure that no beetle larvae survive.
- Firewood tarping can be use to temporarily store infested wood. Tarping will contain emerging adults but does not kill developing larvae. Properly tarped wood is covered with thick (4-6mm) UV resistant plastic sheeting. Tarping wood from early spring through the summer is generally recommended, but given the SCI's moderate winters, it would be prudent to keep wood covered year round. Edges should be sealed with soil to prevent insects from emerging.
- Debarking pieces of wood and drying in direct sunlight for one growing season may also be an effective sterilization method.

Additional Resources

More information will be published in the next two years and made available to the public through the U.S. Forest Service at http://www.fs.fed.us/r5/spf/fhp/gsob.shtml.

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Planarian ***(Bipalium adventitium)***

Invasive planarians (*Platyhelminthes: Turbellaria*) are known to prey on a variety of soil invertebrates including snails, slugs, earthworms, and arthropods.

Physical Description

B. adventiitum are orange brown with a single brown line that extends the length of the body. They are 40-70mm long with a broad head (Dindal 1970).

Range

B. adventitium is thought to have originated in Indonesia (Ducey & Noce 1998). To date, *B. adventitium* has only been found in highly disturbed landscapes such as lawns, agricultural fields, and golf courses. It is not certain whether this is due to their dispersal capabilities or if it is an indication of environmental limitations.

Introduction Pathways

Flatworms can be associated with soil or vegetation transported as potting medium, ballast fill, for landscaping or restoration projects, and in the treads of vehicles or shoes (Winsor et al. 2004).

General Impacts

Bipalium adventitium feeds primarily on earthworms. *B. adventitium* can attack and kill individuals more than 10 times their own size (Lilleskov et al. 2009). Reducing earthworm populations can reduce the soil nutrients available to plants because earthworms play an important role in soil mixing, decomposition of organic matter, and nutrient cycling (Hendrix et al. 2006).

Invasion Ecology

Dispersal/Rate of spread

No information is available on the natural dispersal capabilities of *B. adventitium*.

Potential on Santa Cruz Island

Invasive planaria could be introduced to SCI in soil brought in by TNC or NPS for restoration projects, landscaping or nursery related activities, or in the treads of tires of vehicles.

It is not known at this time whether the earthworms present on SCI are native or introduced (Lyndal Laughrin, UC Reserve director, person. Com., 11/01/10). If the worms are native, then endemic plants have evolved with well-mixed and nutrient rich soil horizons and a reduction in worms may alter plant communities (Hendrix et al. 2006). If the earthworms are non-native, then it is likely that many of the plant species native and endemic to the island are able to survive in less-mixed soils and the removal or reduction of worms would not be as detrimental.

Control & Eradication

Prevention

Sugiura (2008) found that immersion of potted plants in hot water (=43°C) was able to kill flatworms. Dunking plants in hot water is a relatively low cost method of preventing the spread of flatworms via nursery plants.

Eradication

No eradication or control techniques are available for planarians at this time (Kawakami & Okochi 2010).

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Planarian ***(Platydermus manokwari)***

Invasive planarians (*Platyhelminthes: Turbellaria*) are known to prey on a variety of soil invertebrates including snails, slugs, earthworms, and arthropods. The IUCN Invasive Species Specialist Group considers *P. manokwari* to be amongst the world's 100 worth invaders (ISSG 2010).

Physical Description

Adult *P. marnokwari* (Figure 1) are 40 to 65mm long, 4 to 7mm wide, and less than 2mm thick as measured by the flattened cross section with a uniform exterior appearance. The dorsal surface is very dark brown, almost black; with a thin medial pale line and the ventral surface is pale gray. *P. markowari* is more pointed at the head than tail (de Beauchamp 1963).

Invasive *P. manokwari* with head on the right.

Range

P. mankowari was first discovered in Papua New Guinea (ISSG 2010). It has been intentionally introduced to many Pacific Islands including the Maldives and Bagsuk Island in the Philippines as a biocontrol agent for the African giant snail (*Achatina fulica*) (Barker 2002). It has been accidentally introduced to Guam and the Northern Mariana Islands (ISSG 2010). *P. mankowari* is also present in Australia, French Polynesia, Guam, Japan, Micronesia, Palau, Tonga, Vanuatu, and Oahu in Hawaii (ISSG 2010).

Introduction Pathways

Flatworms can be associated with soil or vegetation transported as potting medium, ballast fill, for landscaping or restoration projects, and in the treads of vehicles or shoes (Winsor et al. 2004). *P. manokwari* has also been intentionally introduced as a biocontrol agent for the African giant snail (*Achatina fulica*).

Invasion Ecology

Habitat

P. manokwari is typically found in tropical and subtropical forests. Survival declines when temperature is below 10°C for more than two weeks. *P. manokwari* prefers wet conditions and cannot survive in completely dry habitats (Kaneda et al. in Sugiura & Yamaura 2009).

Dispersal/Rate of spread

No information is available on the natural dispersal capabilities of *P. manokwari.*

General Impacts

P. manokwari prey preferentially on snails, a group which has shown extreme sensitivity to decline and extinction. Mollusks have the highest number of documented extinctions of any major taxonomic group, accounting for 40.2% of recorded animal species extinctions since 1500 (Lydeard et al. 2004). Amongst mollusk extinctions, 68.1% have been terrestrial species (land snails).

Documentation of the impacts of *P. manokwari* has been largely conducted in the laboratory, where the flatworm has been shown to predate snails by following their mucus trail on the ground and up into trees (Iwai et al. 2010b, a). *P. manokwari* does not predate eggs but does go after hatchlings, this species of flatworm has been shown to kill up to 91% of hatchlings within 10 days (Iwai et al. 2010a).

Decline amongst the endemic snail genus *Mandarina* on Chichijima, the largest island in Japan's Ogasawara archipelago, is thought to have been caused by *P. manokwari* predation (Sugiura et al. 2006). *P. manokwari* is also considered a cause of the extinction of native land snails on several Pacific and Pacific Rim islands (Sugiura & Yamaura 2009).

Potential on Santa Cruz Island

Invasive planaria could be introduced to SCI in soil brought in by TNC or NPS for restoration projects, landscaping or nursery related activities, or in the treads of tires of vehicles. This seems unlikely, considering the current range of *P. mankowari* is restricted to the tropics, as described above.

SCI has 6 species of native snails including: *Vertigo californica, Haplotrema duranti, Pristiloma shepardae, Helminthoglypta ayresiana, Striatura pugetensis, Physa virgata* and one non-native snail, *Paralaoma capatspinulae*. If *P. manokwari* were to establish on the island, these species would be at risk of predation and decline. As discussed above, terrestrial snails diversity is on a steep decline worldwide. Other soil invertebrates (slugs, worms, arthropods) may also experience predation by *P. manokwari*.

Control & Eradication

Prevention

Sugiura (2008) found that immersion of potted plants in hot water (=43°C) was able to kill flatworms, this would prevent the spread of flatworms via nursery plants.

Eradication

No eradication or control techniques are available for planarians at this time (Kawakami & Okochi 2010).

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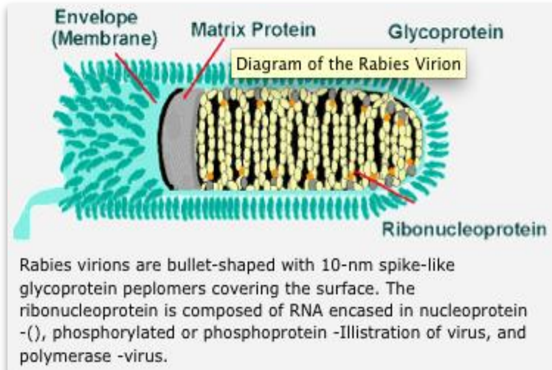
Rabies Virus

According to the Centers for Disease Control (CDC), Rabies is a preventable viral disease of mammals most often transmitted through the bite of a rabid animal. The vast majority of cases reported to the CDC each year occur in wild animals like raccoons, skunks, bats, foxes and coyotes ("CDC - Rabies," 2011).

Physical Description

The rabies virus belongs to the order Mononegavirales - viruses with non-segmented - negative stranded RNA genomes. Within this group, viruses with a distinct "bullet" shape (Figure 1) are classified in the Rhabdoviridae family, which includes at least three genera of animal viruses: Lyssavirus, Ephemerovirus, and Vesiculovirus. The genus Lyssavirus includes rabies virus as well as Lagos bat, Mokola virus, Duvenhage virus, European bat virus 1 & 2 and Australian bat virus ("CDC - Rabies," 2011).



Rabies virus characteristic bullet shaped structure (Source:http://www.cdc.gov/rabies/transmission/virus.html)

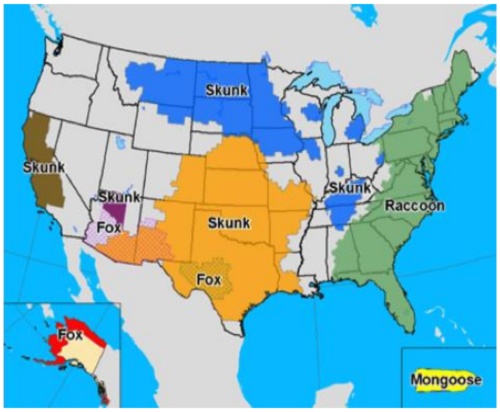
Signs and Symptoms

In animals, the following symptoms are common in the initial stages of rabies:

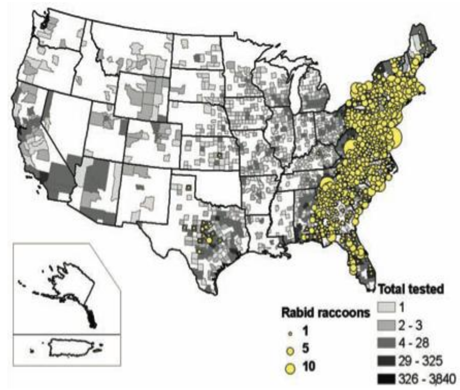
- Loss of appetite
- e in the animals tone or voice due to rabies affecting the voice box
- Animals will chew at the site of the bite
- Infected animals also develop a fever
- After the first signs appear, some animals become very aggressive and bite other animals or inanimate objects.
- Some animals become very docile and hard to wake up.
- Rabies in animals quickly develops into paralysis and ends up in death (Costa, 2011).

Range

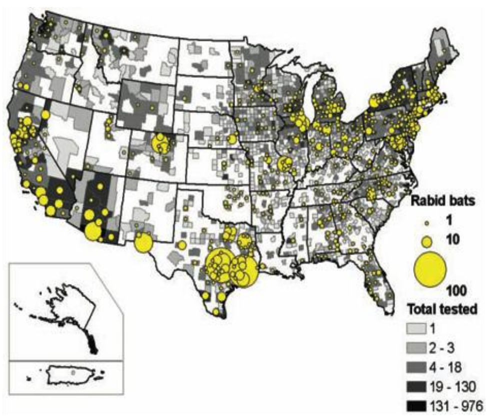
Wild animals account for 92% of the rabies cases reported to the CDC in 2009. Raccoons are the most frequently reported wildlife species (34.8% in 2009), followed by bats (24.3%), skunks (23.9%), foxes (7.5%), and other wild animals including rodents and lagomorphs (1.9%). Distribution of terrestrial "reservoir" animals across the U.S. is broad. Figure 2, below, shows the geographical distribution of rabies reservoirs in the U.S. in 2009. Figures 3 – 7 show the 2009 distribution of reported rabies infections in raccoon, bat, cat, dog, fox, and skunk



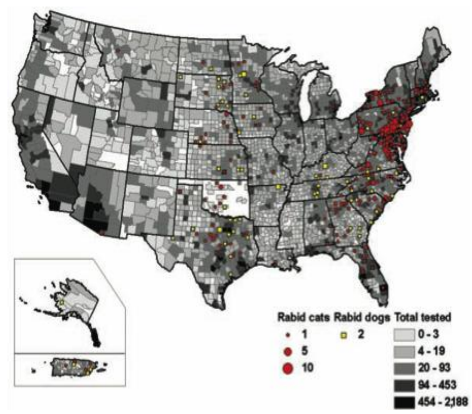
Wild animal "rabies reservoirs" throughout the US. (Source: Blanton, Palmer, & Rupprecht, 2009)



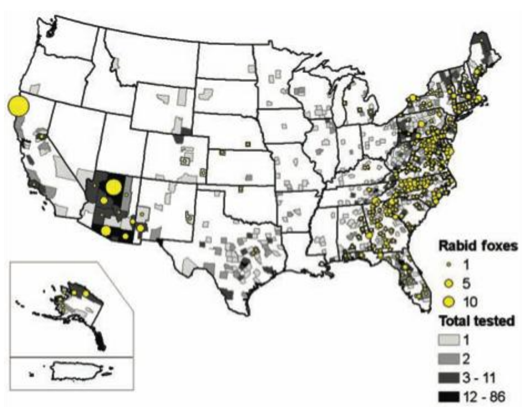
Rabies cases involving raccoons in 2009. (Source: Blanton et al., 2009)



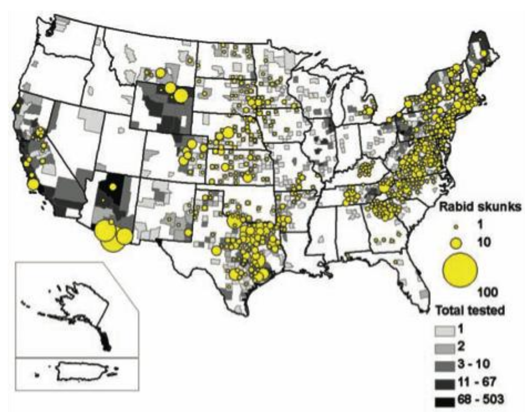
Rabies cases involving bats in 2009. (Source: Blanton et al., 2009)



Rabies cases involving cats and dogs in 2009. (Source Blanton et al., 2009)



Reported cases of rabies in foxes, 2009. (Source: Blanton et al., 2009)



Reported cases of rabies in skunks, 2009. (Source: Blanton et al., 2009)

Among domesticated animals, in 2009, 8% of all reported rabid animals were domestic species. In cats, cases of rabies increased by 2.0% in 2009. Approximately 1% of cats and 0.3% of dogs tested for rabies were found positive in 2009.

Invasion Ecology

Transmission

All mammal species are susceptible to a rabies virus infection. However, certain species act as a reservoir for the disease. Reservoirs for the rabies virus in the United States are raccoons, skunks, foxes, coyotes, and several species of insectivorous bats. Transmission of rabies virus usually begins when infected saliva of a host is passed to an uninfected animal. Most often, transmission occurs when an infected host bites an uninfected animal and the infected saliva is transferred. Other forms of transmission are possible, but rare, these include: contamination of mucous membranes (i.e., eyes, nose, mouth), aerosol transmission, and corneal and organ transplantations ("CDC - Rabies," 2011).

When an infected host bites an uninfected animal, the rabies virus is introduced into the muscle; it travels from the site of the bite to the brain by moving within the nerves. During this time, the animal does not appear ill. This period between the time of the bite and appearance of symptoms is known as the incubation period, which may last for weeks to months. A bite from an animal during this period does not carry the risk of rabies because the virus has not yet made it to the saliva ("CDC - Rabies," 2011).

The time required for the virus to take hold in a new animal varies greatly because of factors such as the site of the exposure (i.e., initial bite), the type of rabies virus, and any immunity in the animal. However, the virus eventually reaches the brain and multiplies, causing an inflammation of the brain. The virus then moves from the brain to the salivary glands and saliva. During this time period – as soon as the virus reaches the brain – an animal will start to show the first signs of rabies. Within 3 to 5 days, the virus has caused enough damage to the brain that the animal begins to show unmistakable signs of rabies. Figure 8 breaks down the process of a rabies infection. Research on cats, dogs and ferrets show that rabies can be excreted in the saliva of infected animals several days before illness is apparent; however, extensive tests have not been done for wildlife species, but it is known that wildlife speices do excrete rabies virus in their saliva before the onset of signs of illness ("CDC - Rabies," 2011).

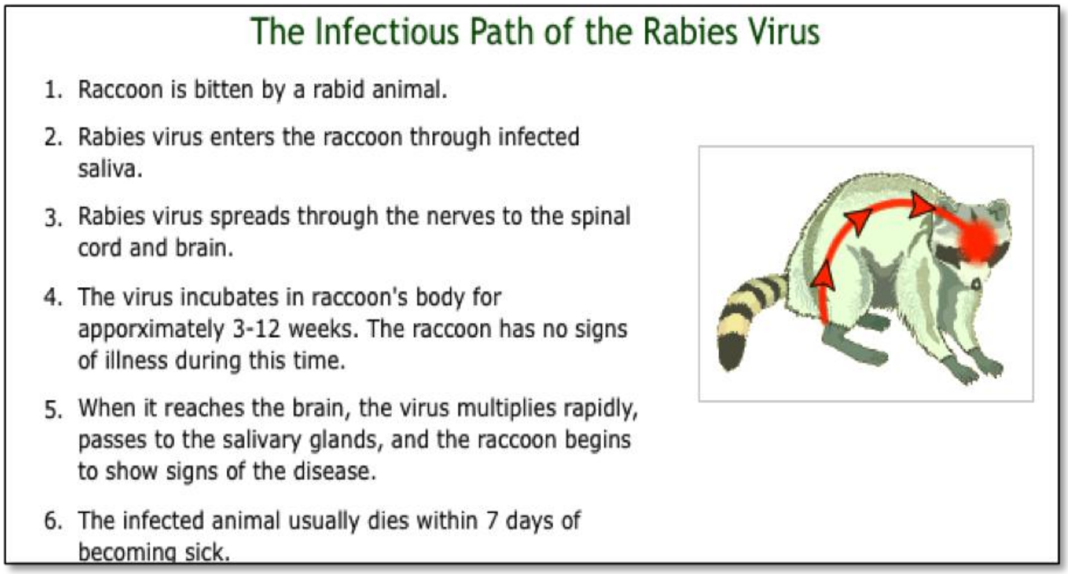


Figure 3 - Infection path of rabies virus. Source: http://www.cdc.gov/rabies/transmission/body.html

Dispersal between animals depends on contact between an infected individual and an uninfected individual. The higher the levels of overlap between home ranges of like species and different species will result in high rates of transmission between animals. In order for island foxes or skunks to become infected, their home ranges will have to overlap with the introduced infected reservoir species (domestic dog or cat, or wild raccoon, skunk, fox, or bat)

Introduction Pathways

Domestic Animals

Among domesticated animals, cats and dogs are the most common vectors for rabies.

Wild Animals

The most common wild animals that are vectors for rabies are: raccoons, skunks, foxes, and bats. Less common wild animals that have been historically reported as vectors for rabies are: mongoose, groundhogs, bobcats, coyotes, opossums, beaver, white-tail deer, river otters, squirrels, cougar, muskrat, and ringtail (Blanton, Palmer, & Rupprecht, 2009)

Potential Pathways:

Of the host species listed above (i.e. vectors) possible pathways for these vectors include National Park Service boats, private boats, airplanes, and natural dispersal.

General Impacts

The rabies virus infects the central nervous system, ultimately causing disease in the brain and death ("CDC - Rabies," 2011). Rabies can affect island fox, skunk, and bat populations. The rabies virus can easily be exchanged between foxes, skunks, and or bats if the species bite each other. Domestic pets also harbor rabies and can easily transfer from an infected individual to uninfected island natives such as the island fox, skunk, or bat. Once established among the population, rabies may have wide ranging negative effects.

Humans are not immune to the effects of rabies. If an outbreak of rabies occurred on the island, human visitors would be put at risk.

Potential on Santa Cruz Island

Native foxes, skunks, and bats on Santa Cruz Island are susceptible to the deleterious effects of rabies. Each of these species acts as a "reservoir" species on the mainland. If rabies were introduced to SCI, all three species could suffer from potentially significant effects of the rabies virus. Potential vectors for Rabies to the island include foxes, skunks, and bats themselves. Also, domestic animals such as cats and dogs are also vectors of Rabies.

Control & Eradication

Public health costs associated with rabies in the form of detection, prevention, and control exceed $300 million annually. (Costs include vaccination of companion animals, animal control programs, maintenance of rabies laboratories, and medical costs).

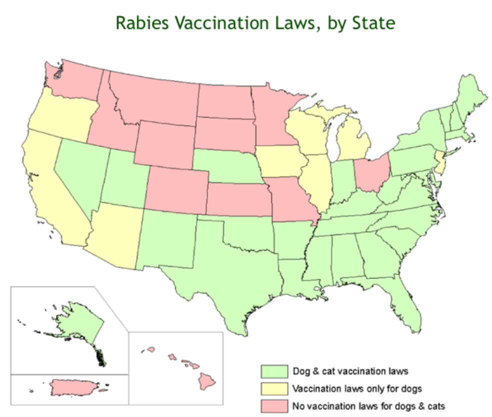


Figure 4 - State legislation requiring rabies vaccination among cats and dogs (2009).(Source: Blanton et al., 2009)

Resources

Centers for Disease Control and Prevention:
http://www.cdc.gov/rabies/

Rabies Surveillance Data in the U.S.:
http://www.cdc.gov/rabies/location/usa/surveillance/index.html

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CDC - Rabies. (2011). *Centers for Disease Control*. Retrieved February 12, 2011, from http://www.cdc.gov/rabies/

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Phytophthora Ramorum

Common names: sudden oak death (SOD), ramorum leaf blight, ramorum dieback, and twig blight.

Physical Description

P. ramorum can attack a diversity of host plants in a variety of ways. Host species and the physical symptoms that they exhibit fall into two main categories: canker forming hosts (canker hosts) and foliar and twig hosts (foliar hosts), with some species experiencing both.

Foliar Host Symptoms

Foliar host symptoms include: spotting on the leaves, leaf necrosis, leaf chlorosis, and leaf or twig dieback. Diagnostic characteristics of these symptoms are discussed in more detail in Section 3.2 of the Early Detection and Rapid Response Plan (EDRR) for *P. ramorum*. Foliar and twig infections may result in dieback, but this can be mild and typically does not typically kill the host plant (Cave et al. 2008).

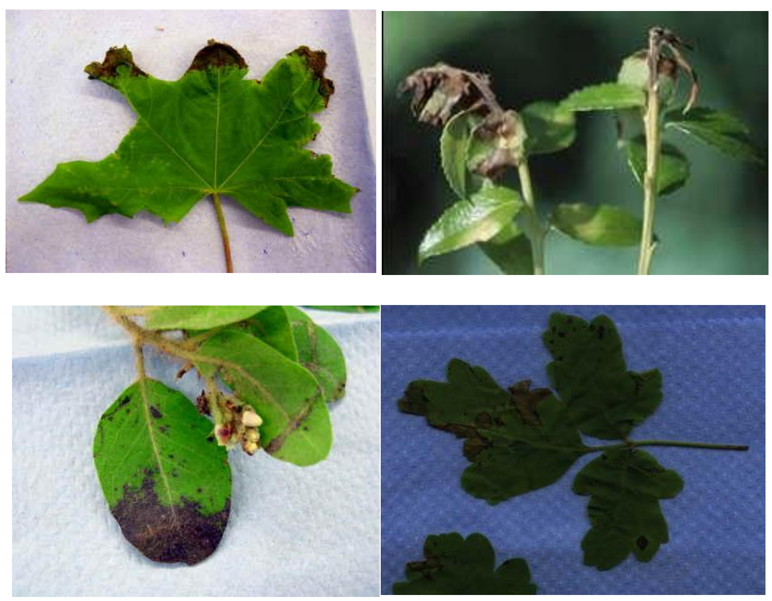

Figure 1. Symptoms of *P. ramorum* infection in big leaf maple leaves (top left) and shoot dieback in California huckleberry (top right), leaf blight in manzanita (bottom left) and poison oak (bottom right) (Photo source: COMTF).

Canker Host Symptoms

Infected canker hosts experience infection on the basal stem leading to branch die back or plant death, this disease is known as SOD in oak trees. Canker hosts are frequently killed through infection by *P. ramorum* (Rizzo et al. 2002a). Diagnostic characteristics of these symptoms discussed in more detail in Section 3.2 of the EDRR plan.

The first symptom of SOD is the presence of bark wounds (or cankers) that exude or "bleed" dark red sap, as shown in Figure 2. Bark removal reveals darkly stained necrotic lesions (Davidson et al. 2003). Lesions that girdle the tree's cambium or secondary attack by native ambrosia beetles cause tree death.

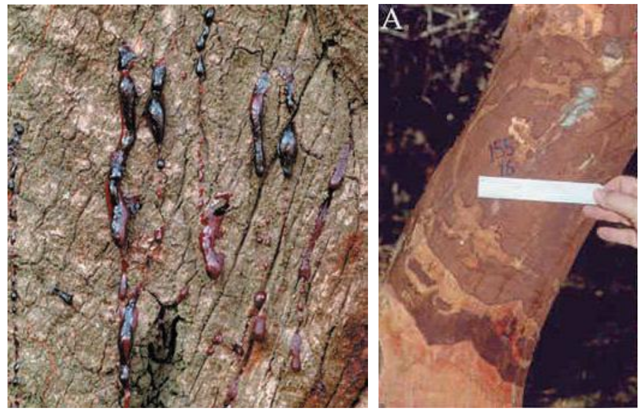

Figure 2. Bark cankers "bleeding" dark red exudates (left) indicate infection by *P. ramorum*. Removing the bark will reveal darkly stained lesions often delimited by thin black lines (right).

Range

The native range of *P. ramorum* is currently unknown, but genetic analyses strongly suggest that it is exotic in origin (Goss et al. 2009).

The first reports of this fungus in the United States (US) or Europe did not surface until the mid 1990's (USDA-CSREES 2005). *P. ramorum* is thought to have first escaped from nurseries in Santa Cruz and Marin counties in the 1980's and spread throughout the San Francisco Bay Area through the movement of infected nursery stock during the 1990s (Garbelotto and Schmidt 2009). Counties currently know to be infected, shown in Figure 3, include: Marin, Santa Cruz, Sonoma, Napa, San Mateo, Monterey, Santa Clara, Mendocino, Solano, Alameda, Contra Costa, Humboldt, Lake, San Francisco, and Oregon's Curry County (COMTF 2004).

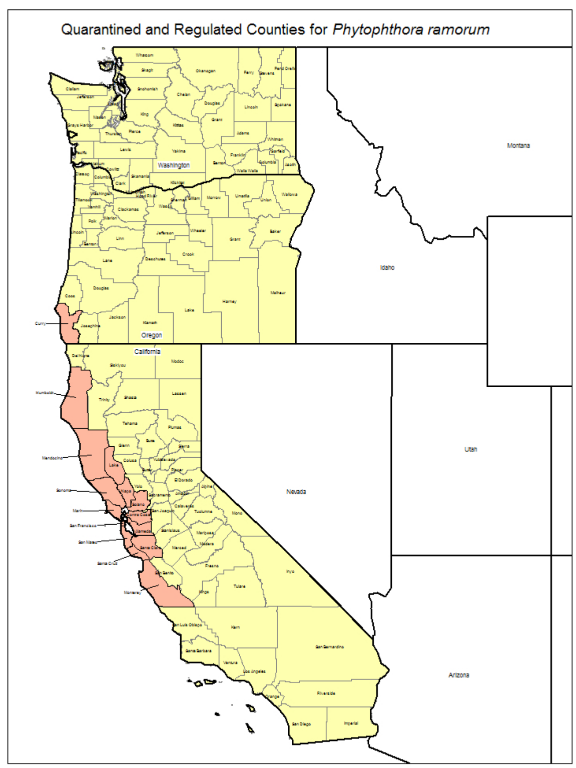

Figure 3. Counties shown in orange have positive detection in forests; the movement of soil, forest products, and nursery stock from these counties is regulated. Yellow indicates that positive detections have all come from nurseries and only nursery stock is regulated (Image source: COMTF 2004).

Infection of forest and nursery products in Europe have been reported in: Belgium, the Czech Republic (eradicated), Denmark, Finland (imported plants only), France, Germany, Ireland, Italy, Netherlands, Norway, Poland, Slovenia, Spain (Mallorca, Islas Baleares), Sweden, Switzerland, and the United Kingdom.

Introduction Pathways

Phytophthora ramorum can be transported through the movement of any infected plant part, organic material, or soil (COMTF 2004). The transportation of infested nursery stock and potting medium is considered to be one of the greatest spread risks for the country as a whole and infected nursery stock has been detected and destroyed in at least 22 states (APHIS 2005a). If infected nursery stock is introduced, the risk of establishment is high because the nursery plant itself is already infected. California, Washington, and Oregon counties regulate the state-to-state movement of nursery stock to prevent the spread of *P. ramorum*. The movement of forest products, nursery stock, and soil from the California counties shown in Figure 3 is also regulated to prevent spreading the disease (COMTF 2004).

Firewood could harbor *P. ramorum* spores, the degree to which spores from firewood can spread to infect native plants is unclear but it may be functionally similar to the spread potential of understory plants which, as described below, is thought to be minimal to insignificant.

Treated lumber also seems an unlikely vector because *P. ramorum* is found only in the outer 1mm-3cm of most oaks (Rizzo et al. 2002b). Furthermore, the movement of forest products from infected counties is regulated. I have not encountered published materials stating that it is safe, but nor is the use of treated lumber is mentioned in the available prevention guides.

Invasion Ecology

Epidemiology – The Role of Foliar and Canker Hosts

The disease cycle for the fungal pathogen *P. ramorum* is polycyclic and relatively complex (Figure 4). Canker hosts, including oaks are frequently killed by infection but their role in disease transmission is limited to potentially insignificant (Davidson et al. 2005, Meentemeyer et al. 2004). Oak trees are considered an epidemiological dead end because they have no role is spreading the disease (Cave et al. 2008). In contrast, foliar hosts may be injured by *P. ramorum* infection but are rarely killed by it, and they act as carriers for the disease, supporting sporulation that spreads infection (COMTF 2004, DiLeo et al. 2009). These portions of the disease cycle must interact in order to cause an epidemic. Widespread mortality of canker host species could not occur without the presence of foliar hosts, and amongst foliar hosts there are just a couple species thought responsible for the majority of the disease's spread, and subsequent oak mortality, in California (Garbelotto et al. 2003).

Infection typically occurs when the reproductive fungal spores germinate on the leaves, twigs, or beneath the bark on the trunk of host species. *P. ramorum* is known to infect potted ornamental plants through the roots, but it is not clear whether this is important in forests systems; host plants in natural settings display no symptoms below the soil line and the pathogen has not been recovered from root tissue (Rizzo et al. 2005).

Whether an individual will become infected also relies on the incoming spore load. Bay laurel and tanoak trees are known to produce spores, Without bay laurel and tanoak, an infestation amongst oaks is unlikely. Incidence of oak mortality and infection on the mainland is almost always in association with bay laurel or tanoak (D. Rizzo, UC Davis, pers.comm, 9/07/10).

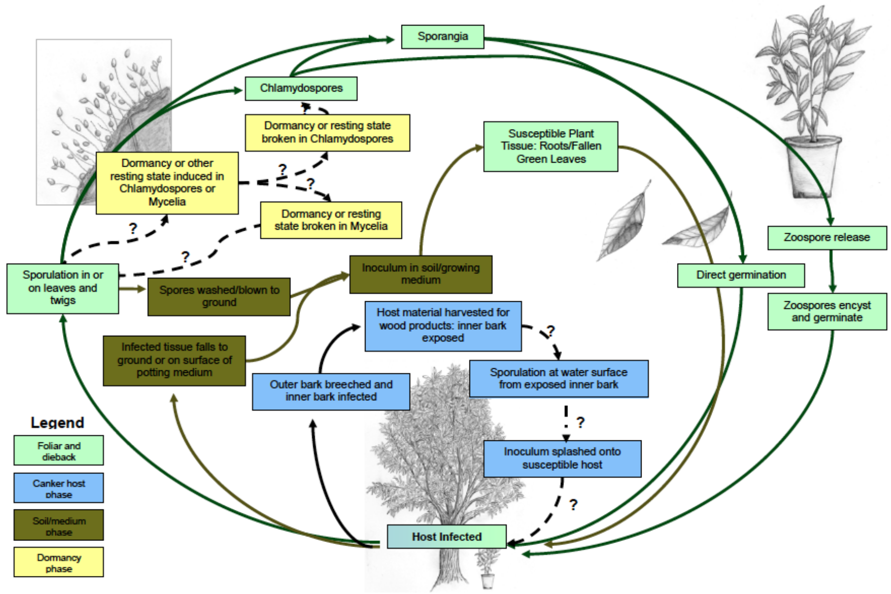

Figure 4.

Life cycle of *P. ramorum*. Image from Cave et al 2007.

Natural Dispersal
If *P. ramorum* is able to establish on host plants and produce spores, it is capable of spreading >1m-3km through rain splash, storms, and streams (Davidson et al. 2005). The majority of long and short-range dispersal is thought to occur due to infected bay laurel and tan oak trees and to some extent other overstory foliar host species as well. The role of understory hosts in the dispersal of infectious sporangia is thought to be minimal to insignificant (Rizzo et al. 2005, D.Rizzo, UC Davis, pers.comm. 9/07/10).

Patterns of infection indicate frequent short-range dispersal and infrequent long range dispersal, both largely driven by spore production on bay laurel and tanoak trees. 50% of newly infected oaks occur within 100m of known infection, resulting in clusters that are typically 100-300m in size (Kelly & Meentemeyer 2002). This is a product of frequent short-range dispersal. These clusters are scattered, sometimes at great distance from each other, which suggests a mechanism for occasional long-range dispersal is present as well. Dispersal 5-15m from bay laurel trees occurs commonly through rainsplash - water droplets that pass through the canopy pick up spores and are blown or deflected laterally (Davidson et al. 2005). Sporangia may occasionally get dislodged by wind and blown up to 200m from bay laurel or tanoak trees and as far as 3km in very rare instances (Rizzo et al. 2005). If these dislodged sporangia land on a host species and are wet for 6-12 hours, they can germinate to infect that host (Garbelotto et al. 2003). Dispersal potential from other over story foliar host species is probably similar, but may be less common because other species produce far fewer spores on their leaves. Dispersal distance in the understory, where spores originate closer to the ground and wind speed is reduced, would likely be insignificant. Infection of understory plants appears primarily to occur from over story hosts and not directly between plants (Rizzo et al. 2005). Because of this, understory plants are not thought to play a significant role in pathogen dispersal (D.Rizzo, UC Davis, pers.comm. 9/07/10). Streams have been shown to carry *P. ramorum* as far as 1km (Rizzo et al. 2005). It seems logical that streams could carry spores or infected organic matter even further, but there is currently no experimental evidence to support this.

Artificial Dispersal
Human movement of soil or organic matter in nursery stock, hiking boots, or vehicle treads is thought responsible for dispersal up to 160km from known sources. State to state dispersal has been through the movement of infected nursery stock (Davidson et al., 2005; Mascheretti et al., 2008).

Timing
Spore production is low or absent during the summer months and the early portion of the rainy season. It is highest during the middle to end of the rainy season. El Niño events and years with extended rains have been correlated with surges in inoculum levels in mixed-evergreen forests (Davidson et al. 2005).

Impacts
Infection of oak (*Quercus* spp.) and tanoak (*Lithocarpus densiflora*) trees results in SOD, which has been spreading through Northern California forests since the mid 1990's and is thought to have killed over a million tanoak and oak trees in the process, including over 200,000 trees in the Big Sur ecoregion (Meentemeyer et al. 2008). Tanoak trees are the most susceptible to infection and mortality, while coast live oaks show greater resistance to the disease than other susceptible species. A wide range of indirect ecological impacts are also significant.

Tanoak trees have been the hardest hit; they are infected more readily and killed more quickly and in higher numbers than other oaks (Rizzo et al. 2002b). Some mixed evergreen forests in northern California have seen reductions in basal area and tree density of over 50% within just 8 years of infection with tanoak mortality as high as 70% at the local level (Waring & Ohara 2008, Swiecki & Bernhardt 2002).

In coast live oaks, impacts are more variable. Disease incidence ranges from 4 - 30% but has been observed to top 50% in localized areas (Rizzo & Garbelotto 2003, Davidson et al. 2005). Some forests have seen annual mortality of coast live oaks increase two-fold over background levels, others have seen an increase as high as ten-fold increase (Rizzo & Garbelotto 2003, McPherson et al. 2010). Most of the decline comes from the loss of large mature trees, which are more frequently infected and killed by SOD (McPherson et al. 2010). Individual coast live oak trees have varying levels of susceptibility to infection, with some displaying resistance to SOD symptoms and mortality. Field observations and lab studies have confirmed that coast live oaks can show particularly slow development of cankers or even callusing over and cessation of symptoms (Garbelotto et al. 2003, Dodd et al. 2005, Rizzo et al. 2005). This variation in susceptibility seems to occur equally at stand, forest, and regional levels. Resistance is thought to be genetic and is linked to multiple loci. If resistant individuals can reproduce and repopulate woodlands with resistant offspring, oak populations in California may be able to recover more quickly and fully than tanoaks.

Ecological impacts of the SOD epidemic are broad and continue to be investigated. By altering the abundance or distribution of dominant canopy species like oaks, *P. ramorum* can affect the structure, diversity, and successional stage of infected forest communities. The loss of large trees can reduce forest basal area and canopy cover (Rizzo et al. 2002b). Mature trees also typically have a high reproductive capacity, so an epidemic of SOD not only changes a forest composition, but also weakens its capacity to quickly recover. Indirect impacts can include changes to system hydrology, nutrient cycling, primary productivity, and trophic effects on almost any forest species (Franklin et al. 1987, Dobson & Crawley 1994).

Potential on SCI

P. ramorum could be introduced on SCI through the transportation of contaminated soil or organic material that originated in or passed through an infected area, including nursery products, soil, dirty footwear, or dirty equipment that has recently encountered the fungus. An introduction of *P. ramorum* spores to SCI is unlikely to result in death of oak trees at anywhere near the scale seen on the mainland because the island lacks the bay laurel, tanoak, and coastal redwood trees, which are key to producing and spreading high spore loads.

Santa Cruz Island is home to four oak species susceptible to infection by *P. ramorum*, including: coast live oak (*Quercus Agrifolia*), California black oak (*Q. kelloggii*), canyon live oak, (*Q. chrysolepis*), Santa Cruz Island oak (*Q. parvula* var. *parvula)* and potentially their hybrids (COMTF 2004). Other susceptible species that occur on SCI are shown in Table 1 along with the symptoms that they typically experience. Those species listed in the table as "Associated hosts" are those that have been observed in the field to be infected by *P. ramorum*, but for which all of Koch's postulates have not been proven experimentally. This list was derived from the complete list of known hosts, as compiled by the USDA Animal and Plant Health Inspection Service (APHIS) and made available through the

California Oak Mortality Task Force (COMTF) website (http://www.suddenoakdeath.org/html/host_plant_lists.html).

The extent to which SCI's foliar host species could support pathogen spread is unclear but relatively promising. None of the plant species on SCI are thought to be important in the spread of *P. ramorum* to oaks, but nor have they been proven to be safe. Only one species, poison oak (*Toxicodendron diversilobum*), has been found associated with infected oaks in the absence of bay laurel (D. Rizzo, UC Davis, pers. comm.). This association has not been confirmed experimentally, so it is far from certain but it should not be dismissed. Aside from poison oak, there is no evidence that understory hosts play an important role in pathogen spread (D. Rizzo, UC Davis, pers. comm.). If any of SCI's overstory foliar host species were infected, such as big leaf maple, they could contribute to spreading the pathogen because any spore they produce can disperse further by virtue of being up higher. In general, *P. ramorum* may be able to spread quite slowly through areas with infected understory hosts and slightly faster through areas with infected over story hosts. The speed and severity of that spread is likely to be significantly less than has been experienced in northern California mixed-evergreen and redwood forests because SCI forests do not contain bay laurel, tanoak, or redwood trees.

If *P. ramorum* were to become established and able to spread on the island, mature (>10cm dbh) coast live oak, black oak, and SCI oak trees would be susceptible to SOD. Coast live and black oaks will be most susceptible, judging by trends on the mainland and it would be a good precaution to assume that hybrids of these species are also susceptible to SODS. Some portion of coast live oaks may be resistant, but there is no guarantee that these genes occur in the population on SCI considering that populations are insular and have limited or no genetic exchange with mainland trees. Infection of blue oak and valley oak, which also occur on the island, has never been reported (Garbelotto and Schmidt 2009). Canyon live oak, while it is a proven host, has not been found infected in the absence of bay laurel and is not thought to be susceptible except under large spore loads, as produced by bay laurel (D. Rizzo, UC Davis, pers.comm. 09/07/10).

Species Name	Common Name	Present on SCI?	Notes	Foliar and twig	Canker	Symptoms
Acer macrophyllum	Bigleaf maple	Y		X		Leaf blight
Adiantum aleuticum	Western maidenhair fern	Y		X		Leaf necropsis
Adiantum jordanii	California maidenhair fern	Y		X		Leaf necropsis
Arbutus menziesii	Madrone	Y**	Very rare	X	X	Cankers, dieback, leaf blight
Arctostaphylos spp	Manzanita	Y	3 *Arctostaphylos* spp	X	X	Leaf blight, canker, dieback
Frangula californica (Rhamnus californica)	California coffeeberry	Y	*R. pirifolia*	X		Leaf blight
Heteromeles arbutifolia	Toyon	Y		X	X	Leaf blight, canker, dieback
Lonicera hispidula	California honeysuckle	Y		X		Leaf blight
Laurus nobilis	Bay laurel	Y**	1 at main ranch	X		Leaf blight
Quercus agrifolia*	Coast live oak	Y			X	Canker, death of saplings, possible death of large trees
Quercus chrysolepis*	Canyon live oak	Y			X	Canker, dieback
Quercus kelloggii*	California black oak	Y			X	Canker, death of large trees
Quercus parvula var. shrevei*	Shreve's oak	N*	Have var. *parvula*		X	Canker, death of large trees
Vaccinium ovatum	Evergreen huckleberry	Y		X	X	Canker, dieback, leaf blight
Rosa gymnocarpa	Wood rose	N*	*Rosa californica* + many cultivars	X		Leaf blight
Salix caprea	Goat willow	N*	4 *Salix* spp	X		Leaf blight
Plants associated with *P. ramorum*						
Berberis diversifolia (Mahonia aquifolium)	Oregon grape	N*	1 endangered *Berberis*	X		Leaf blight
Ceanothus thyrsiflorus	Blueblossom	N*	3 *Ceanothus* taxa	X		
Eucalyptus haemastoma	Scribbly gum	N*	4 *Eucalyptus* spp	X		Leaf chlorosis
Garrya elliptica	Silk tassel tree, coast silktassel	N*	*G. veatchii*			
Nerium oleander	Oleander	Y**	Main ranch			
Prunus lusitanica	Portuguese laurel cherry	N*	*P. ilicifolia*	X		Leaf blight
Prunus laurocerasus	English laurel, cherry laurel	N*		X		Leaf necrosis
Pyracantha koidzumii	Formosa firethorn	N*(**)	Similar spp at main ranch	X		Leaf blight
Ribes laurifolium	Bayleaf currant	N*	2 other *Ribes* spp	X		
Rosa (specific cultivars)	Royal Bonica, Pink Meidland, Pink Sevillana, hybrid roses	N*	*Rosa californica* + many cultivars	X		Leaf blight
Rubus spectabilis	Salmonberry	N*	1 native *Rubus*	X		Leaf blight
Toxicodendron diversilobum	Poison oak	Y			X	Canker

Table 1. SCI Plant species known or suspected to be susceptible to infection by *P. ramorum*

Eradication
There are no curative treatments available for oaks infected with *P. ramorum*. Reducing or stopping spread may be achieved with the preventative application of phosphonate fungicides and the removal of infectious host species.

Fungicide Application
Potassium phosphate, also known as potassium phosphonate or the trade name Agri-Fos, is currently the only chemical treatment approved by the State of California for use against *Phytophthora ramorum* infections on oaks and tanoaks (COMTF 2004). This compound is not a cure, but can help prevent trees from becoming infected or slow the progression of the disease in trees that are newly infected (Garbelotto & Schmidt 2009). Phosphonates have been used to control other *Phytophthora* species in agricultural situations such as avocado orchards, and wildland systems, including the Jarrah forests of Western Australia (Garbelotto & Schmidt 2009). Phosphonates typically act in two ways, inhibiting fungal growth through direct contact and boosting the plant's defenses to control disease indirectly. For *P. ramorum*, phosphonates are not very effective through direct contact, but do help trees to fend off attack by enhancing the production of secondary metabolites that act as antibiotics (Garbelotto & Schmidt 2009).

Application is recommended for plants within 2m of infected understory hosts, 400m from overstory hosts, and along roadways and trails. It is recommended that trees thought at risk of infection be treated twice in the first year after infection is detected, preferably in the late fall and then early spring. After this, treatments should be applied yearly in the fall. These recommendations may change in the new future. Recent studies suggest that a single application of phosphonate, through injection or back application can effectively reduce lesion size in coast live oaks for at least 18months (Garbelotto & Schmidt 2009). The more rigorous application schedule described above is recommended because both the disease and treatments are relatively new.

Agri-fos can be injected or sprayed on the trunk. Trunk sprays are typically mixed with an organosilicate surfactant (trade name Pentrabark), which allows absorption through the bark; both methods are considered equally effective (Garbelotto & Schmidt 2009). Application through injection has the advantage of minimizing dispersal into the environment and is assimilated faster by the tree because it does not first need to be absorbed through the bark. Disadvantages of injection are that drilling the holes requires specialized equipment and training; some injections can fail if the tree is gnarled or decayed, and drilling holes punctures the bark of otherwise healthy trees. The main drawback of bark spray is the potential for drift during application. Spraying will disperse some amount of the chemicals into the surrounding environment, even under good conditions. This is not particularly worrisome for Agri-fos, phosphonates are not toxic to animals, including fish and invertebrates. More information on Agri-fos can be found on the EPA chemical fact sheet (EPA 1998). The surfactant Pentrabark however, is phytotoxic and can kill leaves and mosses associated with the tree. This is mostly an issue with small trees that may have a more substantial portion of their foliage near the tree stem. Application should be done under calm conditions to minimize chemical drift.

Cost of fungicide treatment includes materials and labor. 5 gallons of mixed spray solution of Agri-fos and Pentrabark at retail price is about $200 (2.5 gal Agri-fos and 1 pint Pentrabark). The cost of treating trees will vary depending on the size of the trees; small trees (6" dbh) would cost about $5 and large trees (≈30'dbh) would likely be over $50 for each application (Swiecki et al. 2009). If the chemicals can be purchased at closer to wholesale cost, the cost per tree will be substantially lower. Costs will also rely greatly on the accessibility of targeted trees and thus, the time necessary to reach and treat them. Wildland application presents challenges because of variable terrain and areas with dense understory vegetation. Other SODS treatment operations have utilized four-wheelers for use where trucks cannot reach. Bicycles (walked, not ridden) have been used for areas where four wheelers cannot safely be operated (Figure 4.1b) (Garbelotto & Schmidt 2009).

Removal of Infectious Understory Material

Removing foliar material thought to be spreading infection can help to greatly reduce spore loads, though it will not remove all spores. Understory vegetation within a 100m buffer of known infection is burned and herbicide applied to stumps capable of resprouting, a method developed by the USFS and Oregon Department of Agriculture (Goheen et al. 2009). Some *P. ramorum* was detected in the soil after burning, but most positive detections were from resprouted tanoak trunks. It is not clear how effective this method has been on the landscape level, as new infection sites continue to be identified in Oregon (Goheen et al. 2009). It is recommended in areas of isolated infection and areas where the pathogen has only recently been introduced. As the eradication effort in Oregon continues, treatments will continue to evolve and may provide improved techniques in the future.

Additional Resources

California Oak Mortality Task Force - http://www.suddenoakdeath.org/

Urban Forestry Ecosystems Institute - http://www.ufei.org/ForesTree/detail.lasso?rid=30

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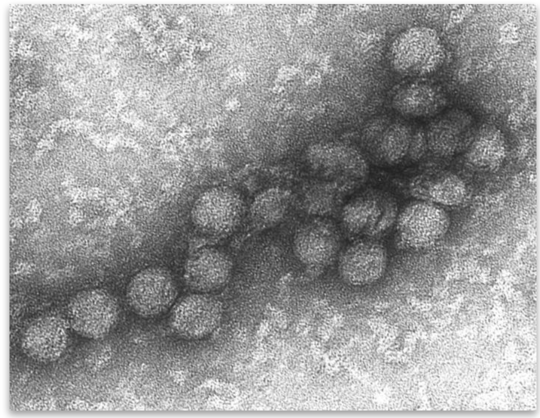
West Nile Virus

The West Nile virus is in the Flaviviridae family and *Falvivirus* genus of viruses. It is related to the viruses causing Japanese encephalitis, St. Louis encephalitis (native to the US), Murray Valley encephalitis, and Kunjin (a subtype of West Nile), which all cause encephalitis in humans (Petersen & Roehrig 2001).



West Nile Virus electron micrograph (Source: CDC)

Physical Description

The *Flavivirus* viruses consist of a capsid containing an RNA strand about 12,000 nucleotides in length (Petersen & Roehrig 2001).

Range

West Nile virus was first discovered in Uganda in 1937 (Smithburn et al. 1940). It is now distributed widely in Africa, Europe, the Middle East, western Asia, and more recently, the United States (Petersen & Roehrig 2001). The virus was first detected in the United States in New York City in 1999. By 2010, West Nile virus had been found in Los Angeles County, including 4 human cases, but not Santa Barbara or Ventura counties. (West Nile CA)

Introduction Pathways

The virus is typically confined to a mosquito-bird (vector-host) cycle. The virus is introduced to new regions by being carried by these mobile individuals. At least 43 species of mosquito have been found to transmit the disease, many of which are from the *Culex* genus (Hubálek & Halouzka 1999). Ticks have also been carriers of the virus but they are a much less common vector (Campbell et al. 2002).

The CDC lists 326 bird species which have been reported to the West Nile avian mortality database as being potential hosts of the virus (CDC 2010). Birds in the family Corvidae are known to be a very common host species and are particularly sensitive to the virus (Campbell et al. 2002, Komar et al 2003). Humans, horses, and to a lesser degree, additional small mammal species have also been able to host the virus (Campbell et al. 2002, Marfin et al. 2001). However, they are much less common as hosts than birds. Birds have also been known to obtain the virus by eating other dead infected birds (Komar et al 2003).

Invasion Ecology

Habitat

The virus is most prevalent in areas where mosquitos are likely to occur, such as areas with standing water. Areas and years with warm winters and dry summers also lead to

West Nile outbreaks (Epstein 2001). Future climate change may cause an increase in outbreaks in areas likely to become warmer.

Dispersal

Reproduction of West Nile virus requires both host and vector species. Amplification of the virus occurs in the host while transmission occurs in the vectors (Campbell et al 2002). *Culex* mosquitos are the most common vector and birds are the most common host.

West Nile virus spreads very rapidly. One year after its initial detection in the US in 1999, the virus was found in 12 US states and Washington DC (Marfin et al. 2001), although infection of humans still remained centered around New York (Petersen & Roehrig 2001). By 2002, the virus had been detected in 42 states. West Nile was first detected in *Culex tarsalis* mosquitos in the Imperial Valley of California in 2003 (Reisen 2004). However, a woman in Los Angeles was diagnosed as potentially being infected with West Nile in 2002 (Enserink 2002). The bird species in Europe which host the virus are migratory, promoting its spread across the continent. This may become a means of dispersal in the US as well if migratory birds become major carriers (Campbell et al. 2002, Rappole et al. 2000). Birds in the Atlantic and Mississipi flyways have been found to be seropositive for the virus, but none in the Pacific flyway (Reisen 2004).

There are several ways the virus is thought to have spread through California (Reisen 2004). During the summer, many bird species flock together, allowing for increased transmission. This would explain the summertime appearance of West Nile and similar diseases. Additionally, mosquitos can be carried along the edge of summer monsoon storm fronts from the Gulf. Dispersal through commercial truck traffic is also possible, although in 2003 the truck traffic pattern did not correspond to where West Nile was found that year.

General Impacts

Impacts on avian populations are more severe than on humans (Petersen & Roehrig 2001, Enserink 2002). In one study, all crows inoculated with the virus died (McClean et al 2006). However, exact mortality rates have not been studied enough in the wild to be determined. Most birds and humans can carry the virus asymptomatically.

When humans do present with symptoms, they include fever. Less than 15% of those infected experience brain inflammation (Hubálek & Halouzka 1999). Most human victims of the disease are elderly (Campbell et al 2002). Human infection can be avoided by the use of insect repellant and avoiding areas of high mosquito activity (Campbell et al 2002).

Potential on Santa Cruz Island

The range of host and vector species varies regionally, making many species potential agents of introduction onto Santa Cruz Island (Petersen & Roehrig 2001, Hubálek & Halouzka 1999). The Island scrub jay, an endemic to Santa Cruz Island, as well as other corvid species, may be at risk for infection since corvids are common hosts to the virus. Additional passerines and raptors would also be susceptible to infection. Mosquitos can be harbored in the wetland areas of the island where standing water is present.

Control & Eradication

Surveillance, reduction of breading grounds, education, and control of mosquitos are part of the integrated pest control recommended by the CDC (CDC pesticides). The presence of the virus can be detected by monitoring for dead birds and determining cause of death (Marfin et al 2001). Sentinel chickens are also used to detect the virus, by being tested for seroconversion every two weeks (Reisen 2004). Mosquitos can be trapped and tested for the virus. Carbon dioxide mosquito traps start around $300 for traps with 1 acre of coverage (http://www.mosquitomagnet.com/). The California Vectorborne Disease Surveillance System, an extensive mosquito surveillance is in effect in mainland California (CalSurv). Testing kits and diagnostic laboratories are required to test blood samples of sentinel chickens and other dead birds. Tests can be found here: http://www.enivd.de/test_commercial.htm. Diagnostics by Oregon State University cost $12-25 per sample (http://oregonstate.edu/vetmed/diagnostic/tests).

The best way to combat the virus is to target the vector, the mosquito population, particularly the larval stage (Enserink 2002). This can be done by removing standing water and other known mosquito breeding grounds (CDC prevention). Mosquito populations can be killed by chemical pesticide (Campbell et al 2002). Chemical pesticides can either target larva or adults (CDC pesticide). Larvicides are applied to the water containing the larva, while adulticides are sprayed into the air. Larvicides pose less of a risk to people and other animals (West Nile CA pesticide). Application of pesticides will be regulated by the EPA and potentially cause health issues for humans (CDC pesticide).

Vaccination against the virus is also possible. The Nature Conservancy currently vaccinates a percentage of the Island scrub jays against the virus, at a cost of $200,000 per year (TNC 2010). Vaccines for birds and humans are currently not as well developed as vaccines for horses. A leading vaccine is West Nile Innovator® by Fort Dodge Animal Health. Ravens (*Corvus corvax*) inoculated with West Nile Innovator® exhibited serconversion after 3 vaccinations of 1.0 ml of the vaccine. (Johnson 2005) There was not consistent trend in seroconversion results overall between raptors and corvids. Another vaccine, the DNA plasmid pCBWN that codes for two WNV proteins has also been tested as a vaccine. Six out of nine fishing crows (*Corvus ossifragus*) showed a serological response to 0.5 mg of intramuscularly vaccine (Turell et al 2003). This response did not last longer than 42 days. When exposed to the virus, all intramuscularly injected crows survived exposure. Untreated crows and those treated orally had lower survival rates. An American crow was accidently introduced into the study and died even after intramuscular injection. American crows are more susceptible to West Nile than Fishing crows.

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Terrestrial Plants

Cape Ivy *(Delairea odorata)*

German ivy, African ivy, climbing groundsel, Italian ivy, parlor ivy (ISSG 2010).

Cape ivy from Buena Vista Park, San Francisco

Physical Description

Cape ivy is a perennial, evergreen, climbing vine. Its waxy stolons grow very long both above and below ground. It blankets surrounding trees, shrubs, and other vegetation in dense mats. Flowers are yellow, about the size of a dime, and arranged in groups of twenty or more (Bossard et al. 2000).

Range

Cape ivy originates in the moist montane forests of South Africa, where it has a relatively restricted range (Bossard et al. 2000). Cape ivy has invaded Australia, Italy, Spain, and the United States (Bossard et al. 2000). In the United States it can be found on the east coast, Hawaii, and coastal regions of Oregon and California. Cape ivy was introduced as an ornamental plant to California in the 1950s (National Park Service 2007). It currently occupies 500,000 acres within California, invading at least 15 different habitat types (Alvarez & Cushman 2002). In the Channel Islands, Cape Ivy can be found on Catalina and Anacapa. On Catalina Island it occupies 13,825 square feet in 13 populations (Cal-IPC n.d.). It was found on Santa Cruz once in 1977 but is no longer present (Knapp et al. 2007).

Introduction Pathways

Cape ivy usually spreads through transportation of its stolons (Bossard et al. 2000). It is thought that it was introduced to Anacapa Island as vegetative matter attached to seabirds arriving on the island (Chang 2006). Additionally, cape ivy seeds have a wispy pappus and can spread via wind or water (Department of Natural Resources and Environment 2001). Cape ivy has spread worldwide mostly as a result of introduction as an ornamental plant (Starr et al. 2003).

Invasion Ecology

Habitat

Cape ivy is found in a large number of habitats worldwide. It has invaded 15 California habitat hypes, particularly moist areas. It can survive in dry habitats but experiences die-back in the dry season (Bossard et al. 2000). It is found at upper elevations in Hawaii and its native range in South Africa. In California, it is found between elevations of 0 and 656 ft (Starr et al. 2003).

Dispersal
Cape ivy reproduces vegetatively or through seed. Seeds do not appear to be the primary form of dispersal in California (Robison 2006). In fact, some sources claim viable seeds cannot be created by plants in California (Cal-IPC n.d, .Alvarez & Cushman 2002). While this has been disproven, cape ivy does not appear to be able to self incompatible, decreasing the number of viable seeds available (Robison 2006).

Cape ivy area in the GGNRA increased from 9 acres to 67 acres in 9 years (Alvarez 1997). Stems can grow an average of 1 foot per month (Alvarez 1997).

General Impacts
Cape ivy produces a dense mat of vegetation which reduces sunlight availability for other plants and removes soil nutrients (Alvarez 1997). This reduces survival for native plants. A comparative study performed by Alvarez & Cushman (2002) found that plots containing cape ivy contain approximately 36% less native plant taxa than plots without cape ivy. Most loss of species richness occurs as result of competitive exclusion of grasses and forbs. Additionally, cape ivy is not very palatable and reduces forage for wildlife (Bossard et al. 2000). The weight of the ivy can also cause trees to fall (Bossard et al. 2000).

Potential on Santa Cruz Island
Establishment of cape ivy on Catalina and Anacapa Islands indicates that it is highly possible for it to reinvade Santa Cruz Island. Cape ivy is easily spread because any part of the stem can sprout a new plant when planted in suitable soil (Alvarez & Cushman 2002, Bossard et al. 2000). Its prevalence across many habitat types, its wide range, and its fast rate of spread make it very likely it will get to Santa Cruz Island. The Nature Conservancy considers this species to have a high impact on the island but is relatively easy to remove (Knapp et al. 2007).

Control & Eradication
Cape ivy eradication is most commonly performed manually. However, manual removal is difficult because any broken stem pieces can regenerate (Alvarez & Cushman 2002, Bossard et al. 2000). In 1997 over 8,000 volunteer hours of cape ivy removal were logged in the Golden Gate National Recreation Area (GGNRA) (Alvarez 1997). Efforts in the GGNRA led to containment of 25% of cape ivy infestations in 2 years. Three years of control cost GGNRA $600,000 (Balciunas & Mehelis 2006). Cape ivy was removed at the rate of 1 acre per year for five years on the Audubon Canyon Ranch. In these 5 years, volunteers logged 2375 volunteer hours of cape ivy removal, and paid works logged 880 hours (Blumin & Gluesenkamp 2002).

Several herbicide mixtures have been used to control cape ivy. A mixture of herbicides 0.5% Triclopyr and 0.5% glyphosate have also been proven effective against the species

(Alvarez 1997, Cal-IPC n.d.). Roundup Poison Ivy & Tough Brush Killer Plus is a mixture of Triclopyr and glyphosate. A 1 quart concentrate of the chemical which can be diluted to 5 gallons costs approximately $30 (The Home Depot 2010). Bossard et al (2 000) recommend a mixture of Roundup and Garlon4, which was used on Anacapa Island. Herbicide is usually dismissed in favor of manual removal for cost reasons (Alvarez 1997).

Biological control agents are under study (Bossard et al. 2000). Potential agents include a galling fly (*Parafreutreta regalis*), a small leaf-mining moth (*Acrolepia*), and a defoliating moth (*Diota rostrata*) (Starr et al 2003). This method is not tested enough to be considered feasible for Santa Cruz Island yet.

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Fountain grass (*Pennisetum setaceum*)

Common name: Fountaingrass, crimson fountain grass, yerba de fuente

Physical Description

Pennisetum setaceum is a warm climate, C_4 African perennial bunchgrass with a densely clumped growth form and erect stems that grow up to 1 m high (Benton 1998). *P. setaceum's* small flowers are grouped in pink, purple, or cream colored bristly, upright inflorescences 6-15 inches long (ISSG 2006).

Fountain grass (Source: Forest & Kim Starr, http://www.hear.org/starr/)

Range

P. setaceum is native to North Africa and the Middle East, where it occurs primarily in arid areas along the coast and in the Sahara (Williams et al 1995). *P. setaceum* has been introduced, primarily as an ornamental grass, to Arizona, California, Florida, Hawaii, Fiji, South Africa, and Australia (Williams et al. 1995). Within the Channel Islands, *P. setaceum* is present on Santa Rosa, Santa Nicolas, and Santa Catalina Islands (Sweet & Holt 2010).

P. setaceum is limited to areas with a median annual rainfall of less han 50 inches or 127 centimeters (Benton 1998). *P. setaceum* is not as successful at invading areas in southern California, most likely due to the precipitation seasonality, as California receives most of its rain in the winter months (Poulin et al. 2007). Hawaii receives precipitation year round and Arizona receives much of its precipitation in the summer months. If summer rainfall in southern California increases due to climate change, *P. setaceum* may be more successful at invading natural areas in Southern California(Poulin et al. 2005).

Introduction Pathways

P. setaceum seeds can be transported through anthropogenic sources (clothing, vehicles, and gear) and naturally (wind, water, and animals) (Benton 1998).

Invasion Ecology

Habitat

In Hawaii, *P. setaceum* invades bare lava flows to rangelands, within a wide elevational range (Benton 1998)(Pima Invasive Species Council (PISC) 2002). *P. setaceum* has been successful in washes and on roadsides in Arizona (PISC 2002). In Southern California, *P. setaceum* has not seen a dramatic increase; however *P. setaceum* has invaded along roadsides, in ruderal areas, and on southwest-facing hillsides and rocky outcrops in coastal sage scrub, chaparral edges, and desert slopes and washes (Sweet & Holt 2010).

Dispersal

Plants flower from July through October, although they can flower year-round (ISSG 2006). Seeds may remain viable in the soil for up to 7 years (Goergen & Daehler 2001). Individual plants may live as long as 20 years (ISSG 2006). Wind, water, and vehicle dispersal likely help *P. setaceum* spread into highly disturbed areas in Arizona and California (PISC 2002) .

General Impacts

P. setaceum can disrupt and alter ecosystem processes, such as succession, the disturbance regime, and hydrological transport (Vitousek 1992, Cuddihy & Stone 1990). *P. setaceum* alters ecosystem processes by altering native species abundance, increasing the fuel load, and increasing ground cover (Cuddihy & Stone 1990). Altered fire regimes and crowding caused by *P. setaceum* reduce native plant abundances in natural areas of Hawaii and South Africa (Rahlao et al. 2009, Castillo 1997, PISC 2002). *P. setaceum* can also displace native plants through water use and shading other plants early in their development (Lovich 2006).

Potential on Santa Cruz Island

P. setaceum is listed a moderate threat in California by the California Invasive Plant Council and, as such, *P. setaceum* may not be highly invasive on the island (Lovich 2006). If *P. setaceum* is invasive on the island, suitable habitat initially includes areas with a lot of human and vehicle traffic such as hiking trails, along roadsides, and near campgrounds. Given enough time, *P. setaceum* may also invade dry perennial streambeds, southwest-facing slopes and rocky areas in coastal sage scrub, chaparral edges, and desert slopes and washes. Invasions in southern California have not been extensive, thus *P. setaceum* is unlikely to develop a large distribution on the island. This may change in the future, if climate change results in increased summer rainfall. If *P. setaceum* does invade Santa Cruz Island, the fire regime, native plant abundances, and hydrologic transport may be altered.

Control & Eradication

Management efforts to control and eradicate this species are occurring on a large scale in Arizona and Hawaii. For small, newly established individuals manual removal may completely remove *P. setaceum* (PISC 2002, ISSG 2006). Influorescences should be removed from the plant and placed in a container in order to prevent seeds from germinating. Castillo et al. (2007) found that prescribed burning reduced *P. setaceum* fuel loads, but fire may easily spread on Santa Cruz Island. Prescribed burning may not eradicate *P. setaceum* in that area, as burning will only remove the current biomass and not the seed bank present in the soil. Moreover, D'Antonio and Vitousek (1992) found that *P. setaceum* may actually be stimulated by fire, as they rapidly grow following a fire and can displace native plants that grow more slowly and are not adapted to fire.

In Hawaiian dry upland ecosystems, application of glyphosate (Roundup) or hexazinone (Velpar) have been shown to kill individual plants, however abundance decreased more with accompanying manual removal (Castillo 1997). Extensive monitoring of control areas is required for many years following eradication, because *P. setaceum* seeds can survive for up to 7 years in the soil. There is no known method of biological control for *P. setaceum*, as there are no specific enemies (Lovich 2006) .

Resources

Global Invasive Species Database of the IUCN Invasive Species Specialist Group:
http://www.issg.org/database/welcome/

UCR Center for Invasive Species Research
http://cisr.ucr.edu/fountain_grass.html

California Invasive Plant Council
http://www.cal-ipc.org/ip/management/ipcw/pages/detailreport.cfm@usernumber=66&surveynumber=182.php

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Terrestrial Animals

Argentine Ant (*Linepithema humile, Iridomyrmex humilis*)

Common name- Argentine ant, sugar ant, tramp ant

Physical Description

Linepithema humile vary from light to dark brown in color, the wingless worker ants range between 2 and 3mm long, the queens and males are slightly larger and darker (UC IPM Online 2009) . Characteristics that differentiate the argentine ant from other species are 5 to 8 large teeth, eyes that are lower than the widest point on their heads, and antennae that are divided into twelve segments (UC IPM Online 2009, Texas A&M University Dept. of Entomology 2008). *L. humile* have an additional node that separates their hind body segments, and they are smooth with no hair on their heads (UC IPM Online 2009, ISSG 2009, Texas A&M University Dept. of Entomology 2008).They do not sting, and often travel in ant trails up to five ants wide. They have a musty smell when crushed as opposed to a more common acidic smell that other ants give off when destroyed (UC IPM Online 2009, ISSG 2009).

Range

L. humile is native to South America, specifically the territories of northern Argentina, Uruguay, Paraguay and southern Brazil (ISSG 2009). Over the past several decades they have been introduced through anthropogenic means, mainly human commerce, in Australia, Bermuda, Chile, Cuba, France, Italy, Japan, Mexico, New Zealand, Peru, Portugal, South Africa, Spain, Switzerland, United Arab Emirates, United Kingdom and the United States (ISSG 2009, Holway 1995). Over 28 separate introductions have been cited from six continents, and several oceanic islands (ISSG 2009). *L. humile* are especially successful in Mediterranean and subtropical climates; they are now recognized as one of the 100 "World's Worst" invaders due to their successful establishment in infested ranges (Browne et al. 2010, ISSG 2009, Calderwood et al. 1999).

Introduction Pathways

It is suggested that the introduction of Argentine ants originally occurred via trans-Atlantic trade routes connecting South America with the Iberian Peninsula over the last century (Roura-Pascual et al. 2009, Holway 1995). New Zealand, the biosecurity authority, recognized that for Argentine ants, spread prevention is a vital component of controlling and eradicating the species. They determine risk trade-offs to allocate resources towards particular trade routes and facilities like ports and airports as well as un-cleared imported goods (Corin et al. 2007). There is limited information regarding their initial spread other than by human commerce such as in plant products, packaging material, building supplies and heavy machinery (Calderwood 1999; Williams 1994). *L. humile* are commonly transported in cargo, nursery trade items, and can be moved by transport vehicles. Winged dispersal of reproductive females is rare or absent, and *L. humile* colonies reproduce by budding off into smaller colonies; this means self-mediated long distance dispersal is limited, and they are largely dependent on human mediated dispersal (ISSG 2009, Holway 1995).

Habitat

L. humile thrives in subtropical and Mediterranean climates, are very active foragers with voracious appetites, and will utilize almost any food source but have a preference for sweet substances (Browne et al. 2010, ISSG 2009, Calderwood et al. 1999). Argentine ants have also been observed forming symbiotic relationships with aphids and other scale insects in agricultural areas (UC IPM Online 2009, Browne et al. 2010). They prefer higher soil temperatures and close proximity to water more so than most native ant species (LSU IPM Online 2010). *L. humile* flourish in sand and clay loam soils where nests are easier for them to build (LSU IPM Online 2010). In urban settings *L humile* create habitat in kitchens, bathrooms, walls of buildings, under paved surfaces, in mulch and compost piles and brick and lumber materials (LSU IPM Online 2010, UC IPM Online 2009).

Ward (1987) conducted a study to determine the extent to which Argentine ant invaded natural habitats of the lower Sacramento Valley. He surveyed 4 natural habitats: valley riparian woodland, foothill riparian woodland, blue oak-digger pine woodland, and chaparral. "Of the four types of natural habitat surveyed, only valley riparian woodland was found to contain populations of I. humilis. Detailed sampling of the other habitats failed to detect l. humilis in foothill habitats in lower Sacramento Valley. It was found to rather widely distributed and locally abundant in valley riparian woodland. A consideration of the features of riparian sites with, and without, I. humilis populations reveals the following: 1) I. humilis is almost exclusively confined to sites with permanent sources of water. 2) There is suggestion from the data that riparian sites with I. humilis populations are more likely to be close to urban areas. The difference in distances between the two kinds of sites approaches statistical significance. 3) Valley riparian sites occupied by *I.humilis* tend to be environmentally degraded. There is more frequent encroachment by nonnative trees and the mean estimated overall disturbance is greater for I. humilis sites" (Ward 1987).

Dispersal: Reproduction, Home Range, and Movement

Linepithema humile has limited dispersal abilities because their queens are flightless unlike other ant species, limiting their ability to spread by flight. Additionally, the colonies only grow and branch off into new colonies on an average distance of $150m/yr^{-1}$ (Roura-Pascual et al. 2009). Argentine ants do however have multiple queens in a colony, up to 8 per 1,000 workers at times. They split colonies often in the spring and summer to colonize new sights, and the colonies are not antagonistic towards each other which may enable their localized expansion and ability to create very large super colonies (UC IPM Online 2009).

L. humile are sexual haplodipoid system invertebrates; the workers are sterile, but can rear eggs and larvae into sexuals in the absence of queens (ISSG 2009). Virgin queens mate in the nest and disperse through budding, worker bees have been observed killing queens after one year to replace them with newly mated queens (ISSG 2009). Queens can lay as many as 60 eggs per day, and winged male and female reproductives are produced during the spring, although remember they mate in the nest because *L. humile* are flightless (Texas A&M University Dept. of Entomology 2008). Ultimately the rate of spread of the Argentine ant is quite slow, anthropogenic action has assisted their widespread distribution considerably over the last century.

General Impacts

The most common direct impact Argentine ants impose on native communities is displacement of native ant species (ISSG 2009, Browne et al. 2010, Calderwood et al. 1999, NYGARD et al. 2008). *L. humile* fight with foraging native ant species and prevent establishment of new colonies by preying on winged queens (Human & Gordon 1996). While impacts to habitat structure are often observed to be minimal, displacement of native plant species may impact key environmental processes such as seed dispersal (Human & Gordon 1996, Calderwood et al. 1999, Ward 1987). *L. humile* have great potential to alter ecosystem processes including ant mediated seed dispersal and plant pollination (ISSG 2009). In southern California, coastal horned lizards experienced a severe population decline due to Argentine ants displacing the native ant species upon which they feed (Suarez et al. 2000).

In agricultural areas, *L. humile* protect crop pests such as aphids and scale from predators and parasitoids, and in turn receive an excretion known as honeydew (UC IPM Online 2009). In agricultural areas this has caused increased population densities of the aphids in turn causing increased crop damage (LSU IPM Online 2010). Alien insect pests probably cause the United States $15.9 billion dollars in crop losses every year, *L. humile* are considered the number 1 citrus pest in Australia (Pimentel et al. 2001, ISSG 2009, Browne et al. 2010). Argentine ants have been observed killing baby birds in their nests, and have even displaced domesticated dogs and cats from their usual inhabitant areas (Browne et al. 2010, ISSG 2009). In South Africa, they can collect up to 42% of available nectar prior to bee foraging (ISSG 2009).

Potential on Santa Cruz Island

L. humile was discovered on Santa Cruz Island in 1996 (Calderwood et al. 1999). The initial introduction pathway location has been identified by The Nature Conservancy and others as Valley Anchorage, an old Navy installation site (Browne et al. 2010, Calderwood et al. 1999, Wetterer et al. 2000). Around 1995 salvage from the Navy outbuildings were moved into research areas in the central valley, possibly increasing the rate of spread of the species to the inland areas of the island (Cory personal communication, 2010). Currently the Nature Conservancy is under contract to complete an Argentine Ante delimitation report with FBA Consulting, a New Zealand company. The potential for further introductions strongly exists if prohibitive measures are not taken with soil and lumber products transported to the island, and biosecurity guidelines are not implemented limiting the further introduction or spread of *L. humile* through anthropogenic actions.

Eradication

Due to the nesting behavior of L. *humile*, and the existence of numerous queens in a colony, it has often proven impractical to spray pesticides or use boiling water as with mound building ants (LSU IPM Online 2010). In some instances Argentine queens have been stimulated to increase egg production when sprayed with pesticides (LSU IPM Online 2010). Prevention, quarantine, and rapid response are the best management strategies for preventing the establishment of invasive ants (ISSG 2009). Hydramethylnon has been used often to eradicate *L. humile*, it breaks down quickly in the environment, but is almost always accompanied by non-target effects and is highly soluble in water increasing the potential to harm aquatic invertebrates (ISSG 2009). Little information is available regarding cost of Argentine ant eradications, although Fire ant eradication has been pursued from the turn of the century using very similar toxins. Between 1957 and 1961, one million hectares were sprayed with persistent insecticide to remove fire ant at a cost of $15 million dollars, ultimately providing only temporary eradication results (Myers et al. 1998).

FBA consulting has recommended a combination of aerial treatments combined with hand baiting to eradicate *L. humile*; they have concluded that the eradication of these ants from Santa Cruz Island is feasible and that there will be interactions with non-target species and bait treatment (Browne et al. 2010). The recommended bait for this project is a wet past formulation manufactured by Bait Technology out of New Zealand. Cost estimation for this project was not provided by the consulting firm.

Additional Resources

Global Invasive Species Database of the IUCN Invasive Species Specialist Group:
http://www.issg.org/database/species

University of California Agriculture and Natural Resources Integrated Pest Management:
http://www.ipm.ucdavis.edu/

Louisiana State University Ag Center Research and Extension Integrated Pest Management:
http://www.agctr.lsu.edu/en/crops_livestock/crops/Integrated_Pest_Management/

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Domestic Cat (*Felix catus*)

Range
F.catus is thought to have descended from the African wild cat (*Felix lybica*) and been domesticated in Egypt beginning around 6,000BC. Currently, *F. catus* are present worldwide, including many offshore islands.

Free ranging cats in the US are estimated to kill 500 million birds annually.

Introduction Pathways
F. catus are often introduced by humans that keep them as pets or as working cats to keep down rodent populations on farms or on boats. Cats on San Nicholas and San Clemente Island were introduced as house cats of military personnel (Kate Faulkner, NPS, pers. comm; 10/12/2010, Barlow 2010).

Invasion Ecology
Habitat
F. catus are habitat generalists but show some preference for riparian areas. They are also likely to be associated with human habitation if food scraps are frequently available (Danoff-Burg 2002).

Dispersal
Like many invasive species, *F. catus* are intensive breeders. Females can be in estrous as many as 5 times per year and may have as many as 3 litters per year, averaging 4-6 kittens in each litter. Young reach sexual maturity within 7- 12 months (ISSG 2009).

Prey availability seems to be the primary factor determining home range size, which is highly variable (Edwards et al. 2008, Barratt 1997). Studies in Australia and New Zealand give mean home ranges of 7 to 28ha for domestic cats and up to 958ha for feral cats. Male and female home ranges typically overlap (ISSG 2009).

General Impacts
F. catus are dietary generalists, and therefore likely to consume a wide range of native species. In natural settings, they feed primarily on small mammals, forest birds, seabirds, reptiles, amphibians, and occasionally insects. Predation by cats has resulted in or been associated with numerous recorded instances of decline, reproductive failure, or extirpation of birds and mammals (Bonnaud et al. 2007, Courchamp et al. 2000, Matias & Catry 2008, Risbey et al. 1999). In 2009, The American Bird Conservancy estimated that free-ranging cats kill over 500 million birds annually in the United States (Audobon Society 2009). Throughout the California Islands (those between Point Conception, CA and Point Eugenia, Mexico) *F. catus* has been associated with the extinction of 2 small mammal species and 8 bird species and the extirpation of 29 bird species (Figure 2; USFWS 2009). The final environmental assessment for the removal of feral cats from

San Nicholas Island provides an excellent extended review of the impacts of *F. catus* worldwide and specific to the California Islands (USFWS 2009).

	Island	Extinct mammals	Extinct birds	Extirpated birds
California	Anacapa	-	-	1
	Santa Barbara	-	-	3
	San Clemente	-	-	3
Mexico	Guadalupe	-	6	~8
	Asuncion	-	-	5
	Coronado North	-	-	2
	Natividad	-	-	1
	San Benito	-	1	-
	San Martin	1	-	1
	San Roque	1	-	4
	Todos Santos	-	1	1
	SUM	**2**	**8**	**~29**

Impact on native species in the California Islands (Source: USFWS 2009).

Potential on Santa Cruz Island
It seems unlikely that *F. catus* would be introduced on Santa Cruz Island. If they were to establish however, small mammal, forest bird, sea bird, reptile and amphibian populations would be at risk of predation.

Control & Eradication

Potential for Control

Control of feral cat populations generally occurs through the use of trapping or poison baiting. Trapping is time consuming, and would incur additional expense because of the likelihood of catching foxes inadvertently is high. A trapping program would require NEPA documentation and FWS approval, both of which would require significant time and resource inputs to procure. Given these high upfront costs, it seems far more likely that managers would choose to attempt a full eradication (as described below) rather than invest in long term control.

Potential for Eradication

Methods- Eradication can involve trapping, and hunting with specialized dogs, poison bait, and the introduction of biological controls, particularly feline viruses such as feline panleucopaenia virus (FPV) (Nogales et al. 2004). A combination of these methods is typically necessary to fully eradicate a feral population. Viruses are successful in reducing population numbers, but because resistance can develop, this method alone may not remove every individual. Because cats are predators and not scavengers, developing attractive bait through which to trap or poison cats is a challenge. Baiting and biological control are thought to be more effective at the beginning of eradication, but hunting and trapping may be required to remove the last remaining individuals (Nogales et al. 2004).

Success rate- *F. catus* has been successfully eradicated on at least 49 islands, including San Nicholas Island, CA (Nogales et al. 2004). 75% of successful eradications have been on small islands (<10ha) and only 11 have been on islands larger than >10km^2. A published value for the rate at which cat eradications fail is not available. Eradication of cats on large islands can prove exceedingly difficult.

Cost – Only a few published values are available for the cost of cat eradication. Cost is likely to vary with island size, remoteness, size and density of invasive population, and bureaucracy. Mitigation for nontarget species, environmental compliance, and legal challenges would also present additional and potentially large costs. The case that relates best to SCI is San Nicolas Island, where the same regulatory and cultural conditions exist. Total cost of eradication on San Nicholas was ~$3million (Barlow 2010, Kate Faulkner, NPS, pers. comm; 10/12/2010). The effort included trapping and hunting with specialized dogs, extensive mitigation and environmental compliance to insure that eradication actions did not affect the native fox and to provide foster care for captured cats. Estimates are for eradication on large island would provide valuable insights into how the size and variable terrain on SCI would influence cost. No such estimates are available at this time.

Relevancy to SCI – The eradication on San Nicolas is a good example of what one might expect on SCI in terms of regulatory and legal pressures, but because the island is so much smaller, it is difficult to draw direct conclusions about the potential for success or cost of a cat eradication on SCI. Rational and documentation supporting the eradication plan and efforts to mitigate effects to foxes on San Nicolas were successful in gaining a Finding of No Significant Impact from the US Fish and Wildlife Service. Any future efforts would be able to utilize this documentation and techniques, which may help reduce administrative and planning cost. Public relations tools, including the rescue facility for captured cats, could also be replicated.

San Nicolas cannot however, tell us how cost and effectiveness will scale up to the size of SCI. Intuitively, more cats over a larger area would be both more difficult and costly to remove. For example, the National Park Service removed a total of 54 cats from the ~6200ha of San Nicolas over 2 years (plus an additional 2 years of planning) (Barlow 2010, Kate Faulkner, NPS, pers. comm; 10/12/2010). On Marion Island, which at 29,000ha is relatively close to the size of SCI, the cat population before eradication began was estimated at 2130+/-290 and growing at 26% per year (Bester et al. 2002). Eradication on Marion Island took 19 years to achieve utilizing every known method at least once. Knowledge of cat eradication methods has improved since that time. The successful cat eradication on Macquarie Island (12,700ha) in 2001 could more provide insight into the cost and effectiveness of cat eradication on large islands however there are currently no publications available on this topic.

Additional Resources

Global Invasive Species Database of the IUCN Invasive Species Specialist Group: http://www.issg.org/database/welcome/

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House Mouse (*Mus musculus*)

Common name- field mouse, wood mouse, kiore-iti (Maori),

Physical Description

Adults are light brown to black with belly fur that is white, brown or grey. *M. musculus* has large black eyes, thin and protruding round ears, a pointed muzzle, long whiskers, and a long tail (60-105mm) that is approximately as long as the body length including the head (65-95mm) (ISSG 2009).

The house mouse (*Mus musculus*)

	House Mouse	Deer Mouse
Colour	Greyish to light brown on top; light brown underside.	Reddish-brown to pale grey on top; has a white belly and feet.
Tail	Less hairy, scales present on tail.	Furry tail; brown on top and white on the underside.
Ears, Eyes	Small ears and eyes.	Larger prominent ears and eyes.
Size	Smaller than deer mouse.	The body weight of an adult deer mouse is 50% greater than that of a house mouse.

Differences between house mice and deer mice (Source: UC extension).

Range

M. musculus is native to India. They have been transported by humans to Europe, Africa, North and South America, Australia and numerous oceanic islands (Pocock et al. 2005). *M.musculus* can survive in climate from tropical to sub-Antarctic (ISSG 2009).

Introduction Pathways

M.musculus can stow away in vehicles, airplanes, boxes, or bags if they have been stored in infested areas and especially if they contain food. *M. musculus* is most likely to stowaway in grain, hay, or other bulk agricultural products. Baker (1994) estimates that there are 7 mices/100 tonnes of grain or 70/100 tonnes of hay or straw, this adds up to tens of thousands of mice per year when all US exports are considered. There are no reports of *M.musculus* swimming from boats.

Invasion Ecology

Habitat

M. musculus is typically commensal, meaning that it typically lives in close association with humans, occupying houses, storage buildings, and other structures (Timm 2006). *M. musculus* populations can also be feral and are known to occur in a variety of natural habitats including: agricultural areas, coastland, natural forests, planted forests, range/grasslands, riparian zones, disturbed areas, and scrub/shrublands (ISSG 2009).

Dispersal: Reproduction, Home Range, and Movement

M. musculus are intensive and flexible breeders; they can breed seasonally or non-seasonally. The life span of a mouse is about 9 to 12 months. During this time, a single female may have 5 to 10 litters of 5-9 young. Young reach reproductive maturity in 6 to 10 months.

At low population densities, *M. musculus* is found at densities ranging from 0-50 mice/ha with reproductive outbreaks bringing levels up to 50-200 mice/ha (Singleton et al. 2005). Cereal-growing areas in southeastern Australian frequently are known to experience irruptions that reach densities of 200- >800 individuals/ha (Singleton et al. 2005. Home range sizes in studies from an agricultural setting in Australia ranged from 0.014 ha to 0.2 ha, but other research suggest they can be as much as ten times larger outside the breeding season (Singleton et al. 2005, Clapperton 2006).

Mice rarely cross roads and prefer to stay close to cover. Estimates of root mean square dispersal for *M. musculus* are 20-35m (Chepko-Sade et al. 1987, Timm 2006). Information on the frequency of long-range dispersal is less consistent, but suggests that 10-30% of individuals will explore or relocate to ranges between 50-500m away (Chepko-Sade et al. 1987, Pocock et al. 2005).

General Impacts

M. musculus invasion on islands has been shown to suppress plants and invertebrates through herbivory and predation (Angel et al. 2009). Land and seabirds have been impacted on some islands through predation of chicks and eggs by *M. musculus*. This was revealed only recently through video footage showing groups of mice attacking and killing chicks of the endangered Tristan albatross (*Diomeda dabbenena*) (ISSG 2009). Mouse predation is also known to impact nests of Atlantic petrels (*Pterodroma incerta*) and Gough buntings (*Rowettia goughensis*), and suspected to be a factor in the decline of the threatened grey petrel (*Procellaria cinerea*) and great-winged petrel (*Pterodroma macroptera*) (ISSG, IUCN Red List). The most severe impacts from *M. musculus* invasion, including predation of chicks, have been found on islands where the native biota evolved without mammals. Where competitors or predators exist, *M. musculus* population densities have remained small and the most damaging ecological effects have not been observed (Angel et al. 2009).

M. musculus is also well-known as the cause major economic losses through the consuming and spoiling crops. Mice have also been known vectors of disease including salmonella and the bubonic plague, but are not considered the primary vector for either.

Potential on Santa Cruz Island

SCI would provide ample habitat for *M. musculus*. Suitable habitat includes areas associated with human habitation such as the TNC main ranch and NPS Scorpion Ranch or natural areas within the island's fields, forests, and riparian areas. *M. musculus* would likely compete with native deermice and harvest mice. The result of competition between native and invasive rodents cannot be predicted. Posisble outcomes include the decline of native species, coexistance of all mouse species, or failure of *M. musculus* to establish after introduction. Predation by foxes would likely restrict population growth. Invasions on other islands suggest that under pressure from competition and predation, population density of invading mice remains suppressed and impacts to native biota are not as severe (Angel et al. 2009).

Control & Eradication

Potential for Control

Long-term control of house mice is typically accomplished through the use of bait stations delivering anticoagulant rodenticides. The associated costs are low, Parkes (2008) estimate that controlling mouse populations over a few hundred hectares would cost ~$140 in equipment and $250/year assuming staff could check and change bait 3-4times/year without special trips to the island. The threats to native species and regulatory barriers to using poison on the SCI are likely to be prohibitive to this approach, as discussed below.

Snap traps can also be used for control, but are labor intensive. Traps would need to be checked, emptied, and reset each day to maximize effectiveness. Again, mitigating impacts to foxes, skunks, birds, and native mice would be necessary and potentially cost prohibitive.

Potential for Eradication

Methods – Almost all successful eradications have used anticoagulant poison delivered either aerially with helicopters, though bait stations, or by hand. Islands on which eradication has been attempted range from 0.7ha - 800 ha. Successful eradication without the use of poison has only been accomplished on two small islands: Green Cay (14ha) and the Midway Atoll Spit in Hawaii (0.8ha).

Success rate - House mouse eradication attempts have failed in 19% of reported cases, compared with just 5% for black rats (*Rattus rattus*) (Howald et al. 2007). In aerial baiting, failures are thought to have resulted from the use or insufficient bait or insufficient coverage. Because mouse home ranges are 0.014 ha to 0.2 ha, even a small gap in coverage can miss a territory and fail to eradicate. Bait competition with invertebrates and differences in toxicant resistance and aversion to bait between subspecies have also been linked to failed attempts.

Cost - Howald et al (2007) reported that island area is the most important factor influencing rodent eradication costs, but certainly not the only factor. In rodent eradications where data is available, costs range from $123-$20,000ha^{-1} (Howald et al. 2007). Other factors influencing cost include island remoteness and any necessary mitigation for nontarget species, environmental compliance, or legal challenges. The two cases that relate best to SCI are Anacapa Island, where the same regulatory and cultural conditions exist, and Gough Island in the south Atlantic which, at 9100ha, is the largest island by far on which house mouse eradication has been proposed. Aerial baiting on Anacapa Island for rats cost $1.8million (~$6100/ha) and took over 2 years to plan and another 2 years to execute. A preliminary report on the feasibility of eradicating house mice on Gough Island estimates the cost of an aerial bait eradication operation at between $1.2 – almost $3 million dollars ($132 – $330/ha).

Relevancy to SCI - It is important to note however, that house mice have never been eradicated from an island even close to the size of SCI. There have also never been attempts to eradicate house mice in the presence of so many sensitive and federally protected species. The use of poison on SCI would be very contentious and present numerous direct and secondary threats to the island's other sensitive biota, particularly the native island deer mouse, harvest mouse, Island scrub jay, nesting seabirds, bald eagles, and the federally protected Santa Cruz Island fox. There is no clear way at this time to target house mice separately from the native deer and harvest mice or to avoid the ingestion of poisoned carcasses by foxes, eagles, and other birds of prey. Methods for mitigating or avoiding nontarget affects to these species would need to be developed, requiring additional time and resources. Environmental compliance with NEPA and the ESA and potential legal challenges present significant hurdles to the implementation of an eradication effort on SCI using poison bait.

Resources

University of California Integrated Pest Management Program - House Mouse Pest Notes:
http://www.ipm.ucdavis.edu/PMG/PESTNOTES/pn7483.html#REFERENCE

Global Invasive Species Database of the IUCN Invasive Species Specialist Group:
http://www.issg.org/database/welcome/

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New Zealand Mud Snail (*Potamoprygus antipodarum*)

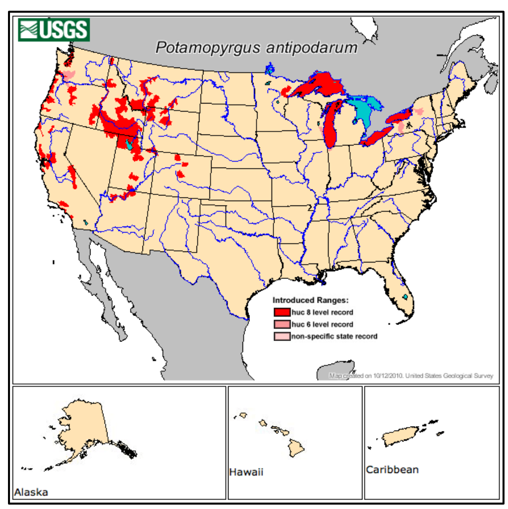
Physical Description

The average size of *P. antipodarum* is approximately 5mm. The maximum size is around12mm. It has dextral (right hand) coiling with 7 to 8 whorls. Shell colors vary from gray and dark brown to light brown. The operculum, a secreted plate, is thin and serves to block aperture of the shell. The aperture is oval. Some *P. antipodarum* in different regions display different morphs of the typical physical description. In the Great Lakes region, shells exhibit a keel in the middle of each whorl. In other regions, shells have a periostracal ornamentation that resemble spines for anti-predator defence (Zaranko et al. 1997)(Holomuzki & Biggs 2006) (Levri et al. 2007).

New Zealand Mud Snail (*Potamoprygus antipodarum*) (Source: www.protectyourwaters.net)

Range

P. antipodarum originates from New Zealand, it is found in freshwater streams and lakes of NZ and adjacent small islands. Self sustaining non-indigenous populations are found in Australia, Asia, Europe, and North America (US and Canada) (USGS - NAS 2011).



NZ Mud Snail US Distribution

In 1987, *P. antipodarum* was found in the middle portion of the Snake River in Idaho. Around that time it was also found in the Madison River in Montana. In 1994, additional discoveries were made in the Madison River near the boundary of Yellowstone National Park. They have been found in the southwestern and northwestern portions of Lake Ontario, the Welland Canal in Canada, and near the mouth of the Columbia River. More recently, in 2001, they were discovered in the Owens River in California, the Colorado River in Arizona, and the Green river in Utah, in 2002. In 2004, *P. antipodarum* was found near Boulder, CO in a small creek (USGS - NAS 2011).

As of 2010, *P. anipodarum* is wide spread in California. Originally found in the Owens River Valley, it is now found in the Bay Area, Redding, Arcata, and Southern California Counties. It has been recorded specifically in the Santa Monica Mountains Recreation area and Los Padres National Forest (2011).

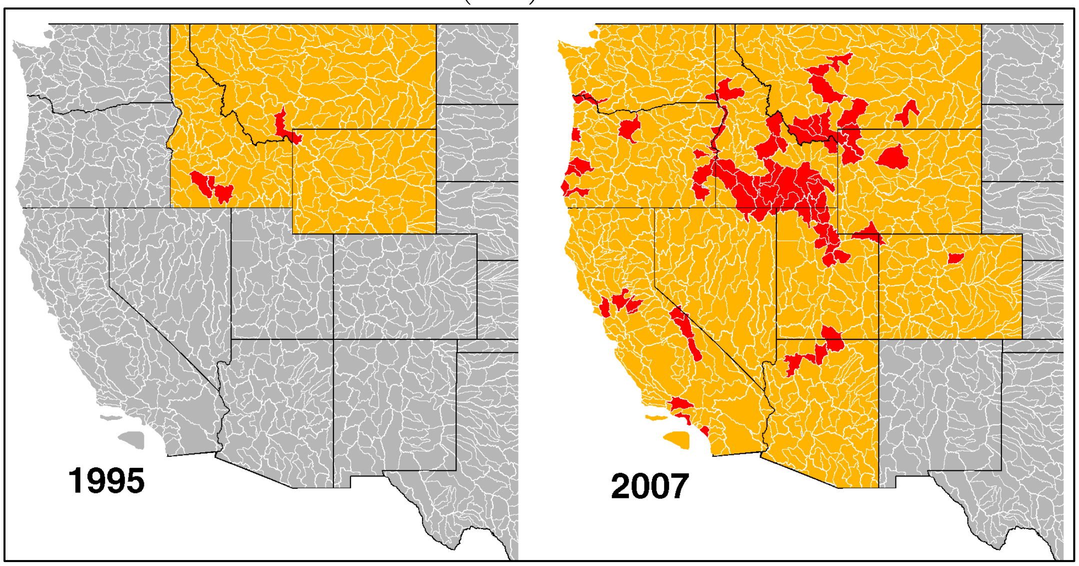
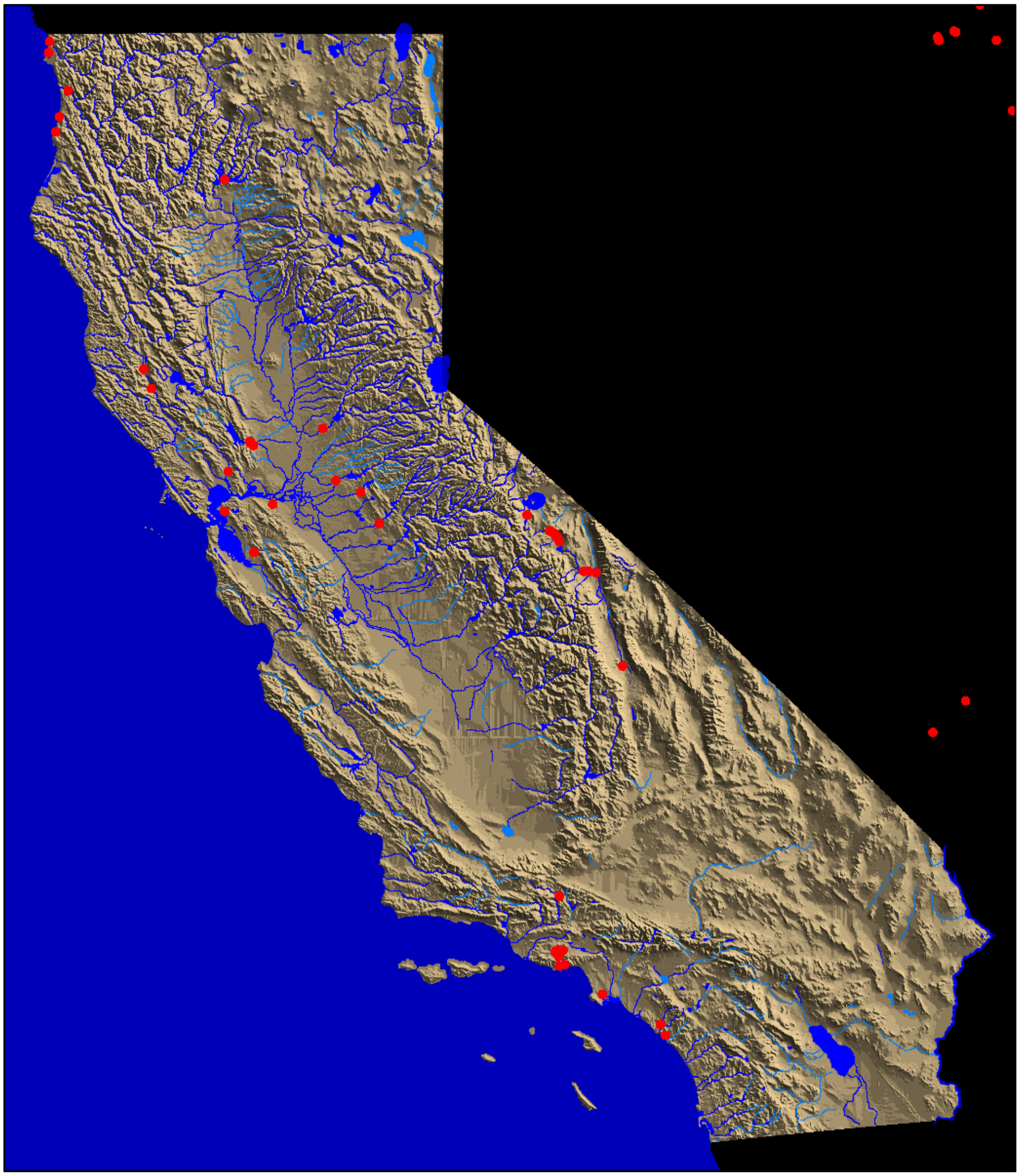


Figure 5 - Known distribution of of New Zealand Mudsnail in 1995 and 2007 in watersheds of 9 western states. (Sources: http://www.esg.montana.edu/aim/mollusca/nzms/status.html &New Zealand Mudsnail Management and Control Plan Working Group 2007)



Known distribution of New Zealand Mud Snail in California. (Source: http://www.esg.montana.edu/aim/mollusca/nzms/status.html & New Zealand Mudsnail Management and Control Plan Working Group 2007)

Introduction Pathways

In 2003 the Aquatic Nuisance Species Task Frorce (ANSTF) established the NZ Mudsnail Management Plan Working Group. In 2007 the Working Group created the National Management Control Plan (New Zealand Mudsnail Management and Control Plan Working Group 2007). This plan identifies the following pathways and vectors for *P. antipodarum.*

- Fish hatcheries and associated stocking operations
- Recreational watercraft and trailers
- Recreational water users
- Natural resource management activities
- Commercial shipping
- Sand / gravel mining, extraction, and dredging
- Aquatic plant trade and collections
- Transport by fish, wildlife and livestock
- Firefighting
- Transport by water flow
- Transport by volitional movement

Of the vectors and pathways listed above, many are not applicable to Santa Cruz Island. However, a few are worth looking at in more detail. The following details are outlined in the 2007 NZ Mudsnail Management and Control Plan.

Recreational water users: When embedded in mud or attached to plant debri, NZ mudsnails may be transported on fishing gear, waders and boots, swimsuits and swimming toys and even horses and dogs. Hikers, backpackers, and bicyclists may inadvertently transfer the snail when encountering multiple stream crossings during their outings. The snail's small size allows it to be carried in small crevices that might escape detection

Natural resource management activities: Personnel involved in monitoring projects, restoration activities, and other natural resource activities that cross watershed boundaries may transport NZ mudsnails to new water bodies via their gear, vehicles, or clothing. Without knowledge or pre-planning, field staff may not have access to facilities or equipment that allows decontamination between work sites. Mudsnails can live in moist environments near the edges of streams, and therefore can be picked up and moved by people who are not wading in the water. Citizen and classroom monitoring groups are another potential vector for spread of ANS.

Sand/gravel mining, extraction, and dredging: Any waterway operations that remove and transport mud, sand, and other bottom materials from areas with NZ mudsnails can serve as a vector for new introductions. Dredges that move frequently between rivers and estuaries are particularly vulnerable sources of regional spread. Maintenance of canals and ditches by landowners, ranchers, water and power agencies, and flood control personnel also has the ability to spread ANS. On Santa Cruz Island, vehicles and machinery frequently cross streams and can very easily transport snails from a contaminated stream or estuary to another uncontaminated stream on the other side of the island. Additionally, the common practice of moving gravel from one area to another for purposes of creating smoother roads may increase chances of NZ mudsnail spreading within the island.

Firefighting: NZ mudsnails could be spread by firefighting machinery or equipment that is moved from one place to another across streams and rivers to fight backcountry or forest fires. Transporting large helicopter-deployed water buckets between water bodies is a particular concern. Spread could also occur through human and pack animal activity.

Transport by water flow: Water flow can spread NZ mudsnails downstream within a watershed (where they then may come in contact with new vectors that would transport them outside the basin). This vector typically would vary seasonally based on flood events or periodic management of water levels in ponds and reservoirs. In lakes and ponds, snails have been reported to raft on floating algae mats and other vegetation (Vareille-Morel 1983 and Ribi and Arter 1986 as cited in Ribi 1986, Dorgelo 1987). Additionally, NZ mudsnails can simply float at the water's surface or cling to the underside of the surface film (Gangloff et. al, 1998). Both floating and rafting behaviors are commonly observed in other snails, including anywhere that dead and uprooted vegetation accumulates in ponds. In addition to rafting and floating, gastropods have been reported to undergo "drifting" behavior in flowing water systems. Marsh (1980) found that Physa gyrina drifted at rates exceeding 500,000 individuals m3 sec-1 under "normal" flow conditions. It is not known to what extent NZ mudsnails exhibit drift behavior.

Transport by volitional movement: As noted earlier, NZ mudsnails are capable of moving at speeds exceeding 1 m/hour (Richards 2002). Although unlikely to be a vector between river basins, volitional movement can obviously spread NZ mudsnails within a watershed (to sites where they then may come in contact with new vectors that could transport them outside the basin).

Invasion ecology

Reproduction: The mud snail reproduces annually in the spring and summer and each female produces approximately 230 young per year (USGS - NAS 2011). It is an asexual reproducer that can reproduce quickly and reach densities as high as one-half million per m^2 (USGS - Florida Caribbean Science Center 2002). Females are born with developing embryos in their reproductive system, which means it only takes one individual to be introduced into a new watershed to make an impact. (USGS - NAS 2011).

Rates: *P. antipodarum* has been known to travel 60m upstream in 3 months through "positive rheotactic behavior" (the process of turning to face upstream)

Nutrition: Mud Snails is a "scraper/grazer" (ISSG) that prefers to feed on dead and dying plant and animal material, diatoms, algae, and bacteria (USGS - Florida Caribbean Science Center 2002).

Dispersal: Common dispersal methods for P. *antipodarum* are ignorant possession and sea-freight. The original arrival of P. *antipodarum* to North America was most likely from ship ballast in the Great Lakes and the continued spread of P. *antipodarum* throughout the US has been through ignorant possession. Examples of ignorant possession are the transport of live game fish from infested waters to western rivers (USGS, Caribbean Science Center) or from unintentional human transport in shoes and equipment. Mud snails are small enough that anglers, swimmers, hikers, and restoration workers can inadvertently transport snails in equipment (ISSG).

Habitat: Ideal habitat for P. *antipodarum* is varied and includes, rivers, reservoirs, lakes, and estuaries. It is able to withstand desiccation (extreme drying), as well as a variety of temperature regimes. However, it thrives in systems with high primary productivity, constant flows, and constant temperatures. In river systems it can thrive in all types of environments including eutrophic, clear, silt, sand, gravel, cobbles and vegetation. P. *antipodarum* can survive in estuaries and brackish water with a salinity level of up to 17-24%. It does not however survive in freezing temperatures (ISSG). P. *antipodarum* can survive in the gut

General Impacts

P. *antipodarum* can impact resident trout and macroinvertebrate populations and disrupt pipe infrastructure. P. *antipodarum* has been shown to reduce trout populations in western streams by impacting the food chain and altering the physical characteristics of the streams themselves (2010).

More importantly, P. *antipodarum* also competes aggressively with other macroinvertebrates, including native snails. In the Yellowstone region, research has shown that high densities of P. *antipodarum* can be associated with low colonization of other native macroinvertebrates (Kerans et al. 2005). In Europe, P. *antipoarum* has caused declines in species richness and native mollusk populations. In affected geothermally heated rivers and water bodies in the US P. *antipodarum* has reached densities of 300,000 m^2, which alters nutrient flows and primary productivity (USGS - NAS 2011). NZ mudsnail is known to consume up to 75% of the gross primary production. The productivity of native invertebrate grazers and the rest of a food web is often limited by the quality of algal food. Thus the impact of NZ mudsnail on periphyton communities could be important factor that can influence a whole ecosystem . The University of California Riparian Invasion Research Lab (RIVR) has found that high densities of P. *antipodarum* can significantly decrease tadpole survivorship . Interestingly, in Australia, the increased presence of P. *antipodarum* correlates with increased abundance of native invertebrates, most likely do to the ingestion of the snails feces (USGS - NAS 2011).

Establishment of P. *antipodarum* in Santa Cruz Island's fresh water systems could reduce the diversity and/or abundance of macroinvertebrate populations and, in turn, impact the species that rely on them as a food source.

In developed systems, *P. antipodarum* is also known as a biofouler for facilities and infrastructure, blocking pipes and underwater surfaces (USGS - Florida Caribbean Science Center 2002).

Potential on Santa Cruz Island

Potential areas of incursion on SCI:

- The new wetlands project at Prisoners harbor. This project will require extensive restoration efforts, most likely from many contractors with heavy equipment and volunteer hours. If equipment or personnel working on the project have recently been in contaminated areas, there is high probability of an invasion.
- La Cascada is a popular swimming hole and one of the only year round flowing streams. This area is frequented by many visitors to the central valley and used for swimming and relaxing. Due to the high traffic, and consistently wet conditions, there is also risk of invasion in this area.
- Recreational users, such as hikers, and contractors that have been working or spending time in an invaded lake or stream have the potential to transport *P. antipodarum* in their personal equipment or work equipment.

Control & Eradication

As with most aquatic nuisance species, management options after a successful introduction are very limited, so prevention and education are most important. (New Zealand Mudsnail Management and Control Plan Working Group 2007)

P. antipodarum is most likely to be spread to new waters via contaminated equipment. Methods for controlling spread include freezing or desiccation at high temperatures with low humidity. Larger *P. antipodarum* can typically survive desiccation longer than smaller ones, and for all size-classes mortality generally increased with increased exposure time. Thoroughly freezing or drying potentially contaminated equipment will limit the spread of *P. antipodarum* to uninfected aquatic ecosystems (Richards et al. 2004).

If prevention measures fail, and NZ mudsnails arrive on the island, there are methods for eradication, but the situation must be deemed feasible and practical before attempting. An eradication can be successful if 1) total kill is likely, recognizing the survival of even one NZ mudsnail can negate an eradication attempt; 2) if environmental damage will be caused and if so estimated recovery costs, and 3) if there will be impacts to non-targeted and threatened and endangered species.

The National Park Service states that there are few effective treatments to completely eliminate *P. antipodarum*, and continues to say that physical removal or crushing of shells may only make matters worse by spreading eggs to new sites (ISSG). Non-chemical treatments include using temperature, humidity or desiccation to kill the target species. This would involve draining the infested area and exposing NZ mudsnail to sunlight during summer months. Flame-throwers have been used in hatcheries in raceways.

Alternatively, an area can be drained in the winter, if the substrate freezes down to a level where NZ mudsnail exists, full eradication is possible.

Chemical treatments are possible for NZ mudsnail, however chemical treatments would not be selective for *P. antipodarum* and would also eliminate native invertebrate populations (ISSG). However, there are some situations where chemical treatments may be applicable and effective. In cases where a small stream, creek, lake, or estuary are infected a chemical eradication may be more effective than if a large river or lake were infected. Small water bodies are more likely isolate the invader. According to the New Zealand Mudsnail Management and Control Plan, (2007) chemical treatment can be effective in small lakes and ponds, water bodies that can be temporarily hydrologically separated (e.g. curtain, wall), irrigation canals, and fish hatcheries. In these small water bodies, if it is possible to isolate a water body from drainage area, it is easier to apply chemical treatments without downstream damage. Likewise, if it is possible to drain a water body, allowing the substrate to heat and dry in the summer or freeze in the winter would be equally effective. (New Zealand Mudsnail Management and Control Plan Working Group 2007)

According to the New Zealand Mudsnail Management and Control Plan, (2007) the following chemicals are used to eradicate NZ mudsnail: Bayer 73 (Francis-Floyd et al. 1997), copper sulfate, and 4-nitro-3-trifluoromethylphenol sodium salt (TFM). The only molluscicide known to have been tested against NZ mudsnails is Bayluscide (a.i. niclosamide). This test, conducted by Montana Fish, Wildlife, and Parks (FWP), was to determine the feasibility of eradicating NZ mudsnails from a small spring creek along the lower Madison River. One hundred percent mortality occurred after 48 exposure units of Bayluscide. An exposure unit is 1 ppm for 1 hour (Don Skarr, Montana FWP, pers. comm.). Preliminary investigations also suggest that copper and carbon dioxide under pressure may prove useful in both decontaminating fish hatchery water supplies and preventing spread into uncontaminated areas of a hatchery. Ozone has not been shown to be effective in killing NZ mudsnails in a hatchery environment (Moffitt, pers. comm.)

Laboratory research suggests that GreenClean PRO can eliminate mollusks without harming fish, animals, and plants. In 2005, Sean Garretson of Portland State University's Center for Lakes and Reservoirs conducted a laboratory study using GreenClean® PRO to control NZ mudsnails. GreenClean® is a non-copper-based algaecide that eliminates a broad spectrum of algae on contact. It is designed for lakes, ponds, and other large bodies of water, as well as for unpainted surfaces, such as beaches, docks, and walkways. Its active ingredient, sodium carbonate peroxyhydrate, creates a powerful oxidation reaction that destroys algal cell membranes and chlorophyll, providing immediate control of algae. The producer, BioSafe Systems, claims that the algaecide is fish, animal and plant safe (see www.biosafesystems.com). (New Zealand Mudsnail Management and Control Plan Working Group 2007)

Finally, research is being conducted using parasites of NZ mudsnails to control population size by inhibiting reproduction. Current studies of the efficacy and specificity of a tremadode parasite from the native range of NZ mudsnail as a biloical control agent have shown positive results. However, biological control entails the introduction of another non-native species. The costs of this have to be weighed against the costs of ecological damage caused by the NZ mudsnail. (New Zealand Mudsnail Management and Control Plan Working Group 2007)

Resources

California Fish and Game Invasive Species Program:
http://www.dfg.ca.gov/invasives/mudsnail/

USGS Nonindigenous Aquatic Species:
http://nas.er.usgs.gov/queries/factsheet.aspx?SpeciesID=1008

Global Invasive Species Database:
http://www.issg.org/database/species/ecology.asp?si=449&fr=1&sts

Protect Your Waters: a public awareness campaign by the US Fish and Wildlife Service and US Coast Guard:
http://www.protectyourwaters.net/hitchhikers/mollusks_new_zealand_mudsnail.php

Montana State University:
http://www.esg.montana.edu/aim/mollusca/nzms/research.html

UCSB Riparian Invasion Research Laboratory (RIVR):
http://rivrlab.msi.ucsb.edu/NZMS_data/mudsnail.php

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Red imported fire ant (*Solenopsis invicta* Buren)

Common name- fourmi de feu (French), rote importierte Feuerameise (German)

Physical Description

Solonopsis invicta. **(Source: USDA- APHIS)**

S. invicta workers are physically differentiated into more than two different body-forms (polymorphic), known as major and minor workers (Holway *et al.* 2002). Major workers are larger than minor workers, but there are a range of sizes for each category. *S. invicta* varies in size from 2 to 6mm in length (Holway et al 2002). *S. invicta* is predominantly reddish-brown in color, but can also be black, as shown in Figure 1 (Sarnat et al 2008). *S. invicta* has antennae with 10 segments, no antennal scrobes, no propodeal spines, an unsculptured head and body, two-segmented waist, and a stinger on their gaster (Sarnat 2008). *S. invicta* also has a middle tooth on the anterior clypeal margin, which is what differentiates *S. invicta* from the tropical fire ant (*Solenopsis geminata*) (Sarnat 2008). Their nests all have a honeycomb-like internal structure. Their nests may be up to 60 cm high and 6 feet deep dome-shaped mounds without any obvious entrance or exit, however mounds may not be evident at all (Holway et al 2002).

Range

S. invicta is native to Brazil, but has been introduced to the Antigua, Australia, Barbuda, Bahamas, Cayman Islands, China, Hong Kong, Malaysia, New Zealand Paraguay, Puerto Rico, Singapore, Taiwan, Trinidad and Tobago, Turks and Caicos Islands, United States, and the Virgin Islands (ISSG 2008). In the United States, *S. invicta* was introduced to Alabama and spread to Arkansas, California, Florida, Georgia, Louisiana, Maryland, Mississippi, New Mexico, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Virginia (Holway et al. 2002, ISSG 2008). In California, *S. invicta* is present in San Joaquin, Orange, Riverside, Los Angeles, and Sacramento counties (Jetter et al. 2002).

Introduction Pathways

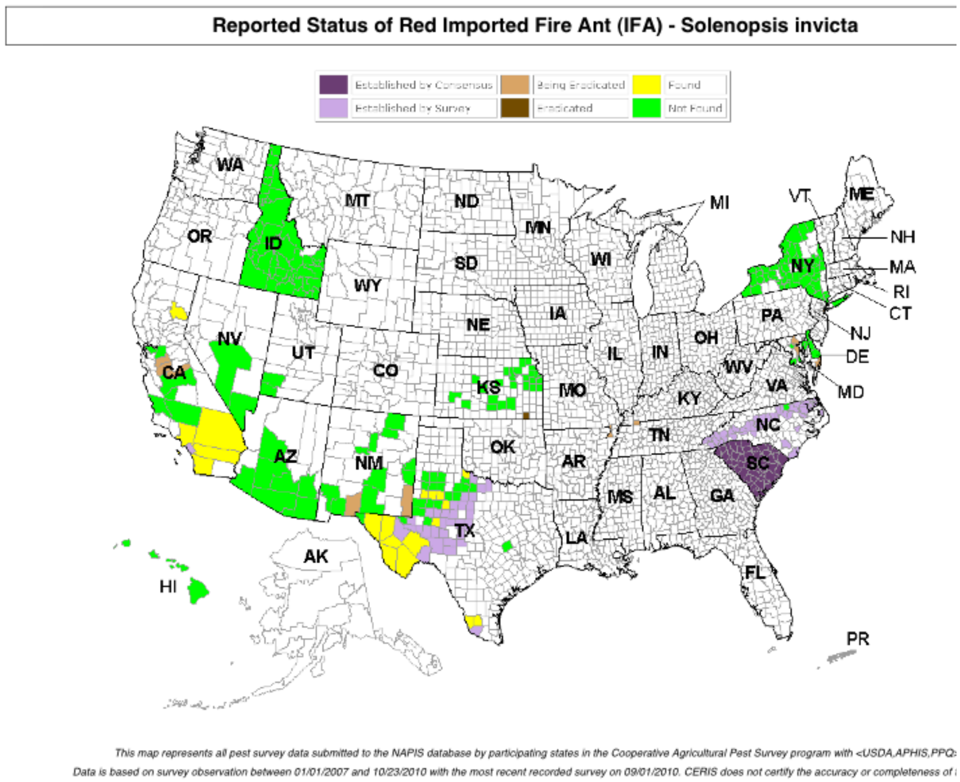
S. invicta is likely transported via machinery or equipment used in areas where they occur, potting soil from nursery plants, and/or queens transported via car, train, or truck during a mating flight (Wilson and Brown 1958, Vinson and Greenberg 1986, Porter et al. 1988).

Invasion Ecology

Habitat

S. invicta occurs in hot, arid areas receiving more than 510mm of precipitation per year or in areas with a permanent source of water (such as lakes, rivers, springs, lawns or agricultural areas) (Morrison et al 2004). In their introduced range, *S. invicta* and *S.*

geminata are more likely to colonize open and disturbed environments and human associated habitats (Holway et al. 2002). *S. invicta* builds mounds for brood thermoregulation (Morrison et al 2004). Mounds are easier to build in open, sunny areas, thus *S. invicta* is less of a threat in densely wooded forest habitats (Morrison et al 2004).



Current distribution of *S. invicta* in the United States

Dispersal

S.invicta occurs in both polygyne (single queen colonies) and monogyne (multiple queen colonies, formed from budding) populations (Porter et al 1990). *S. invicta* polygyne populations spread from a single queen who births reproductive females who leave the colony and establish a mound nearby. Polygyne populations spread at a rate of 10-40 m/year in Texas (Porter et al 1988). For monogyne populations of *S. invicta*, winged reproductive females can travel several kilometers during a mating flight and may be transported via nursery stock, train, and/or automobile (Wilson and Brown 1958, Vinson and Greenberg 1986, Porter et al. 1988).

In areas where *S. invicta* overlaps with the *S. geminata*, they have hybridized (Vander Meer et al 1985, Holway et al. 2002); the hybrid occurs in Mississippi, Alabama, Georgia, and Tennessee (Williams et al 2001).

General Impacts
S. invicta has an omnivorous diet, which includes invertebrates, vertebrates, plant materials, and oily and sugary foods (ISSG 2008). *S. invicta* have been found on dead young birds and vertebrates, but in some cases it is unclear whether *S. invicta* was the cause of death (Holway et al 2008). In the United States, *S. invicta* negatively impacted fourteen bird species, thirteen reptile species, one fish species, and two small mammal species directly through predation, competition, and/or stinging (Holway *et al.* 2002). *S. invicta* reduces invertebrate and reptile biodiversity and has the potential to devastate native ant populations (McGlynn 1999). It is competitively dominant to most other invasive ant species; it has displaced the Argentine ant (*Linepithema humile*) in areas in the United States where both species have been introduced (Holway *et al.* 2002).

S. invicta can sting people and animals. Stings may result in an allergic reaction; less than 1 percent of the world population is susceptible to an allergic reaction from a sting (Jetter et al 2002). Parks and recreational areas may become unsafe for children, as *S. invicta* prefers grassy open areas. *S. invicta* has infested and damaged electrical equipment, such as computers, swimming pool pumps, cars, and washing machines (Jetter et al 2002). Agricultural impacts include damage to crops and/or livestock, interference with equipment, and the stinging of workers in the field (ISSG 2008).

The current economic impact of *S. invicta* on humans, agriculture, and wildlife in the United States is estimated at $1 billion per year (Pimentel et al. 2000, Morrison et al 2004). The Australian Bureau of Agricultural Resource Economics has estimated the losses to agriculture in Australia are more than AU $6.7 billion over 30 years (ISSG 2008). Gutrich et al. (2007) estimated that the introduction and establishment of the red imported fire ant in Hawaii would have an economic impact of US $ 211 million/year.

Potential on Santa Cruz Island
Santa Cruz Island currently hosts an infestation of *L. humile*, which would not deter *S. invicta*, because *S. invicta* is competitively dominant. Any open grassy areas around human structures that have an external source of water nearby may be susceptible to *S. invicta* invasion. This likely includes the campgrounds, NPS buildings, the UC Reserve Station, and the main ranch. *S. invicta* may negatively impact the breeding birds, small mammals, 32 native species of ants, and other island invertebrates present on the island (Browne et al 2010). *S. invicta* may also damage equipment present in the areas surrounding invasion. Furthermore, the presence of *S. invicta* may reduce recreational visitation to the island, especially by those with small children.

Control & Eradication
Most established *S. invicta* infestations in the US have not been successfully eradicated; however some populations have been limited to certain areas (ISSG 2008). For a period of approximately four decades, the federal government attempted to eradicate *S. invicta* from approximately 20 million hectares in the southern US using pesticides at a cost of

$200 million (Williams et al 2001). In Texas in 2000, approximately $580 million was spent to control this pest (ISSG 2008).

To effectively eradicate *S. invicta*, the invasion must be detected early on (Holway et al 2002, NPS 2010). Currently, there are many methods that are successful for small invasions: application of boiling water or steam or chemical applications (NPS 2010). Boiling water has been used to varying degrees of success. For greater success, 3 or more gallons of boiling water should be used to treat each mound and more treatments may be necessary (National Park Service 2010). Water may also be applied as steam using a steam generator; however both methods may be difficult to use in remote areas (National Park Service 2010, Holway et al 2002). If the steam or boiling water does not reach the queen, the treatment will be unsuccessful and will need to be repeated. Applying steam or boiling water is risky as the applicator may receive burns from the equipment or water and/or stings from agitated ants.

Chemical applications involve individual mound treatments or broadcast of chemicals outside mounds. All chemical applications are sensitive to temperature, because S. invicta activity varies according to the temperature and the chemical potency is related to temperature (NPS 2010). Individual mounds can be treated with a mound drench, mound injections, baits, dusts, and fumigation. Mound drenches work best when the ground is wet from recent rains or wetting prior to the treatment (NPS 2010). Mound drenches are estimated to cost $0.15–0.25/mound, while bait may cost $9–15/acre or $0.50 – 0.90/mound (Vogt 2005). This estimate does not include the labor or travel cost associated with the treatments. Mound injections are similar to mound drenches, however the chemical is applied as an aerosol instead of a liquid. Groups of mounds may be treated with broadcast baits. Individual mound treatments are effective and rapid for small invasions; however broadcast baits are slow (2–8 weeks), but effective for large invasions (NPS 2010).

Biological control is currently being studied in the United States to test the effectiveness and the ecological impacts associated with each method. The most effective biological controls are a nematode, *Neoaplectana carpocapsae,* and a straw itch mite, *Pyemotes tritici*. While *P. tritici* is effective at eradicating mounds of *S. invicta*, this species is known to affect other species and to bite humans (NPS 2010). Other species being studied include two phorid flies from South America, *Pseudacteon tricuspis* and *Pseudacteon curvatus*, which have been introduced into the United States (ISSG 2008). The flies lay their eggs in the heads of *S. invicta* and the larvae consume the contents, ultimately decapitating the ant. Phorid flies also alter the behavior of S. invicta, as the ants will not forage if the flies are active above them (ISSG 2008).

Resources
Global Invasive Species Database of the IUCN Invasive Species Specialist Group: http://www.issg.org/database/welcome/

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Snakes

The only invasive snake species which have been given close study are the brown tree snake (*Boiga irregularis*) and species from the Boidae and Pythonidae families present in the Florida Everglades. These include Anaconda *(Eunectes murinus)*, Indian or Burmese Python *(Python molurus)*, Northern African Python *(Python sebae)*, Reticulated Python (*Broghammerus reticulatus)*, and the Boa Constrictor (*Boa constrictor*) (Reed & Rodda 2009). We will focus on the brown tree snake due to the impact it has had on island biodiversoty. However, due to the lack of habitat and climate match of these species to the Channel Islands, we expand our discussion to include the Southern Pacific Rattlesnake (*Crotalus oreganus helleri*) as an example of a local species which could potentially inhabit the island.

Brown Tree Snake (Source: National Park Service)

Physical Description

Snakes come in a wide range of sizes. Snakes in the boa and python families can reach up to 10 m in length and weigh over 100 kg, although most individuals only reach about 6 m (Reed & Rodda 2009). In comparison, the soil dwelling Brahminy blind snake (*Ramphotyphlops braminus*), which some believe is an introduced species in much of its range, can be as small as 64 mm (Nussbaum 1980).

Brown Tree Snake

The brown tree snake is usually 1 or 2 m but can reach 3 m. They are yellowish brown and covered in vague splotches. Their heads are wider than their necks (ISSG 2009).

Southern Pacific Rattlesnake (Source: USGS)

Southern Pacific Rattlesnake

Identifying features of rattlesnakes are their triangular head and a rattle at the end of their body which grows each time the skin is shed (UC 2004). The Southern Pacific Rattlesnake is about 1 meter long. (Aquarium of the Pacific n.d.). They are an olive-brown with dark brown splotches (California Herps n.d.).

Range

Snakes are found worldwide. Snakes that have become invasive in the United States are mostly tropical and subtropical in origin (Reed 2005). However, the majority of Pacific islands do not have any native snakes, and therefore have seen the most snake introductions (Loope et al. 2001). Many snakes have been introduced in the Florida Everglades because the climate is most similar to their home range (Reed 2005). Santa Cruz Island is home to the endemic Santa Cruz Island Gopher Snake, which also occurs on Santa Rosa Island (California Herps 2010).

Brown Tree Snake
Brown tree snakes naturally occur in Eastern Indonesia, New Guinea, the Solomon Islands, and parts of Australia. The species was introduced to Guam after World War II (Rodda et al. 1992). The brown tree snake has been identified in Hawaii but has yet to establish a self-sustaining population.

Western Pacific Rattlesnake
The Western rattlesnake occurs throughout the western United States. The range of the Southern pacific subspecies (*C. o. helleri*) starts in Santa Barbara County and goes south to Baja California (California Herps n.d.). It is reported to be present on Santa Catalina Island (Catalina Conservancy n.d.).

Introduction Pathways
Non-native snakes are often introduced into the United States through the pet trade, and then released into the wild as abandoned pets (Reed 2005). About 1 million snakes have been imported into the United States through the pet trade, 60% of them being boa constrictors (Reed & Rodda 2009). An unknown number of these are released or escape (Reed 2005). Some of the most common pet species include boas, pythons, rat snakes, bullsnakes, pit vipers, king snakes (Loope et al. 2001). The large number of introductions makes these species those with the greatest risk of introduction as released pets.

Accidental transport of snakes is most likely to occur with species with a few of the following characteristics: nocturnal, secretive, have high densities, and can reproduce parthenogenically (Loope et al. 2001). Few species meet these criteria. Snakes are capable of being transported long distances due to their ability to fast for long periods of time and fit in small spaces (Rodda et al. 1997).

Brown Tree Snake
The Brown Tree Snake was introduced along with military equipment being moved to Guam after World War II (Rodda et al. 1997). It went unnoticed because it is a nocturnal species and is active when humans are not present. Accidental transport of snakes is most likely to occur with species with a few of the following characteristics: nocturnal, secretive, have high densities, and can reproduce parthenogenically (Loope et al. 2001). Few species meet these criteria.

Southern Pacific Rattlesnake
The Southern Pacific Rattlesnake is not a known invasive so no historical vectors exist for the species.

Invasion Ecology

Habitat

Snakes have exploited a wide variety of habitats. Anacondas are usually found in water while other boids are usually found on land. Pythonids are found in both aquatic and terrestrial habitats (Reed & Rodda 2009). These species usually prefer warmer habitats, though some such as the Burmese python can tolerate cooler temperatures than the rest.

Brown Tree Snake

The brown tree snake is found in tropical climates. It is arboreal, as the name implies (Rodda et al. 1997). The snake is nocturnal, and descends to the ground at night to forage (ISSG 2009). It is found in a variety of habitats, but is frequently reported to be in human dominated areas, and forests (ISSG 2009).

Southern Pacific Rattlesnake

The Southern Pacific Rattlesnake occupies a wide range of habitats, including all habitats on Catalina (Catalina Conservancy n.d.).

Dispersal

Snakes have a variety of reproductive strategies. They can be live-bearing (boids) or egg-laying (pythonids). The females of some species can store sperm internally, and some may reproduce parthenogenically (Reed 2005, Rodda et al. 1997). Pythons have the largest number of young, with a maximum of 124 young by the Reticulated Python. These species begin to reproduce around 3-5 years of age (Reed & Rodda 2009). Clutch size is usually correlated with body size in snakes, so these giant released snakes are likely to reproduce better than smaller native snakes (Reed 2005).

Not much is known about dispersal due to the difficulty of detection (detection probability in the Everglades is thought to be 1 in 1,000) (Reed & Rodda 2009). However, snakes are very fast moving and likely to be able to disperse quickly.

Brown Tree Snake

A typical clutch size of the brown tree snake is 3-4 eggs (Rodda et al. 1997). For this reason, the brown tree snake was not very prevalent on Guam for the first 35 years after introduction (Rodda et al. 1992). The brown tree snake females is a species in which females can store sperm internally, meaning they can invade an area without appearing gravid, and still be able to reproduce (Whittier & Limpus 1996).

Southern Pacific Rattlesnake

Rattlesnakes are ovoviviparous, giving birth to live young (Aquarium of the Pacific n.d.). The Southern Pacific Rattlesnake births between 4 and 12 young per year (Catalina Conservancy n.d.).

General Impacts

Boids, pythonids, and the brown tree snake are generalists and feed on a wide variety of bird, mammal, and reptile species (Reed & Rodda 2009). Snakes are usually not capable of depressing prey populations due to their relatively limited abundances. Additionally, snakes are only likely to impact populations where prey species have not adapted to snake predators.

Snakes are carriers of many pathogens, including Salmonella, Clostridium, Escherichia, Mycobacterium, and Staphylococcus. They may also be carriers of parasites such as ticks which may harbor diseases such as Lyme disease, tularemia, Siberian tick typhus, and tickborne relapsing fever. Boid snakes (boas and pythons) may also carry the virus known as inclusion body disease (IBD), which could impact native boid snakes which live in the Western United States, though none are present on Santa Cruz Island (Reed 2005).

Brown Tree Snake
The brown tree snake killed 10 native bird and 9 native lizard species on Guam (Pimentel et al. 2005). The high abundance of snakes on Guam (100/ha), as well as the lack of coeveolution of prey populations to snakes (Loope et al. 2001, Rodda et al. 1997), made the impact of brown tree snakes uncharacteristically high. Bird species on Santa Cruz Island are not likely to be adapted to snake predators, as the only snake on the island is not arboreal.

The total damage caused by Brown Tree Snakes in Guam is $1 million per year, with control costs being another $11 million (Pimentel et al. 2005). These costs include profits lost due to power outages caused by the snake climbing utility poles.

Southern Pacific Rattlesnake
Rattlesnakes eat birds, small mammals, other snakes, frogs, and insects (California Herps n.d.). Since Santa Cruz Island does have a native snake species, prey species have adapted to snake presence and the impacts from introduction of a new species may be low.

Rattlesnakes can impact humans on the island as a result of their venomous bite. Rattlesnakes usually do not bite unless handled or stepped on (CA Department of Fish and Game n.d.). A couple deaths result from approximately 800 rattlesnake bites in California each year. Other bites result in tissue damage.

Potential on Santa Cruz Island
Probability of snake invasion on Santa Cruz Island is low because introduction would have to be intentional. The most common invasive species are large and would be easy to detect at an introduction point. Many of the species invasive to the Everglades would not be able to survive on Santa Cruz Island because the climate is too cold (Reed & Rodda 2009). Those most likely to be able to handle the climate are Burmese pythons (Reed & Rodda 2009) and boa constrictors (Reed 2005). Though not introduced into the wild of the United States, *Morelia spilota* has a wide distribution in Australia, New Guinea, and Indonesia, and may also be able to live in the California climate (Reed 2005).

Brown Tree Snake
No vectors to Santa Cruz Island currently originate in the Brown Tree Snake range. Additionally, the climate and habitat of the island does not match that of Santa Cruz Island.

Southern Pacific Rattlesnake
Rattlesnakes do occupy areas near Santa Cruz Island. Their ability to fit in small places and their secretive nature makes their detection difficult. Despite this, rattlesnakes are not known to have become invasive anywhere.

Control & Eradication
No large scale eradications of snakes have been successful (Reed & Rodda 2009). One issue with using poison to eradicate snakes is they can go for months without eating, making the method slow and inefficient. Another problem is the large invasive snakes in the United States would require very high dosages of a poison in order for it to be effective, increasing the risk of mortality of non-target species.

Brown Tree Snake
Physical barriers (fences, etc.) were used on Guam to keep the Brown Tree Snake out of reserves. However these barriers were ineffective because the snake could climb trees to get over them and storms would knock the barriers down (Rodda et al. 2002). Acetaminophen hidden in dead mice has been used as poison for Brown Tree Snakes on Guam (Reed & Rodda 2009, Johnston et al. 2002).

Spread of the brown tree snake from Guam to Hawaii and other vulnerable islands is prevented through implementation of the "Brown Tree Snake Control and Interdiction Plan." This includes using snake traps, capturing snakes by hand, laying poisoned bait, and searching cargo with trained dogs in order to prevent snakes from leaving the island. About 5,000 snakes are removed from departure points in Guam annually. Only twice since the inception of the program have brown tree snakes been found to have left the island of Guam. The Navy has pledged $1.6 million annually and the Air Force $3 million for implementation of this program in 2010-2015 (Deputy Underscretary of Defense 2008).

Southern Pacific Rattlesnake
A method to prevent introduction of rattlesnakes is to remove suitable habitat and hiding places near vector origins and pathways. This would involve removing heavy brush and tall grass, rocks, logs, lumber piles, rodent holes which they may burrow into, or prey populations such as rodents (Salmon et al. 2004). Snakes can squeeze through holes ¼ inch and larger so any such holes should be sealed. Snake exclusion fences should work against rattlesnakes if they are kept free of vegetation which snakes could use to scale the fence (Salmon et al. 2004). A 50'x36" length of fence costs approximately $65 (Academy Fence Company n.d.).

Rattlesnake removal businesses exist to remove the snakes on an individual basis. An approximate estimate for such a service is $50-$100 per snake in addition to fees associated with property inspection (Southern California Snake Removal 2009). The price will depend on the size of the area thought to contain the snake(s).

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Western Gray Squirrel (*Sciurus griseus)*

Common name- Silver-gray Squirrel, the California Gray Squirrel, the Oregon Gray Squirrel, the Columbian Gray Squirrel and the Banner-tail

Physical Description

S. griseus' back coloration ranges from a silvery-grey to salt-and-pepper (Hall 1981). *S. griseus* has a white underbelly, a light reddish-brown coloration on their ears, and a long, bushy tail edged with white. *S. griseus* is larger than the Eastern grey squirrel (*Sciurus carolinensis*). S. griseus ranges from 20 to 24 inches in height, with average tail lengths ranging from 9 to 25 inches (Hall 1981, Carraway and Verts 1994). Adults weigh from 18 to 33 ounces (USFWS 2003).

The western gray squirrel (Source: Mary Cummins, AnimalAdvocates.us from)

Range

S. griseus is native to the Pacific coastal states, including California, Oregon, and Washington and portions of Nevada (Ryan and Carey 1995). In California, the geographic range of the western gray squirrel includes the mountainous and foothill regions of the Klamath, Sierra Nevada, Tehachapi, Little San Bernardino, Santa Rosa, and Laguna Mountains and the Transverse and Peninsular Ranges (Carraway and Verts 1998, USFWS 2003). *S. griseus* has 12 million hectares of habitat prior to the breeding season (USFWS 2003). In Washington, *S grise*us is an ISSSSP species and in Oregon, it is an Oregon Conservation Strategy Species (ODFW 2006). In Nevada, *S. griseus* is found only in the Carson Range (USFWS 2003).

Introduction Pathways

Historically, squirrels were transported to other regions for economic reasons, such as the pet trade, and were introduced into natural areas either through escape or intentional releases (Bertolino 2009). Bertolino (2009) found that 7.9% of squirrels were introduced at least once, with a successful establishment for 90% of the species and 80.6% of the populations. Once a squirrel has been introduced it has a high potential to establish a population and only a few individuals are necessary to establish a viable population.

Invasion Ecology

Habitat

Although *S. griseus* forages for food on the ground, it is primarily arboreal and usually does not stray far from trees (USFWS 2003). *S. griseus* uses tree canopies for escape, cover, and nesting (USFWS 2003). While *S. griseus* will move across small groups of trees or small habitat patches, they generally avoid open spaces (USFWS 2003). *S. griseus* prefers stands greater than 5 acres in size (USFWS 2003). *S. griseus* requires a contiguous tree canopy that allows arboreal travel for at least 198 feet around the nest (Ryan and Carey 1995).

S. griseus prefers stands of mixed conifers, oaks, and other food-bearing trees (USFWS 2003). Sources of food include pine nuts, acorns, green vegetation, seeds, nuts, fleshy fruits, mushrooms, and other foods (USFWS 2003). Pine nuts and acorns serves as the primary food source for storing body fat for winter. A decreased diversity of food increases the likelihood that large-scale mast failures will decrease survivability of *S. griseus* (Ryan and Carey 1995).

S. griseus requires a year round source of water; they will drink from permanent and intermittent water sources such as lakes, marshes, rivers, streams, and puddles (Ryan and Carey 1995).

Dispersal
Males reach sexual maturity at 1 year and females at 10 to 11 months (USFWS 2003). *S. griseus* have one litter with one to five offspring every year, but two litters may be possible (Ryan and Carey 1995). Mating occurs from December through June, with a 43 day gestation period (Ryan and Carey 1995).

Home range sizes vary with age, sex, location, population density, and over time. Home ranges for a male *S. griseus* range from 1.2 acres in an urban park in California to 16 acres in northern Oregon (USFWS 2003). Female home ranges range from 0.3 acre in California to 42 acres in Oregon during the summer (Ryan and Carey 1995).

S. griseus is diurnal and is most active in August and September, while they collect and store food for winter (USFWS 2003). *S. griseus* will not travel farther than 1,280 feet from water and will not travel farther 40 feet of open prairie (USFWS 2003).

General Impacts
S. griseus has not previously been invasive, however other squirrel species have been. *S. carolinensis* reduced the distribution of the native red squirrel (*Sciurus vulgaris*) in Europe through competition for resources and space and pathogen mediation (Gurnell et al. 2006). *S. carolinensis* also damaged trees in forests and commercial tree plantations by stripping off the bark (Bertolino 2009, Kenward 1998). The Abert's squirrel (*Sciurus aberti*) reduced the abundance of the endangered endemic Mount Graham squirrel (*Tamiasciurus hudsonicus grahamensis*) by consuming their resource reserves (Palmer 2007); *S. aberti* also reduce cone crops and pine tree growth (Palmer 2007). The eastern fox squirrel (*Sciuris niger*) has caused population declines in the western gray, Douglas, and Abert's squirrels in their native ranges due to competition for resources. Some species of squirrel are known to chew on electrical wiring (Palmer 2007). *Sciurus* species have also been observed taking bird's eggs and nestlings for consumption (Palmer 2007). The Mexican Red-bellied squirrel (*Sciurus aureogaster*) has reduced native plant, a native tree snail, and bird abundances in Florida (Palmer 2007).

Squirrels are also known disease vectors to humans and other animals, including the poxvirus, Lyme disease, and the bubonic plague (Palmer 2007). Campsites have been closed during peak times due to observations of squirrels carrying fleas with the bubonic plague.

Potential on Santa Cruz Island

S. griseus habitat in oak woodlands is dependent on mature stands of conifer and oak woodlands in California. Oak masts are unpredictable, thus *S. griseus* rely on Douglas Fir (*Pseudotsuga menziesii* var. *menziesii*) and ponderosa pine (*Pinus ponderosa*) seeds during low mast years (Ryan and Carey 1995). Without supplemental food sources during low mast years, *S. griseus* would suffer large-scale mortality on the island. Bird species on the island are not likely to decline because of S. griseus, as there are no reports of bird's egg or nestling consumption by *S. griseus*. S. griseus would likely compete with the native mice for seeds, nuts, fleshy fruit, and green vegetation. Infected *S. griseus* individuals could spread diseases to other animals or humans, such as lyme disease and bubonic plague (Palmer 2007).

Control & Eradication

Warafin, an anti-coagulant poison, is reportedly the most efficient method currently available for squirrel eradication (ISSG 2009). Warafin, like many other anti-coagulants, can cause secondary and tertiary poisoning in non-target birds and mammals (Pepper 1990). Other methods include the use of bounties, free cartridges, tail bonuses, and trapping (ISSG 2009). Bounties, free cartridges, and tail bonuses are used in areas with permitted hunting; these methods are not likely to be implemented on Santa Cruz Island, as there is no permitted hunting on the island by either land manager. Trapping and bait application would need to account for incidental trapping of the island fox and native mice. Given that an eradication attempt in Italy failed because *S. carolinensus* was too widespread, Bertolino (2009) recommends that invasive squirrel populations must be addressed before they become too large.

Resources

The International Union for the Conservation of Nature Red List:
http://www.iucnredlist.org/apps/redlist/details/20011/0

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Raccoon *(Procyon lotor)*

Common name- common raccoon, raccoon, North American raccoon, Northern raccoon, coon.

Physical Description

Procyon lotor is a medium sized mammal, and the largest of the procyonid family. Adult raccoons have a body length of 16 to 28 inches and their tales can vary in additional length from 8 to 16 inches (Dewey & Fox 2001). They generally weigh between 8 and 20 pounds (Wildlife Information.org 2008, Chapman & Feldhamer 1983). *P. lotor* have wide faces with a pointed muzzle, their most distinguishing feature being a facial mask that consists of black fur around their eyes and white face coloring (Dewey & Fox 2001). They also have slightly rounded ears bordered by white fur. Raccoons have contrasting rings on their tails, and long stiff grey or brown guard hairs on their body that shed moisture (Bartoszewicz 2006). They have a dense under fur that insulates against the cold and consists of longer hairs often over an inch (Dewey & Fox 2001).

Raccoons (Source: Dr. Nick Gibbons, Wildlife.Org.)

Range

The native range of *Procyon lotor* is North America, but currently they populate the entire territory of the United States, Southern Canada and Central America (Bartoszewicz 2006). They were introduced to many countries across the European continent through intentional releases for sport, and unintentional escapes from fur market breeders and zoological gardens; their populations proliferated dramatically particularly in western European countries (Bartoszewicz 2006). In Japan, the *P. lotor* invasion is attributed to the escape of the species from households, where they are still often kept as pets (Ikeda, Tohru et al. 2004). Originally some Caribbean Island raccoon populations were described as endemic insular species specifically in the Bahamas, Barbados, and islands of Guadeloupe (Helgen et al. 2008). More recently studies of qualitative morphology and historical publications on these particular populations establish that they are actually the result of human introduction of *P. lotor* (Helgen et al. 2008). Their continual spread in the Caribbean Islands exemplifies the threat to island biodiversity and native wildlife presented by raccoons, and additionally *P. lotor* are not worthy of special conservation attention in this range (Helgen et al. 2008, ISSG 2008). *P. lotor* has gained wide spread range in many countries due to its heightened ability to adapt and thrive under a multitude of environmental conditions.

Introduction Pathways

P. lotor is noted most frequently as being anthropogenically introduced into its non-native range. This can include a variety of pathways as mentioned above, accidental escape from breeding grounds or from households, boat, or deliberate release for sport. Historically pathways have been controlled through anthropogenic actions (Bartoszewicz 2006, ISSG 2008) Because of the mammal's ability to adjust quickly to a vast array of environmental conditions, and adapt quickly to wider home ranges, especially with available food, they become easily and often successfully established following an invasion (Bartoszewicz 2006). *P. lotor* is capable of swimming at an average speed of 3 miles per hour, adults have been observed crossing streams of up to 1000 ft., they can stay in the water for many hours, are comfortable in deep water and can easily swim from a nearby moored boat to land (Catalina Island Conservancy 2009, Raccoon Hunting 101 2009). It is also cited that *P. lotor* may more often prefer not to swim at all and avoid being submerged in water (Bartoszewicz 2006, Wildlife Information.org 2008). Some research does indicate that the raccoon will swim opportunistically up to 1 kilometer to remote islands (Golumbia 1999). Most often *P. lotor* are brought on to island environments via shipping vessel (Helgen et al. 2008, Catalina Island Conservancy 2009).

Invasion Ecology

Habitat

P. lotor initially inhabited deciduous and mixed forests of North America, and prefer moist woodland areas (Bartoszewicz 2006, Dewey & Fox 2001). They have been found to inhabit urban and suburban areas more frequently in the past sixty years, and can thrive in agricultural and farmland areas as well (Dharmarajan et al. 2009). They require ready access to water, and because they are so highly adaptable, today *P. lotor* can thrive in environments ranging from warm and tropical to cold grasslands. In these environments, raccoons can create habitat in woodchuck burrows, caves, mines, deserted buildings, barns, garages, rain sewers, houses and dock and port areas (Dewey & Fox 2001).

Dispersal

Male raccoons often mate with at least two or more females, in the months of January to March. Pregnancy lasts for roughly 65 days, and most of the litters are born in April (Bartoszewicz 2006, ISSG 2008, Wildlife Information.org 2008, Dewey & Fox 2001). Reproductive rate has been shown at 66% in yearlings and 96% in adults, and population growth has been measured in Japan between 20 and 25% (Ikeda et al, 2004). Litter sizes are generally between 2 and 5 individuals, and juveniles remain with their mothers through the first winter, generally about 10 months. Females often stay within their natal area, while males will disburse long distances (Bartoszewicz 2006, ISSG 2008, Dewey & Fox 2001). Home range can vary widely from 35 hectares in urban areas to 2,220 hectares in forested areas (Ikeda et al., 2004). Raccoons are opportunistic and omnivorous mammals and will alter their feeding habits depending on food availability.

General Impacts

Procyon lotor have the potential to threaten native and endemic species both through predation and competition for food and other resources. Raccoons are also major carriers of diseases including rabies, canine distemper virus, and parvovirus which can all remain in the soil for up to several years (Catalina Island Conservancy, 2005). *P. lotor* has also been documented taking over other bird and mammal species nest areas for their own reproductive grounds (Garmestani & Percival 2005, Engeman et al. 2003, Helgen et al. 2008). Raccoons have been stated as the primary cause of sea turtle nest loss in the Ten Thousand Islands archipelago (Garmestani & Percival, 2005).

Potential on Santa Cruz Island

Adult raccoons have been observed to swim up to 1000 feet to cross streams. More often they are cited as preferring to avoid water, swimming or activity involving being fully submerged, as mentioned above. The likelihood of their introduction to Santa Cruz Island by swimming across the deep and rough Pacific Ocean channel is very low (Wildlife Information.org 2008), although the threat of introduction due to stowaway species on shipping vessels may be of significant concern (Catalina Island Conservancy 2009). The diseases that many *P. lotor* carry pose major threats to native island endemics including the endangered Santa Cruz Island fox. Predation and harvest of eggs for food could threaten many island bird species. It is worthwhile to note that both a virile male and fertile female would need to be introduced onto the island at similar time steps in order for the potential of a breeding community to exist, although a single raccoon may also potentially damage island fox and bird populations depending on their life period if successfully transported to the island. All of Santa Cruz Island would provide more than adequate living environment for *P. lotor*, especially the more developed camp site areas and particularly the Central Valley Ranch where there is access to fresh water, a variety of food, and a variety of suitable habitats including urban structures.

Control & Eradication

The majority of the eradication publications on raccoon species refer to hunting or trapping (non-lethal and lethal) methods. In Florida to control *P. lotor* in island environments they trap the raccoons in live traps, then sedate and euthanize them. Hunting them with a 22 caliber rifle is another approach used (Engeman, Richard et al. 2001). Trapping the raccoons on Santa Cruz Island and relocating them to a mainland environment may be an eradication option for management of the threat once invasion has occurred, although this may prove to be more costly than euthanizing or killing the animals and will require a relocation permit from the California Department of Fish and Game (Salmon et al. 2008). The Catalina Island Conservancy has noted that the relocation method was infeasible on Catalina because it is not legal to relocate *P. lotor* to a location other than their origin, of which is unknown (Julie King, Catalina Island Conservancy, personal communication, March 9, 2011). Both hunting and trapping then euthanizing raccoons has been controversial in certain communities, and would likely be controversial in Santa Barbara County as was the pig eradication. Lethal removal is performed on Catalina and is not advertised at all due to controversy associated with the method (Julie King, Catalina Island Conservancy, personal communication, March 9, 2011).

Complete removal of large *P. lotor* subpopulations has been shown to be quite difficult, while isolated small populations with one or a few reproductive females can be successful and effective, no cost is referenced in relations to these types of eradication costs (Koike 2006). The cost of single door live animal traps ranges from $40 to $50 each (Ace Hardware 2010, Sears Marketplace 2010, Amazon.com 2010). This type of trapping would have additional labor cost associated with monitoring and relocation, and may also be infeasible due to the potential of non-target species trapping, particularly the Santa Cruz Island Fox. This method was proven to be inefficient on Catalina Island because more foxes were trapped than raccoons (Julie King, Catalina Island Conservancy, personal communication, March 9, 2011). On Catalina Island, the current method of raccoon rapid response is "lethal removal" with a shot gun and night vision goggles, 150 staff hours were spent to remove four raccoons, and each raccoon is sent for testing once they have been exterminated. Advertising was placed in boating magazines for a seven month period in conjunction with the removal effort, and 60 signs were purchased to be placed on the island and at mainland marina locations. The total cost of equipment associated with the removal of four raccoons on Catalina Island was: $26 Night Vision Goggles, $45/sign at 60 signs, $500 Lab testing fees per raccoon, and labor at the Firearm Certified Technician rate which is highly variable depending on detection efficiency (Julie King, Catalina Island Conservancy, personal communication, March 9, 2011).

Resources

Global Invasive Species Database of the IUCN Invasive Species Specialist Group: http://www.issg.org/database/species

Delivering Alien Invasive Species Inventories for Europe, European Commission 6th Framework
http://www.europe-aliens.org/aboutDAISIE.do

The International Union for the Conservation of Nature Red List: http://www.iucnredlist.org/apps/redlist/details/41686/0

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Commensul Rats (*Rattus* spp)

Common name- *Rattus rattus* – black rat, ship rat, roof rat; *Rattus norvegicus* – Norway rat, wharf rat, brown rat; *Rattus exulans* – Kiore, Pacific rat

Physical Description

R. norvegicus has brown fur on the back with pale grey fur on its belly. The adults normally weigh 150 - 300g, and may reach up to 500g, and are up to 390mm long. They have relatively short ears and a tail that is shorter than the head-body length (Wittenberg, R. (ed.) 2005).

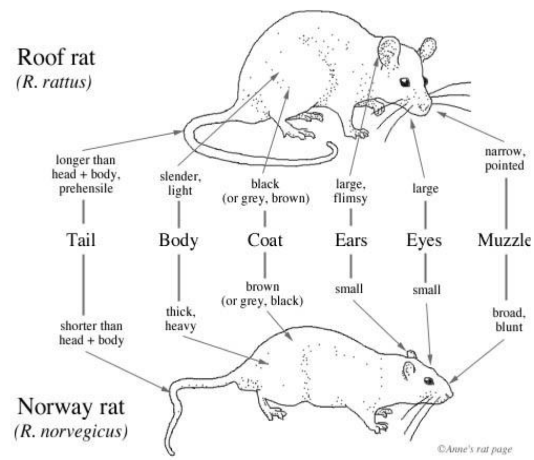

Figure 1. Physical characteristics of *R. norvegicus* and *R. rattus*.

Rattus rattus may be grey-brown on the back with either a similar or creamish-white belly, or it may be black all over. The uniformly-colored tail is always longer than the head and body length combined. Its body weight is usually between 120 and 160 g but it can exceed 200 g (ISSG 2009).

R. exulans has a ruddy brown fur and a whitish belly. Body shape is slender with a pointed snout, large ears, and relatively small feet. *R. exulans* is the smallest of the three commensal rat species. Mature individuals weigh 40 to 80 g. The tail has prominent fine scaly rings and is about the same length as the head and body. Female *R. exulans* have 8 nipples, compared to 10 and 12 nipples normally found on *R. rattus* and *R. norvegicus*, respectively (ISSG 2009). Another distinguishing feature of *R. exulans* is the dark outer edge of the upper side of the hind foot near the ankle; the remainder of the foot is pale (ISSG 2009).

Figure 2. Distribution of (a) *R. rattus* and (b) *R. norvegicus* in the continental US(Marsh 2008).

Range

R. norvegicus is thought to be native to the SE Siberia, NE China and the Hondo region of Japan (Pascal & Lorvelec 2006, ISSG

2009). *R. rattus* is native to the Indian sub-continent. *R. exulans* is native to SE Asia (ISSG 2009a).

Non-native rat species are now present on every continent except Antarctica and on over 80% of the world's island groups (Atkinson 1985). *R. rattus* are established in warm and coastal areas of the US, *R. norvegicus* is established throughout the US (Figure 2) (Marsh 2008). *R. exulans* is widely established throughout Southeast Asia and the pacific, including many Hawaiian islands (ISSG 2009a).

Introduction Pathways

The current rate of island invasions as estimated by Russell, Towns, and Clout (2008) (5.89 islands/20 years) is not statistically different from that estimated by Atkinson (1985) for the previous 3000 years, meaning that the introduction and establishment of rat populations on islands continues to occur.

Rattus species can be transported by stowing away on vessels or in cargo and can crawl or swim from docked, anchored, or shipwrecked vessels to shore. The exact distance beyond which an island is safe from reinvasion by swimming is unknown. *R. norvegicus* have been shown to swim as far as 1-2km in calm waters (Russell & Clout 2005). *R.rattus* and *R. exulans* avoid swimming but can do so when necessary and have been recorded swimming both in the wild and in experimental studies (ISSG 2009a). *R. rattus* may swim up to 500m (Russell & Clout 2005).

Invasion Ecology

Habitat

Rattus species are habitat generalists and occupy many habitat types aside from high mountains (>1,000m). They can be limited by the supply of fresh water, but populations have also been found to persist on islands that lack a source of fresh water (Moors 1985). Rats often live in coastal and riparian areas because high quality forage is close to excellent protective habitat for burrows (Samaniego and Howald 2004). Increased rates of detection have been reported around wharves and associated buildings, which is consistent with common knowledge about rat habitat preferences toward human environments, but could also be an artifact of greater human activity in those areas (Samaniego & Howald 2004, Russell et al. 2008). *R. rattus* and *R. exulans* are excellent climbers and tend to do some portion of foraging above ground (ISSG 2009a).

Reproduction

A simple deterministic growth model developed by Russell, Towns, and Clout (2008) shows that the introduction of a single pregnant female Norway rat could result in a colonizing population of up to 300 rats in just over eight months. This model assumes no mortality; however, it also assumes that litter size and breeding frequency will be average, which may be conservative in an area with abundant food supply and lack of conspecific competition. The overall estimate is likely liberal, but not unrealistic. This model tells us that rats are prolific enough breeders that no invasion is likely to remain localized for long.

Rattus norvegicus home range and dispersal

In recent studies of *Rattus norvegicus* dispersal following introduction to a novel and uninfested environment, individuals remained around their point of arrival for 1-4 days and then began exploring increasingly large areas during the first week after introduction (Russell et al. 2008). By the third week after colonization, the rats had established den sites across the entire island (9.3ha) (Russell et al. 2010). 9.3ha is a significantly larger home range than *R. norvegicus* were previously thought to have, which was about 5-6ha (Bramley 1999).

R. norvegicus was observed to travel 685 +/- 296 m nightly on a rat-free island, generally returning to the den site from the previous night (Russell et al. 2008). This is relatively similar to other estimates of nightly movement, Norway rats can move many kilometers, but average movements of radio-tracked rats in arable land were 340 m for females and 660 m for males (Taylor & Quy 1978). Tracked rats usually move through vegetative cover, except when changing den sites. Males change den sites every 7 days and females every 14 days (Taylor 1978).

Rattus rattus home range and dispersal

There are no studies of *R. rattus* in uninfested novel environments. Existing literature suggests that ship rats have smaller home ranges relative to *R. norvegicus*. Estimates of home range size for male ship rats range from 0.17 - 11.4ha with 1ha appearing most frequently. Females typically have home ranges <1 ha (Clapperton 2006). It seems reasonable to assume that ship rats would also be likely to explore larger areas when introduced into a novel environment without competition or interaction with other rats.

General Impacts

Rats are opportunistic feeders, this allows them to exploit whatever food source is seasonally abundant and then move on to another when the preferred option is depleted. On islands, where native species tend to have developed few defenses to predation or competition and are present at inherently low population levels, the effects of a prolific and opportunistic organism such as rats are predictably severe (Fordham & Brooke 2010, Denslow 2003). They have contributed to the decline, depression, extirpation, or extinction of seabirds, forest birds, forest plants, reptiles, amphibians, small mammals, terrestrial and intertidal invertebrates, and bats on islands worldwide (Towns et al. 2006, Jones et al. 2008). Organisms that are ground or shrub dwelling, flightless, and similar in size or smaller than rats are likely to be the hardest hit by direct predation but competitive or tropic effects can affect most any organism.

Potential on Santa Cruz Island.

Introduction

On Santa Cruz Island this includes the operations of Island Packers Company (IPCo), Channel Islands National Park (CINP), and The Nature Conservancy (TNC) or the anchorage of private boats within swimming distance for *R. Norvegicus* and *R. rattus*.

Invasion

SCI would provide ample habitat for *Rattus* spp. Suitable habitat includes areas associated with human habitation such as the TNC main ranch and NPS Scorpion Ranch or natural areas within the island's fields, forests, and riparian areas. With ample food and available habitat, a rapid breeder like the *Rattus* species are likely to expand and increase in density quickly, however predation by foxes would likely restrict population growth to some extent. Invasions on other islands suggest that the population density of invading mice remains suppressed and impacts to native biota are not as severe when the rodents experience pressure from competition and predation (Angel et al. 2009).

Based on observed impacts of rats elsewhere, invasion on SCI may threaten some seabird, land bird, small mammal, reptile, amphibian, and bat species. An extended review of the flora and fauna that may be impacted by a rat invasion can be found in the introduction of the Early Detection and Rapid Response plan for rats. Despite the abundant ecological anecdotes and research done elsewhere, it is still very difficult to know exactly how rats would interact with the diverse assemblage of species on Santa Cruz Island. SCI's species have evolved with the island fox, another generalist predator, so they may be better able to withstand predation pressure compared to organisms on islands with no native mammals and no native predators. SCI is also a relatively large island (>26,000ha), which means that native biota can exist in larger numbers and be more resistant to population fluctuations. There is little published literature on the invasion ecology of rats on large islands with native mammals and native mammalian predators, which makes it hard to know how important these factors will be in buffering SCI from the impacts of rat invasion seen elsewhere.

What we do know is that non-native rats are thought to be responsible for 40-60% of all recorded bird and reptile extinctions since 1600, and are implicated in the extinction of at least 11 small mammals and at least thirteen forest birds (IC 2006, Harris 2009, Towns et al 2006). Rats have had detrimental effects, mild to devastating, on a range of taxa on islands worldwide through their ability to proliferate rapidly and utilize a wide variety of food sources. It would be wise to consider them an equally serious threat to SCI.

Control and Eradication

Control

Long-term control of rodents is typically accomplished through the use of bait stations delivering anticoagulant rodenticides. The associated costs are low, Parkes estimates that controlling mouse populations over a few hundred hectares would cost ~$140 in equipment and $250/year assuming staff could check and change bait 3-4 times/year without special trips to the island (Parkes 2008). The threats to native species and regulatory barriers to using poison on the SCI are likely to be prohibitive to this approach, as discussed below.

Snap traps can also be used for control, but are labor intensive. Traps would need to be checked, emptied, and reset each day to maximize effectiveness. Again, mitigating impacts to foxes, skunks, birds, and native mice would be necessary and potentially cost prohibitive.

Eradication

Almost all successful eradications have used anticoagulant poison delivered either aerially with helicopters, though bait stations, or by hand. Anacapa Island, in the California Channel Islands, is the only island on which successful rat eradication has occurred in the presence of a native mammal. This eradication involved the capture of native mice followed by aerial baiting and the eventual rerelease of native mice. Anacapa is a small island. Eradication attempts for black rats have failed in 5% of reported cases, compared with 19% for house mice (*Rattus rattus*) (Howald et al. 2007).

Howald et al (2007) reported that island area is the most important factor influencing rodent eradication costs, but certainly not the only factor. In rodent eradications where data is available, costs range from \$123-\$20,000ha^{-1} (Howald et al. 2007). Other factors influencing cost include island remoteness and any necessary mitigation for nontarget species, environmental compliance, or legal challenges. The two cases that relate best to SCI are Anacapa Island, where the same regulatory and cultural conditions exist, and Gough Island in the south Atlantic, which, at 9100ha, is the largest island by far on which a rodent eradication has been proposed. Aerial baiting on Anacapa Island for rats cost \$1.8million (~\$6100/ha) and took over 2 years to plan and another 2 years to execute. A preliminary report on the feasibility of eradicating house mice on Gough Island estimates the cost of an aerial bait eradication operation at between \$1.2 – almost \$3 million dollars (\$132 – \$330/ha).

It is important to note that rats have never been eradicated from an island even close to the size of SCI. There have also never been attempts to eradicate rats in the presence of so many sensitive and federally protected species. The use of poison on SCI would be very contentious and present numerous direct and secondary threats to the island's other sensitive biota, particularly the native island deer mouse, harvest mouse, Island scrub jay, nesting seabirds, bald eagles, and the federally protected Santa Cruz Island fox. There is no clear way at this time to target rats effectively AND separately from the native deer and harvest mice or to avoid the ingestion of poisoned carcasses by foxes, eagles, and other birds of prey. Methods for mitigating or avoiding nontarget affects to these species would need to be developed, requiring additional time and resources. Given the significant hurdles in the way of implementation – environmental compliance with NEPA and the ESA and potential legal challenges – an eradication effort on SCI using poison bait by any application method would prove to be extremely difficult.

Additional Resources

University of California Integrated Pest Management Program - House Mouse Pest Notes: http://www.ipm.ucdavis.edu/PMG/PESTNOTES/pn7483.html#REFERENCE

Global Invasive Species Database of the IUCN Invasive Species Specialist Group: http://www.issg.org/database/welcome/

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