A Decision Support Framework for Designing Territorial Use Rights for Fishing

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Master's Group Project

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The Group Project is required of all students in the Masters of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focuses, interdisciplinary research on the scientific management and policy dimensions of a specific environmental issue. The Final Group Project Report is authored by MESM students and has been reviewed and approved by:

Dr. Christopher Costello

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ABSTRACT

More than three billion people rely on seafood for their primary source of protein, yet this essential food security resource is threatened by overfishing. Small-scale fisheries account for roughly half of the total global fish catch, and are in relatively poorer condition than larger scale and/or more thoroughly managed fisheries. Territorial Use Rights for Fishing (TURFs) paired with marine reserves (TURF-Reserves) have been proposed as a viable management strategy to combat overfishing in many small-scale fisheries. TURF-Reserves provide fishers with exclusive long-term access to defined fishing areas while restricting critical areas from fishing pressures, allowing fishers to benefit from exclusive fishing rights and spillover from reserves. When appropriately designed and implemented, TURF-Reserves can encourage stewardship and empower fishers to better manage their resources, leading to increased catch, healthier marine ecosystems, and a more secure economic future.

One of the most challenging issues facing TURF-Reserve implementation is design. Many global small-scale fisheries lack access to technology, have limited scientific data, and the process of including local stakeholder knowledge is often poorly integrated. To address these challenges we created "TURFtools", a Microsoft Excel tool that incorporates both local knowledge and best available scientific data to facilitate TURF-Reserve design decisions. TURFtools helps communities compare varying spatial design options by assessing the relative ecological and socio-economic outcomes of each. Although applied to the Philippines, TURFtools can be customized to any location. By improving TURF-Reserve design and implementation, TURFtools aims to help provide long-term security for both fishers and the resources on which they rely.

List of Abbreviations

CPUE	Catch per Unit Effort
CTI-CFF	Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security
EDF	Environmental Defense Fund
EEZ	Exclusive Economic Zone
FAO	Food and Agriculture Organization of the United Nations
FISH-DA	Fishing Industries' Support in Handling Decision Applications
LGU	Local Government Units
MSY	Maximum Sustainable Yield
PCRA	Participatory Coastal Resource Assessment
PISCO	Partnership for Interdisciplinary Studies of Coastal Oceans
PSA	Participatory Susceptibility Analysis
RBFM	Rights-Based Fishery Management
SFG	Sustainable Fisheries Group (University of California, Santa Barbara)
TURF	Territorial Use Rights for Fishing
VMS	Vessel Monitoring System

EXECUTIVE SUMMARY

Due to continued global population growth, dietary transitions in developing countries, and climate change, food scarcity is predicted to be one of the most pressing environmental concerns that humans will face in the next 50 years. To prepare for this challenge, many governments are focusing on improving the management of food resources, especially those located in our oceans. More than three billion people rely on seafood for their primary source of protein, yet this essential resource to food security is being threatened by overfishing. Managing fisheries and preventing overfishing, however, has proven difficult due to the open-access nature of ocean resources, which inherently promotes competition, and, in many cases, leads to a "tragedy of the commons" situation. Small-scale fisheries—accounting for roughly half of the global total catch—are particularly vulnerable to overfishing due to limited regulations and minimal enforcement. Improving the management of these small-scale fisheries presents a significant opportunity to increase the productivity and health of marine ecosystems and build more resilient communities.

Within the last 30 years, rights-based solutions have been proposed as a viable option for managing small-scale fisheries. More specifically, Territorial Use Rights for Fishing (TURFs), in which fishers have exclusive access to defined fishing areas, have been recommended as a sound approach for managing near-shore, small-scale fisheries worldwide. The theory of TURF implementation is founded on incentivized management; by giving fishers a secure and long-term stake in their fishery, these programs drive stewardship and empower them to better manage their resource, leading to increased catch, healthier marine ecosystems, and a more secure economic future. There is also increasing evidence that coupling TURFs with marine reserves to form TURF-Reserves, results in "spillover effects" as fish stocks from protected areas spill into the implemented TURFs, benefiting user groups and further incentivizing cooperation.

One of the most challenging issues of implementing a TURF-Reserve lies in its design. While the need for stakeholder involvement is recognized, the process by which their feedback is included into a decision framework is complicated. This Group Project aims to improve the manner in which local environmental knowledge is incorporated into scientific TURF-Reserve design. By constructing a TURF-Reserve design model and an accompanying tool that incorporates both the best available scientific data and local stakeholder knowledge, we provide a decision-making framework that can be integrated into the current Fish Forever program model in the Philippines and other small-scale fisheries applications. The inputs needed to assess various tradeoffs within a TURF-Reserve are populated with local knowledge paired with the best available scientific data. Through research regarding stakeholder involvement and behavior change, we create an easily accessible tool that site managers can use to engage local stakeholders. This involvement in the design process increases community acceptance and buy-in of the TURF-Reserve design.

Although focused on the Philippines, this project will be incorporated into Environmental Defense Fund, Fish Forever, and other partner organization's resource took-kits to facilitate TURF-Reserve design in other countries and contexts. Fish Forever will be able to replicate this standardized, but customizable, tool for assisting in TURF-Reserve design and implementation across the globe, and provide long-term security for both small-scale fishers and the fish they rely on.

INTRODUCTION

Since the mid-1900s, global fisheries catch has increased more than 800% (Caddy & Cochrane 2001), stressing fish populations worldwide. With advancements in technology and a steadily increasing demand for seafood, the primary protein source for more than three billion people is threatened with exploitation and overfishing (FAO 2012). Projected population growth and increasing per capita protein consumption worldwide are expected to increase the pressure on marine resources, enhancing the danger of overexploitation in poorly managed fisheries (Creel 2003; Tilman et al. 2011).

While commercial fishers are responsible for half of the global fish catch, they compromise only 10% of global fishers; the other 90% of fishers operate in small-scale, near-shore, artisanal fisheries (Berkes et al. 2001). The Food and Agriculture Organization of the United Nations (FAO) estimates that 50 million of the world's 51 million fishers are in small-scale fisheries, catching nearly half of the world's fish (Berkes et al. 2001). These fisheries generally consist of subsistence fishers whose catch is confined to small or local markets, contribute heavily to local food security, and help maintain sustainable and cultural livelihoods. Despite the artisanal nature of these small-scale fisheries, they generate greater pressure on coastal resources than commercial fisheries (Leópold et. al 2014). Costello et al. support this conclusion, finding that small-scale fisheries are generally in relatively poorer condition than larger scale and/or more thoroughly managed fisheries (2012). The study further estimates, however, that if rebuilt and properly managed, a significant amount of stocks targeted by small-scale fisheries could provide increased sustainable harvest while avoiding overfishing and depletion of resources.

Improving the management of these small-scale fisheries presents a significant opportunity to increase the productivity and health of marine ecosystems and build more resilient communities. Governments and numerous organizations around the world, including Environmental Defense Fund (EDF), have recently set a goal to ensure 50% of global fisheries are sustainably managed by 2022 (50in10.org). Currently, Rights-based Fisheries Management (RBFM) tools are being employed globally in an attempt to dissipate the threat of overfishing. Territorial Use Rights for Fishing, or TURFs, have been proposed as a sound approach for managing near-shore, small-scale fisheries, and can be combined with marine reserves to form TURF-Reserve management systems. To date, formal TURF-Reserve systems have been implemented in more than 40 countries.

RIGHTS-BASED FISHERIES MANAGEMENT TOOLS

In an important attempt to prevent fisheries collapse, the 1982 UN Convention on Law of the Sea, which extended a coastal nation's Exclusive Economic Zone (EEZ) to 200 miles offshore, set in motion many of the current management practices we see today (Wilen et al. 2012). Although governments instituted top-down command and control approaches as a means to reduce total catch, shortened seasons, gear restrictions, and quota systems did not fully solve the problems of overexploitation (Wilen et al. 2012).

Marine Reserves

Marine reserves restrict fishing activities in certain areas and are implemented to achieve conservation goals and provide scientists with a more accurate depiction of intact marine ecosystems (Gaines et al. 2010). When implemented properly, they have been shown to increase species abundance and diversity, reproductive output, total catch, and fishery profits (Alcala & Russ 2006; Sala et al. 2013; Hilborn 2004). These results, however, are dependent on enforcement, fishers' behavioral responses to closed fishing grounds, and the fishing regulations adjacent to the reserve (Gaines et al. 2010). Despite these limitations, marine reserves act as a buffer against the impacts of overfishing, and combining marine reserves with TURFs may help regulate fishing pressures outside the reserve.

TURFs & TURF-Reserves

By giving fishers a secure, long-term stake in their fishery, TURF programs incentivize stewardship and empower fishers to improve their livelihoods, and increase cooperation, monitoring, and enforcement among fishers (Castilla & Gelcich 2008; Sosa-Cordero et al. 2008; McCay et al. 2014). Increasingly, TURFs are being used in conjunction with no-take marine reserves ("TURF-Reserves"). TURF-Reserves combine conservation and fisheries management goals by allocating fishing rights to a clearly defined user group within a specific area and restricting critical areas from fishing pressures (Afflerbach et al. 2014). It is expected that this pairing allows fishers who have exclusive access to the TURF to benefit from spillover of fish stocks from reserves, further incentivizing cooperation. Although local fishing communities worry that closures may lead to a short-term economic loss, it has been found that the benefits of a marine reserve (tourism, ecosystem services, increased abundance) can outweigh the costs in as little as five years (Sala et al. 2013).

Global Distribution of TURFs

The implementation of TURFs and TURF-Reserves is widespread. DiscoverTURFs, a 2014 group project thesis group from University of California Santa Barbara's Bren School of Environmental Science & Management, identified 11,762 formal TURF systems in 41 countries (Auriemma et al. 2014). These figures, obtained through literature review, survey responses, and targeted online searches, actually underrepresent the actual number of global TURF systems. Currently, 11 countries are either developing TURFs or have yet to establish TURFs despite the existence of regulatory framework allowing them. Nevertheless, TURF systems are commonly employed to manage fisheries across the globe. Their presence spans 6 continents (Africa, Asia, Europe, North America, South America, and Oceania), with Japan, Chile, and Mexico managing the largest number of TURFs (976, 793, and 500+, respectively) (Auriemma et al. 2014). Afflerbach et al. identify 27 TURF-Reserve systems from 10 different countries, ranging in location from Brazil to Vanuatu, and provide the first systematic evaluation of these management regimes (2014).

Characteristics of TURF Success

No two TURFs are alike, and success factors vary by location (Costello 2012; Launio et al. 2009). There are, however, certain characteristics common to many successful TURFs, including a clearly defined user group, high enforceability, tenure, coordination among users, and the inclusion of low mobility species

(Pollnac et al, 2001; Launio et al., 2009; Wilen et al., 2012; Cinner et al. 2013; Auriemma et al. 2014). Gutierrez et al. (2013) identifies strong leadership, individual quotas, and protected areas as contributing factors of success of fisheries co-management. Spatial attributes, such as total area and the extent to which a TURF is enclosed by physical geographic boundaries, are also key factors that facilitate the success of managing a TURF and help fisheries meet their stated objectives. These factors allow for a clearer delineation of boundaries and aid in the monitoring of illegal fishing (McCay et al. 2014; Wilen et al. 2012). In limiting access to certain individuals, users assume responsibility for the health and profitability of the fishery and work together to meet their goals, and longer-term management plans allow for users to see the benefits of their actions through increased catch and profits. Incorporating local stakeholders, however, may be the most crucial factor when considering a marine spatial planning design and implementation processes (Launio et al. 2009; Johannes et al. 2008; Berkes et al. 2001).

There are many benefits to including local knowledge into the design of a TURF or TURF-Reserve. Scientific data for many small-scale fisheries is often sparse, making it difficult to determine reserve areas and TURF boundaries. Similarly, a lack of knowledge regarding community interactions and local customs can lead to ineffective design. In these cases, local knowledge is an important resource for management, and ignoring the fisher's ecological knowledge may put fishery resources at risk, or unnecessarily compromise the welfare of resource users (Johannes et al. 2008). Spatial distributions, seasonal variations of resources and human uses of the seascape, and local ecological knowledge are essential to achieving a broader and more diverse knowledge base (Gerhardinger 2009), and must be incorporated with scientific knowledge when considering any form of marine spatial planning (Rassweiler et al. 2014). Leópold et al. (2013) further prove the benefits of incorporating local ecological knowledge by producing realistic spatial representations of small-scale fisheries in New Caledonia only using interview survey results.

Local stakeholders need be engaged in the process from the start so that designs can be modified to reflect their needs (Alcala, 2006). Not only does this create structures based on cultural and local norms, which enhances the overall strength of community buy-in, it also increases cooperation and the likelihood of monitoring and enforcement (May, 2008). Similarly, community dialogue, engagement in leadership, and group work has been shown to be a strong enforcer toward sustainable cultural change (Arnold, 2010). In the context of TURF-Reserve designs, this is displayed in the creation of community groups in which local knowledge, practices, and expectations are gathered and discussed. Keeping communities and key stakeholders engaged in the discussion about potential changes in fisheries management will bolster a TURF-Reserve's potential success.

It can be expected that incorporating local ecological knowledge into the design process will help develop trust between community members and fisheries management decision makers. This may increase the likelihood of community buy-in, thereby enhancing the effectiveness of the TURF-Reserve in meeting the proposed goals.

MARINE SPATIAL PLANNING

As fishery managers and fishing communities around the world develop new TURFs, they need access to resources and tools to help them weigh trade-offs between design options, including key species to manage and the location of boundaries. The Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) and the Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security (CTI-CFF) offer guides for species identification and marine reserve planning. Environmental Defense Fund's (EDF) Catch Share Design Manual (Bonzon et al. 2013) and associated volumes on TURFs (Poon & Bonzon 2013) are the most comprehensive guides currently available to practitioners interested in designing and implementing TURFs. The manuals draw from theoretical literature and practical experiences with catch shares (including TURFs) around the world to provide step-by-step design guidance. Existing and ongoing research, particularly by University of California, Santa Barbara's Sustainable Fisheries Group (SFG), provides additional quantitative data that can be integrated with the best practices outlined in EDF's design manual. While there is a wealth of case studies, research, and design tools for no-take reserves and marine spatial planning, there remains a need for a tool that integrates TURF and reserve design considerations in the context of isolated near-shore fisheries.

The geographical and spatial configuration of a TURF and a TURF-Reserve system is crucial to ensure success in meeting the proposed social, economic and ecological goals. High natural variability in coastal ecosystems makes TURF-Reserve regions extremely heterogeneous in the way in which resources are distributed (Wilen, 2004). Due to this distribution, spatial variability should be considered for effective management of resources. In order to include this variability into planning, fisheries researchers have developed and implemented a series of technologies to account for both oceanographic patterns and biological aspects of the environment and the species that are to be managed (Leópold et al. 2014).

More often than not, small-scale fisheries lack appropriate information to conduct robust analysis like the one presented above (Johannes 1998; Leópold et al. 2014). Given this deficit of information, researchers are exploring alternative low-cost methods to effectively manage small-scale fisheries. Leópold et al. (2014) use local ecological knowledge of fishers to map fishing effort and catch size in four mangrove systems in New Caledonia. They use the ArcGIS platform to map information provided by fishers in an effort to understand the spatial processes of exploited fisheries dynamics. In the field of marine spatial planning, the translation of paper maps and verbal information into GIS databases to incorporate local ecological knowledge has become a common methodology (Aswani & Lauer 2006; Rassweiler et al. 2014; Scholz et al. 2003; Gerdhardinger et al. 2009). Vessel Monitoring Systems (VMS) used by large-scale commercial fisheries are also employed to help researchers gain a better understanding of fishing intensity, gear use, and the spatial and temporal distribution of fishing activity. Using this information, Campbell et al. (2014) models changes in fishing activity due to the implementation of marine reserves, showing that they may cause increased fishing effort in previously underfished areas, competition among fishers, and pressure on various habitats.

However, utilization of GIS and VMS tools requires significant technical skill and computing resources, and substantial monetary investments. A low-cost methodology to capitalize on fisher's ecological knowledge presents a powerful opportunity to tackle spatial modeling of TURF and TURF-Reserve systems in places that lack formal or traditional information. By spatially modeling TURF and TURF-Reserve systems, the outcomes of different geographical configurations can be assessed. Although incorporating local knowledge into a spatially differentiated bio-economic model is challenging, it could ensure important conservation and economic benefits.

For the specific case of small-scale coastal fisheries, Costello and Kaffine (2009) explore the effects of implementing marine reserves in a TURF-regulated system in Southern California using spatial modeling and analyzing ecological and economic outcomes. The study assesses the spatial variability of the system by dividing the coastal area into 48 hypothetical TURFs, each one with different habitat quality based on kelp cover. After accounting for larval dispersal, they calculate the percentage change in profit and biomass in each of the patches where a marine reserve was implemented. Using this method, the outcomes of different geographical configuration of a TURF and a TURF/Reserve system may be evaluated.

Fish Forever & The Philippines Context

Fish Forever, a partnership between EDF, SFG, and Rare, is currently working with Local Government Units (LGU) in the Philippines towards the establishment of TURF-Reserves (www.fishforever.org). The program has four (4) prototype sites in the Philippines in which it will first implement the TURF-Reserve design process. The program has partnered with relevant governance units, and has performed, or is in the process of performing, baseline assessments considering ecological and biological parameters, governance, and socio-economic conditions. Local fishery managers have conducted interviews with fishers and community members to provide key information in determining baseline assessments.

The Philippines is composed of 36,289km of coastline amongst 7,107 islands in the Coral Triangle. The Coral Triangle refers to the marine tropical waters between Indonesia, Malaysia, the Philippines, Papua New Guinea, Solomon Islands, and Timor-Leste, and it contains greater marine biodiversity than the Great Barrier Reef and the Caribbean in terms of reef species and hard coral species (World Bank 2005). The Philippines ranked among the top fish producing countries in 2003, reporting a total production of 2,169,164 tons divided approximately equally between the commercial and municipal sectors (FAO.org). However, 99% of fishers belong to the municipal sector, and approximately half of the over 100 million Philippine population lives on the coast (BFAR.da.gov), and is representative of the locations Fish Forever aims to improve. Near-shore resources of the Philippines are heavily exploited, and there is evidence of a declining catch per unit effort as far back as the 1960s (Green et al. 2003; FAO.org). Decreases in quality and changes in composition of species fished in the Philippines have also been observed (FAO.org).

Decrease in stocks and increase in population is an alarming trend, and in the next decade fisheries food deficits are expected to rise from 40% to 80% per capita in some regions of the Philippines (White & Cruz Trinidad 1998). In order to better manage these critical coastal resources, the Philippines is moving towards a coastal management planning system devolved to local governmental units (LGU). LGUs are considered at the city or municipal level, with barangays, or villages, as subcomponents. Under this system, municipalities control 15 km from the coast and the coastal zone 1 km inland. Fisheries management plans, including the potential creation and management of marine reserves, fall within the coastal management-planning jurisdiction (DENR, 2001).

Fish Forever is helping to engage local stakeholders in developing initial recommendations regarding TURF-Reserve design. This will be part of a series of fisheries management planning workshops and the formation of fisheries associations and/or cooperatives by local government agencies as needed. Finally, the TURF-Reserve will be designed with stakeholder input and put into legal ordinance. With lessons learned from the prototype, Fish Forever will scale up with 12 more sites in the Philippines chosen in the summer of 2014. In the other countries where Fish Forever plans to implement TURF-Reserves (Brazil, Indonesia, Mozambique, and Belize), a similar scaling strategy will be applied. Through proven results in these initial sites, Fish Forever is looking to generate demand for mass replication of their standardized, but customizable, model for TURF-Reserve design and implementation. This follows several 'theory of change' strategies such as that described by Malcolm Gladwell in *The Tipping Point* (Draft Fish Forever Partnership Strategy 2012).

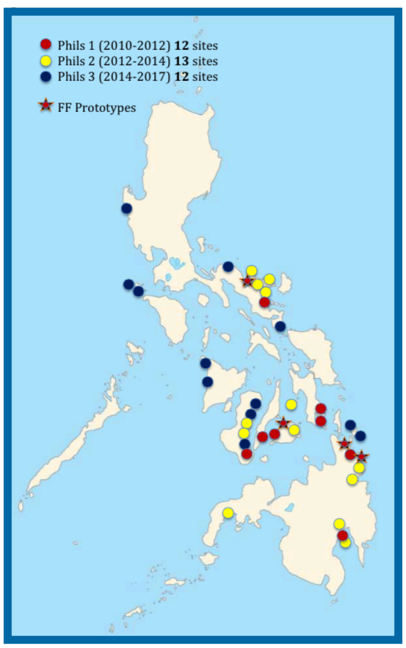

Figure 1. Fish Forever prototype and cohort sites in the Philippines (Rare 2015).

Fish Forever's Stakeholder Engagement Strategy

Effective biological conservation, such as sustainable long-term fisheries management, is a difficult process. Strategies to improve environmental management practices and conservation demand behavior change (Arnold 2010). The change can be achieved politically or economically, or through local management and education. Many of the most successful environmental management cases, however, have been due to cultural behavior changes (Butler et al. 2013). Overcoming ingrained cultural practices can be politically difficult, though if they are not incorporated into management practices, they can often result in non-compliance (Hamzah et al. 2013). Engaging stakeholders in decision-making processes and management decisions is an effective way to invoke behavior change.

Behavior change is characterized as understanding people, their choices, and the motivation of a given stakeholder group to make a change (Butler et al. 2013; Balmford 2006; Ehrlich & Kennedy 2005), and Fish Forever's Pride Campaigns are centered around the theory that conservation has a strong foothold in "non-rational" human psychology (Sekera et al. 2012). Within each community, the Fish Forever project benefits from the expertise of Rare in 'social marketing' Pride Campaigns, as well as Rare's strategy to engage stakeholders emotionally and intellectually in the design process of their local system (Figure 1).

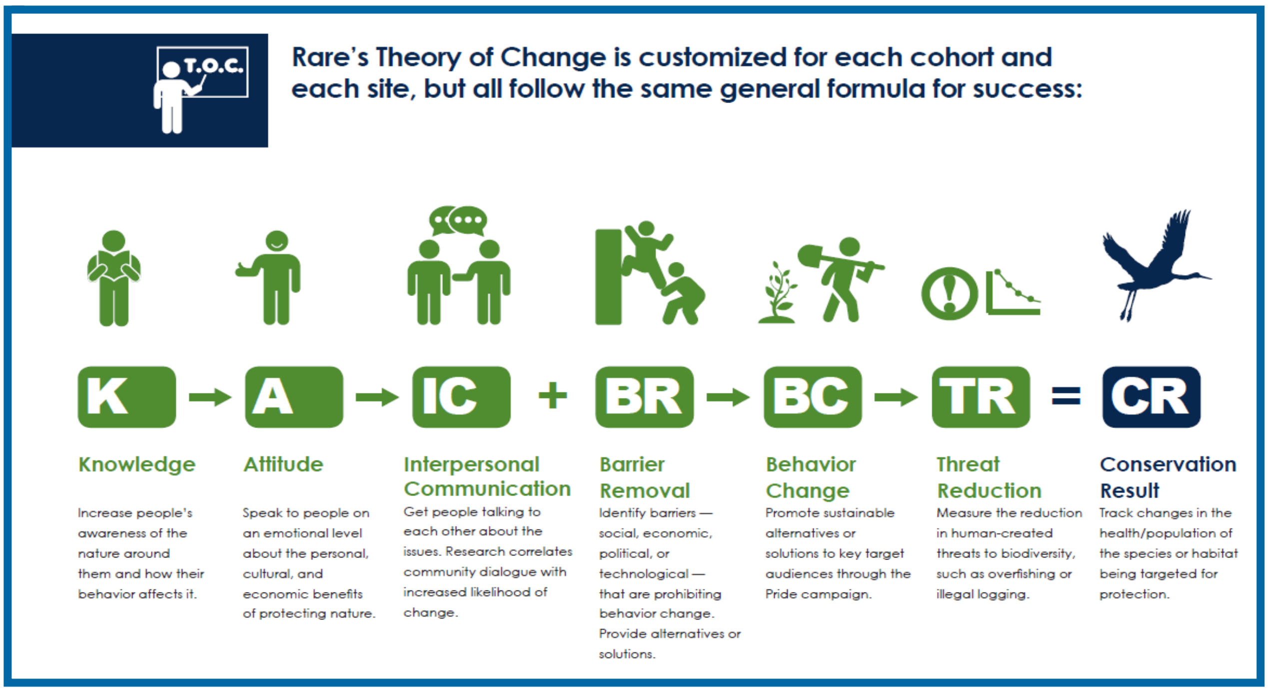

Figure 2. Rare's Theory of Change. (Draft Fish Forever Partnership Strategy 2012).

A critical component of this process is 'Barrier Removal,' which in the case of TURFs relates to a lack of technical capacity for fisheries management. The TURF-Reserve design tool addresses this technical capacity and behavior change barrier by providing an accessible modeling platform and effective communication structure for a non-technical audience.

Technology and Communications

To help determine the appropriate technological medium, we analyzed the impact of various technologies on fishery management. Potential objectives at the beginning of the project included developing a web-based communication tool to aid in TURF-Reserve design. In order to create a tool for the broader Fish Forever context, and based on literature review and conversations with Fish Forever partners, we conclude that a TURF-Reserve design tool is most effective as a Microsoft Excel based instrument due to the program's adaptability, limited technological expertise barriers, and current use at prototype sites. Future iterations may trend towards a web-based tool. Technology-based behavior change and adoption methods are outside the scope of this paper and will be implemented by Rare. Instead, we focus on the tool's manual use process of the tool by a trained site coordinator. Our literature review addresses these topics so that the reader can understand the complexities of various technologically based alternatives in the future.

Success factors of technology-based behavior change models in developing countries have primarily been studied in the areas of public health and online education systems; fewer have been conducted on technology usage and spatial design (Noell and Glasgow 1999; Long and Spurlock 2008; Pitt et al. 2011). The means by which stakeholder input is gathered into a modeling tool in marine spatial planning and/or fisheries management varies widely, including maps transposed to ArcGIS software or direct user model interaction through sophisticated tools such as SeaSketch (http://www.seasketch.org/). Given the isolated and developing-world status of many prospective TURF-Reserve sites, an appropriate technology platform for the design tool is critical in terms of feasibility and effectiveness. If found to be feasible, a high tech platform, such as a mobile app, may have increased benefits in interactivity, accuracy, and computing power; however, lack of familiarity and local resistance to technology adoption are potential threats to this model.

Despite growing technology in developing countries, there has been documented resistance to adopting new technologies. A recent case study in Malaysia examines local fisher's incorporation of new technologies, including GPS, echo sounders, and cell phones, all of which are shown to increase catch and decrease effort. With the exception of the mobile phone, however, technology is not embraced, and traditional fishing methods are still relied upon. Technology adoption in Malaysia is related to knowledge, experience/tradition, and age (Hamzah et al. 2013). Especially in small villages where knowledge networks are limited, new technologies often require specialized literacy and knowledge that is not incorporated into the community. Prior experience is also shown to influence attitude and behavior. If the technological learning process is not incorporated into direct fisher's experience, the technology is less likely to be adopted. Lastly, older and more experienced fishers are less inclined to incorporate non-traditional fishing methods (Hamzah et al. 2013). Knowing the limitations to technology adoption in Malaysia could help overcome technological resistance elsewhere if implemented strategically. Furthermore, studies in health care show that new technology has greater success when incorporated into a decision support framework, instead of implemented alone (Nell and Glasgow, 1999).

OBJECTIVES

The goal of this project is to develop a tool that assists small-scale fishing communities design potential TURFs and associated marine reserves given the available technology and local biological, governance, and socio-economic data such as targeted species, fishing behavior and controls, and habitat characteristics. As fishery managers and fishing communities around the world develop new TURF-Reserves, they need access to resources and tools to help them weigh trade-offs between design options. While a wealth of scientific information and marine spatial planning tools exists, many near-shore artisanal fisheries are located in isolated areas and/or developing nations where access to scientific data is limited and the use of highly technological spatial planning tools is not feasible.

The TURF-Reserve design tool will be integrated into a communication strategy used for TURF-Reserve design, specifically the Fish-Forever stakeholder-inclusive design process in the Philippines. The tool supports effective fishery management by providing a simple framework for fishers, fishery managers, scientists, and other stakeholders to define TURF-Reserve boundaries. The tool can be customized beyond the Fish Forever Philippines TURF-Reserve sites so that it can be applied to other TURF-Reserve design programs internationally. Figure 3 shows a general outline of the steps taken to run the TURF-Reserve design tool.

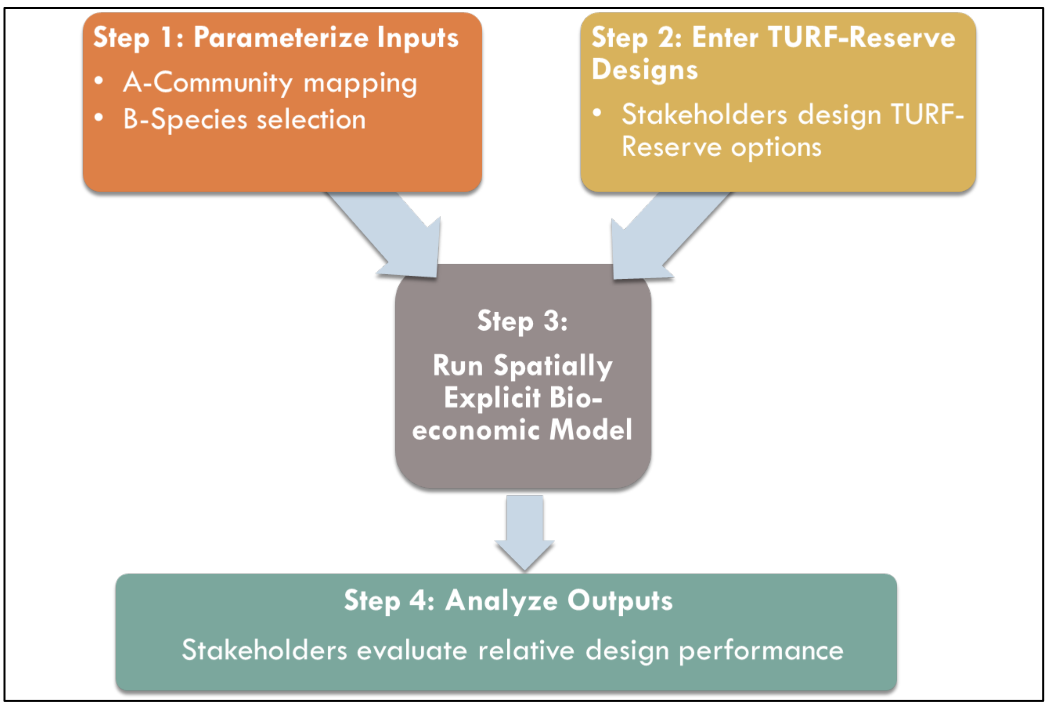

Figure 3. Conceptual framework of TURF-Reserve design tool process.

TECHNICAL APPROACH

In order to provide EDF and Fish Forever with a decision-making framework for TURF-Reserve design, we construct a TURF-Reserve design tool (TURFtools) that incorporates both best available scientific data and local stakeholder knowledge. The model compares tradeoffs of different design and management scenarios, projecting various ecological and socio-economic scenarios. The model does not provide a particular stand-alone outcome for a certain species of TURF-Reserve, but rather compares various designs relative to one another. Although developed in the context of the Philippines, the tool is easily adaptable to allow for implementation in other TURF-Reserve design projects.

In addition to the design tool, we have created an accompanying user guide for site managers. The step-by-step user guide outlines how to spatially map and characterize an area, select target species, design TURF-Reserve options, and manually change information to more accurately reflect local knowledge. Both end products have been reviewed and altered based on feedback from EDF, SFG, Rare working groups, and Fish Forever site managers.

TURFtools was designed within Fish Forever's framework, or "toolbox", of other TURF-Reserve tools. These tools include guidance for species selection, TURF-Reserve design, as well as fisheries management and assessment tool for these areas. The tools can be used individually, or together, as is seen appropriate for each site.

The following section describes the equations, inputs, model interface, and outputs associated with the TURF-Reserve design tool.

THE MODEL

TURFtools weighs different design and management options to facilitate a decision-making framework for TURF-Reserve design and specifically the Fish Forever program in the Philippines. The model collects critical inputs and test designs resulting from various stakeholder-involvement processes.

To create TURFtools, we utilize global databases for species-specific information, TURF-Reserve modeling components leveraging published literature and models under development within the Sustainable Fisheries Group, and site-specific data as collected in the Philippines Fish Forever sites. This approach allows us to balance scientific accuracy and complexity with field data feasibility. The model permits manipulation of biological, economic, spatial, and other pertinent inputs to produce graphical outcomes to evaluate design decisions. The decision to use preset data found in global databases versus local environmental knowledge depends on the feasibility and accuracy of local data available.

THE EQUATIONS

We use a logistic growth model to simulate population dynamics, which is run independently for each patch within the matrix. Age-structure models require more complete data sets and prove useful when harvest policies are based on size limits, both of which are not present in the Philippines case (age-structure models also require software programs more advanced than Microsoft Excel). The matrix is a 10x10 grid (100 patches total) that is used to spatially represent the design site. Within each patch, the site manager chooses an Open Access, TURF, or Reserve management regime based on the TURF-Reserve design options derived from local input. Each management regime is associated with a unique set of equations that incorporate the values associated with habitat characterizations and "Areas of Interest" (See 'Inputs' section for further explanation).

Input parameters for each species are differentiated based on habitat use, reflected in the model as carrying capacity by habitat. As model is not age structured, and there is no differentiation between larval and adult dynamics. There is also no consideration of species or habitat interactions in this model. Patches interact through dispersal, however, and growth and harvest dynamics are determined through habitat characterization and fishing policy. We maintain a simple population model in order to decrease the data input demands. The general equations describing these dynamics, and an explanation of the notation, are explained below.

Common Notation for Model Equations

$N_{i,j,t}$ = Initial stock in patch (i) for species (j) at time (t)

$H_{i,j,t}$ = Legal harvest in patch (i) for species (j) at time (t)

$IH_{i,j,t}$ = Illegal harvest in patch (i) for species (j) at time (t)

$S_{i,j,t}$ = Settlement after growth in patch (i) for species (j) at time (t)

j_x = Stock status of species (j) in habitat X

$k_{x,j}$ = Carrying capacity of habitat (x) for species (j)

$f_{[OA,SQ,TU,RE]}$ = Fishing policy in a designated management regime

C_j = Cost per unit of harvest for species (j)

P_j = Price per unit of harvest for species (j)

q_j = Catchability coefficient for species (j)

$\sum_i^p N_{t0,i\ldots p}$ = Total stock size in all patches at time (t=0)

p = Number of patches

T = Time horizon

ρ^t = Discounting factor

$\pi_{j,t}$ = Total profits from species (j) in time (t)

θ = Open Access dynamic constant

IF_j = Illegal fishing constant for species (j)

$N_{i,j,bg}$ = Stock status in patch (i) for species (j) before growth

$G_{i,j,t}$ = Growth in patch (i) for species (j) at time (t)

r_j = Intrinsic growth rate for species (j)

$GD_{Pi,i}$ = Gaussian probability distribution of an individual starting in patch (Pi) and moving to patch (i)

I. General Dynamic Equation for Patch *i*

The general dynamic equation is calculated for each patch and represents the basic interactions occurring.

$$N_{i,j,t} = N_{i,j,t} - H_{i,j,t} - IH_{i,j,t} + S_{i,j,t}$$

Each component of the equation is expanded below.

II. Initial Stock: $N_{i,j,t}$

The initial stock (*t=0*) in patch (*i*) is determined by the stock status of species in habitat (*X*) and the carrying capacity for that species, so that:

$$N_{i,j,t=0} = N_{i,j,t=0} * K_{i,j}$$

For *t > 0*, the initial stock of the period is given by the preceding stock in the general dynamic equation (t+1, t+2, etc.).

III. Legal Harvest: $H_{i,j,t,}$

Legal harvest levels depend on whether the patch is designated as Open Access, TURF, or Reserve, and is determined as follows:

A.) Legal Harvest Policies

The following legal harvest policies are used to calculate the fishing mortality rate in each patch type.

i.) Open Access (OA) equilibrium:

$$f_{OA} = 1 - \frac{c_j}{p_j * \sum_i^p N_{i,j,t} * q_j}$$

There is no single fishing policy for Open Access patches, and this policy lies on a spectrum between harvesting all settlement from the previous year (Status Quo assumption) and Open Access equilibrium where total profits of the fishery equals 0 (represented by a theta parameter (θ)). This spectrum is intended to provide a range of fishing policies that better represent the actual state of the fishing effort. In order to determine the appropriate policy, the site manager responsible for data entry will choose θ based on local knowledge of the status of the fishery.

ii.) Status quo (SQ):

$$f_{SQ} = S_{i,j,t-1}$$

SQ represents status quo where the stock is maintained in those patches by harvesting the settlement from the previous year.

iii.) TURF (TU):

$$f_{TU} = max_f \sum_{t}^{T} \rho^t * \pi_{j,t}(f)$$

This fishing policy represents optimal fishing mortality in the TURF by maximizing NPV in the system.

iv.) Reserve (RE):

$$f_{RE} = 0$$

By definition, fishing is not allowed within a Reserve. Therefore, the fishing policy equals 0.

B.) Legal Harvest Levels

Legal harvest levels represent how legal harvest policies are applied on an annual basis.

i.) Open Access (OA) patches:

$$H_{i,j,t} = N_{i,j,t} * f_{SQ,j}(1-\theta) + N_{i,j,t} * f_{OA,j}(\theta)$$

ii.) TURF (TU) patches:

$$H_{i,j,t} = f_{TU,j} * N_{i,j,t}$$

iii.) Reserve (RE) patches:

$$H_{i,j,t} = f_{RE,j} * N_{i,j,t}$$

IV. Illegal Harvest: $\boldsymbol{IH_{i,j,t}}$

Illegal harvest levels depend on whether the patch is designated as Open Access, TURF, or Reserve. For TURF and Reserve patches, the illegal harvest is a percentage of the optimal fishing policy. For Open Access patches, it is a fraction of the Status Quo fishing mortality.

A.) Illegal Harvest Policies

i.) Open Access (OA) patches:

$$IH_{i,j,t} = f_{SQ} * IF_j * N_{i,j,t}$$

ii.) TURF (TU) patches:

$$IH_{i,j,t} = f_{TU} * IF_j * N_{i,j,t}$$

iii.) Reserve (RE) patches:

$$IH_{i,j,t} = f_{TU} * IF_j * N_{i,j,t}$$

V. Settlement: $S_{i,j,t}$

The stock that settles in each patch is determined by the growth in each patch and the spatial movement of individuals.

A.) Stock Before Growth (bg):

$$N_{i,j,bg} = N_{i,j,t} - H_{i,j,t} - IH_{i,j,t}$$

B.) Growth (G):

$$G_{i,j,t} = N_{i,j,bg} * r_j(1 - \frac{N_{i,j,bg}}{K_{X,j}})$$

The spatial movement of individuals is determined by a Gaussian probability distribution ($GD_{p_i,i}$). This is defined as the probability than an individual starting in the center of a patch (p_i) will move into any part of a given patch (*i*). This depends on both the distance between patches and the home range of the target species.

$$GD_{Pi,i} = Fraction\ of\ individuals\ that\ disperse\ from\ patch\ (Pi) to\ patch\ (i)$$

Assuming a closed system, Ret represents the fraction of the growth that would have traveled out of the design area.

$$Ret = 1 - \sum GD_{pi,i}$$

This fraction is summed and distributed back into the system equally across all patches. We assume that the net amount of fishes that leave the system equals the amount that comes in because we have no information regarding whether these sites are sinks or sources of stock. Therefore, assuming that the net change is zero is the most precautionary way to proceed.

$$S_{i,j,t} = \sum_i^P G_{i,j,t} * GD_{Pi,i} + G_{i,j,t} * (\frac{r_j}{P})$$

VI. Discounted Profits

Profits are only considered from legal harvest in TURF and Open Access patches as illegal harvest is assume to be performed by fishermen outside of the community. Therefore, profits in time t are:

$$\pi(H_i) = P_j \sum_i^p H_{i \ldots P,j,t} - (\frac{c_j \sum_i^p H_{i,j,t}}{q_j \sum_i^p N_{i,j,t}})$$

Net Present Value (NPV) for *T* years is:

$$NPV = \sum_{t=0}^{T} \rho^t * \pi_{t,j}$$

The Inputs

This section describes the inputs used in the TURF-Reserve design tool. Our model is designed to facilitate use in poor data environments and uses primarily qualitative prompts for spatial and species-specific information. This information is then translated into quantitative parameters based on information found via literature review. In order to make the TURF-Reserve design tool adaptable to a specific location, a trained model user can manipulate parameterized values to improve the accuracy of inputs when more precise data becomes available. Non-model parameters, such as the percentage of spawning areas covered or group-specific fishing areas for multiple communities within the design area, are also incorporated into the mapping process. As these are subject to change based on the needs of the community, they are not included in the discussion below.

Input Data Sources

The spatial, bio-economic, and social data needed for TURFtools can be collected through both community surveying and scientific literature review. The tool's assumed best available local data is based on the pre-existing community surveying in the Philippines, known as the Participatory Coastal Resource Assessment (PCRA). These surveys conduct spatial mapping exercises, habitat assessments, fisheries trend diagrams, and community surveying of social and economic demographics (PCRA 2013). The PCRA has been adapted by Fish Forever and tailored into a more targeted *TURF-Reserve Design Survey,* which conducts community-based surveying to collect data specific for the TURF-Reserve design process.

Data not available through community surveying was obtained through literature review of scientific papers conducted in the region, from scientific studies at nearby universities, papers, censuses, and additional community surveying.

Biological data includes:

- Home range
- Intrinsic growth rate
- Overall stock status of the target species
- Habitat use

Social and economic information includes:

- Price of target species

- Cost of fishing
- Qualitative estimate of illegal fishing relative to current management policy
- Primary type of fishing gear used to catch target species

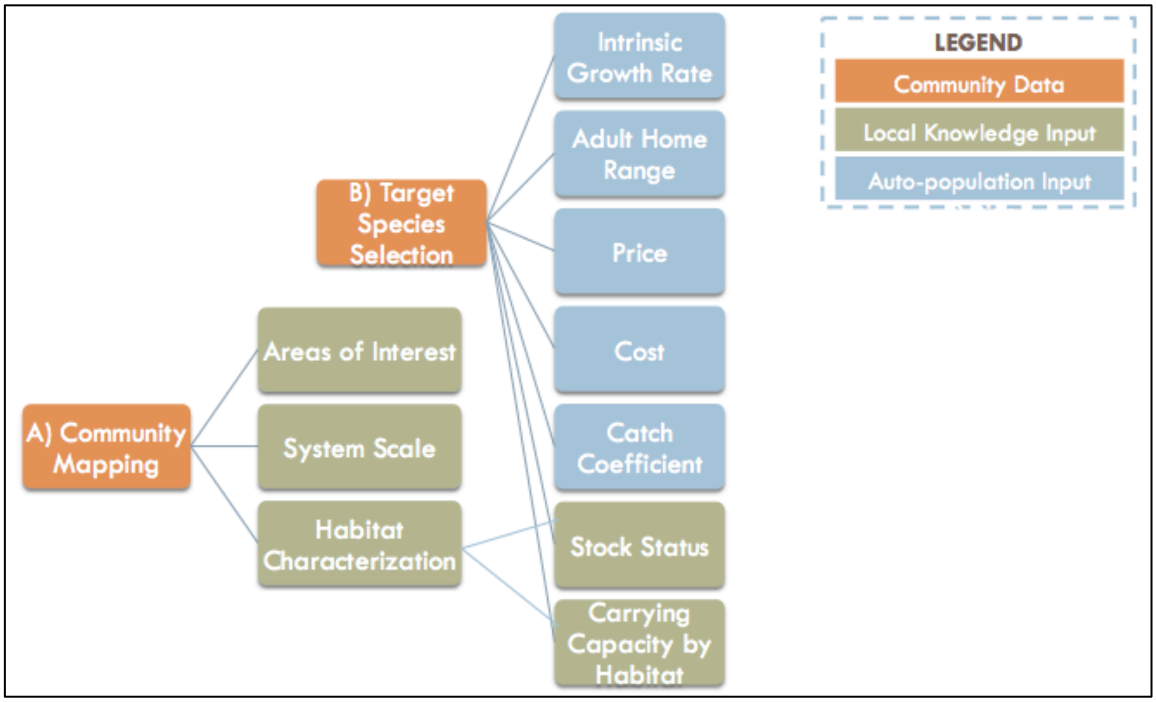

Figure 4. Input parameterization schemative. Colors represent the data source utilized to obtain relevant information.

Figure 4 shows the varying inputs necessary for the tool and their sources. Users will be guided through the input parameterization process through an extensive user manual and corresponding model interface that prompts for local knowledge based on key community data collection activities. Life history and economic databases supplement local inputs by auto-populating information where available. However, any auto-populated input may be manually corrected when local data is available.

I. Habitat

In our model, habitat type and quality are used to determine the carrying capacity and stock status for each individual patch. Each individual habitat type is associated with a distinct stock status and carrying capacity (explanation below). This simplifies the spatial differentiation of inputs by permitting users to generate a spatially explicit biological profile for each species by determining input values for 12 habitats instead of per 100 patches. Local stakeholders (fishers, community members, fishery managers) will map the varying habitat types of the fishing grounds during the TURF-Reserve Design Survey process. Therefore, basing inputs from habitat mapping provide a spatial frame of reference for users to consider species-specific dynamics.

A.) Habitat Type

Our model includes 12 varying habitat based on the Philippines context. The TURF-Reserve design model is designed to allow fishery managers to redefine critical habitat types for a site's target species in both the Philippines and on a global scale. Any habitat considered not productive for a given species is assigned a carrying capacity of zero, therefore unproductive habitats will have zero population and zero growth. The habitats are as follows: "Mangrove", "Seagrass", "Estuary", "Rocky Shoreline", "Mudflats/Sand", "Pass/Channel/Deep Ocean", "Coral Reef", "Land", "Mariculture", "Degraded Coral Reef", "Degraded Mangrove", and "Other".

TURFtools' pre-populated habitat type selection draws largely from the PCRA (2013) and is bolstered from our literature review. Studies conducted by Honda et al. (2013) and Palomares et al. (2010) stress the importance of coral reef, seagrass, and mangrove habitats and fish populations' use of multiple habitats within a location. Members of the EDF and Fish Forever teams confirmed our chosen habitat types, and, while fewer designations could have been chosen, including a wide array of habitat types allows for less modification to the model when applying it to Fish Forever sites around the world.

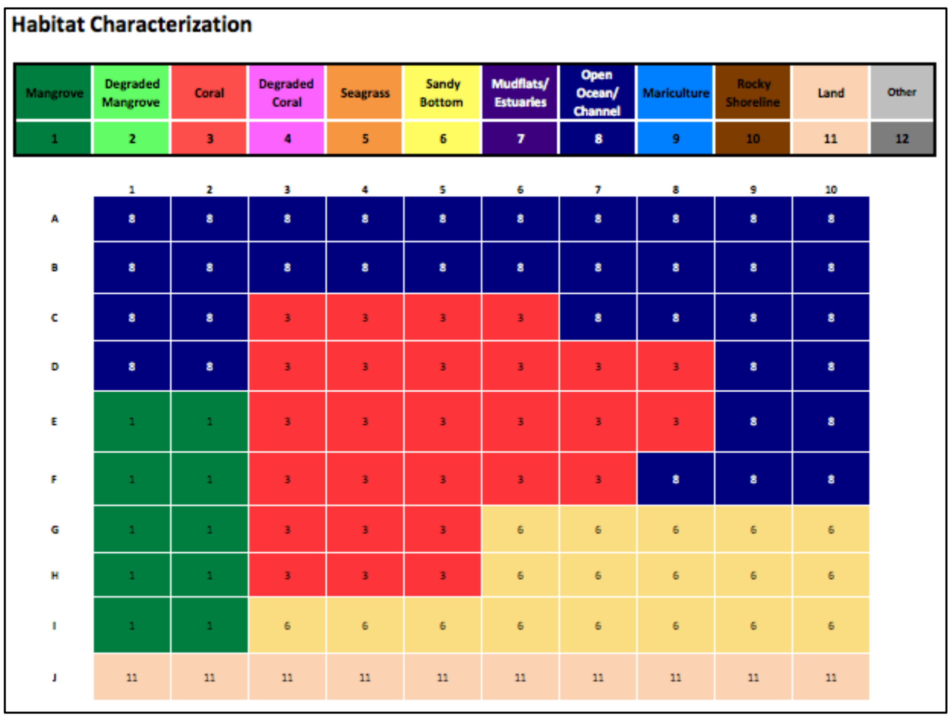

Figure 5. Screenshot of example habitat characterization in TURFtools. Each habitat type is assigned a unique color, and colors will autofill once user defines a patch.

B.) Habitat Quality

The overall quality of a habitat plays a large role in a species' use and productivity. Foley et al. modeled the bio-economic impacts of habitat quality, finding that habitat quality affects the carrying capacity and intrinsic growth of a species. This also impacts total profits, as poor habitats are less productive, which increases total costs and increases fishing costs (2011). To address decreased productivity in degraded habitat areas, we include designations for "Degraded Coral Reef" and "Degraded Mangrove" rather than have users create another visual representation of the targeted area. As mentioned above, users are able to alter the habitat types and can therefore assign other "degraded" habitat types as needed.

Berglund (2012) argues that connectivity, rather than habitat quality, may have a greater impact on the optimal selection of reserves. However, a tool is being developed within the Fish Forever framework to help community members design effective marine reserves. This tool provides more detail on reserve siting, and, when used with TURFtools, the two will complement each other in the design process. An alternative option is to ignore habitat type and quality altogether and allow users to directly identify productivity and use metrics by patch (stock status, carrying capacity, nursery grounds, spawning grounds, etc.). This process, however, would be extremely time intensive and would require a unique input for each individual patch. TURFtools allows for simpler characterization based on an easily understood spatial reference (habitat) and better utilizes community-mapping efforts embedded in the TURF-Reserve Design Survey process.

II. Species Stock Status per Habitat

In order to arrive at our estimate for initial stock status, we utilize both the categorical carrying capacity of a given habitat and the perceived stock status relative to a pristine stock for that given habitat:

$$N_0 = S \times K$$

where S is the estimated stock status determined via user input, K is carrying capacity, and N_0 is the initial stock.

Users are prompted to choose a qualitative stock status for each habitat type from the following descriptors: Pristine, High, Near Average, Low, and Depleted. Each descriptor is assigned a value ranging from 0.0 – 1.0 as follows: Pristine = 1.0, High = 0.8, Near Average = 0.4, Low = 0.2, and Depleted = 0.1. These categories mirror the qualitative categories used by the Australian government to evaluate their fisheries (2002) and reflect the stock status relative to a pristine condition. We apply numerical values to each qualitative category; however, a fishery manager trained in the use of the model can alter these values.

Due to the data-limited nature of small-scale fisheries in the Philippines, the initial stock status will be uncertain. This information may be more accurately extrapolated through a number of methods and sources, including underwater density surveys and landings data. However, underwater density surveys are not species-specific and landings data is often unreliable or unavailable in this applied context. Fishing Industries' Support in Handling Decision Applications, or FISH-DA (n.d.), a Philippines-specific fisheries management tool, reports baseline quantities that may be used when no data is available, but the data is represented in MT/km^2 and only differentiates between demersal and pelagic species types. Lastly, the TURF-Reserve Design Survey and/or PCRA data may be used as a complement, but it currently does not inquire about species-specific or habitat-specific trends. Our current parameterization allows for even the most data-poor communities to utilize the TURF-Reserve design tool and any additional data present at the site can be utilized to adjust stock status value. We also conduct a sensitivity analysis to analyze the range of output values given based on various initial stock sizes. This analysis is expanded on in the "Discussion" section.

III. Species Carrying Capacity based on Habitat

In conjunction with a user-chosen stock level, carrying capacity (*K*) is also used to estimate the initial stock level for each habitat (equation above). Carrying capacity is also a variable in the annual growth equation used in the model. In order to determine a given carrying capacity value, users are given a prompt to determine a species' habitat use.

For each given habitat, users select the relationship between the species and the corresponding habitat. Each habitat use is assigned a value, ranging from 0.0 – 1.0 as follows: Adult Primary = 1.0, Secondary High = 0.8, Secondary Low = 0.5, Transient/Low Density = 0.2, and Not Present = 0.1. This allows for spatial differentiation between relative carrying capacities in the TURF-Reserve design area. Using a maximum value of 1.0 across all species implies uniformity in growth and maximum density between species that is unrealistic. To improve the accuracy of parameterization in the future, conducting biomass surveys on a per-species basis both inside and outside an established marine reserve may yield more accurate information regarding virgin stock levels and carrying capacity. Currently, biomass surveys are executed on a multi-species basis and with inconsistent frequency in the Philippines.

Determining initial stock in this manner does not allow for spatial consideration and may misrepresent situations in which a species is found in one area but not in another (ex. Species A is present on one coral reef but not on another within the TURF-Reserve). The realities of community mapping and manual data entry, however, makes precise spatial mapping more difficult. We partially account for this difficulty by providing an option to treat degraded habitats as a distinct habitat category.

This method also negates habitat interaction impacts on carrying capacity. In the case of essential habitats, the availability of the complementary habitat is pivotal to the performance of a species in another habitat. An example of this is found in the use of mangroves as nursery grounds for species that are found primarily on coral reefs as adults. If mangroves are destroyed, this may impact stock growth potential on a nearby coral reef (Foley et al. 2011; Mumby et al. 2004). This habitat interaction has potential implications for the carrying capacity designated per patch, but it adds a significant layer of complexity to the model parameterization. Given the single habitat-wide parameterization structure of the model and the assumption of static habitat quality over 20 years, inclusion of complementary habitat interaction would overcomplicate our model unnecessarily.

IV. Growth Rate

The intrinsic growth rate represents the maximum rate at which a population grows under ideal conditions. This input is of vital importance in determining the rate at which a fish stock can be harvested sustainably. A literature review of relevant species and their growth rates yielded few results, as most species-specific life history data utilize an age-structure model that neglects the intrinsic growth rate parameter. Researchers from the SFG, however, have just recently compiled intrinsic growth information for a host of global fish species. To arrive at these values, SFG uses data and the Catch-MSY

Method outlined by Martell & Froese (2013). These data are cross-referenced with previously collected home range information and include all species for which growth rate data were available (growth rates range from 0.0 – 1.3). Once a user identifies a target species, the corresponding growth rate will auto-populate. If no growth rate is identified, the user is asked to choose a similar species to estimate this input parameter.

To determine the intrinsic growth rate for a species, the Catch-MSY (Maximum Sustainable Yield) data rely on global catch data. Although growth rate values may not be universal, this method provides a reasonable value for population projections that differentiates between slow, medium, and fast-growth species. This also offers Fish Forever relatively accurate information that can be applied to multiple project sites. We considered mirroring Patrick et al.'s Productivity Susceptibility Analysis (PSA) (2009) which separates growth rates into low, medium, and high categories, but this leads to less differentiation among specific fish species. Even with the categorization, we would be forced to parameterize growth rates for each category.

As mentioned above, the Catch-MSY method relies on global catch data, and therefore may not accurately reflect a species' growth rate for a particular locale (variation may exist across similar species in different locations). To improve upon the work done by SFG, local catch data could be integrated into the Catch-MSY method if sufficient catch records are collected.

V. Dispersal

Dispersal is used in the model to determine the "spillover" effect in a defined area. The model extrapolates home ranges to categorized values ranging between 1,000-50,000 meters based on our literature review. The size of the home range determines the proportion of how much growth of a given stock remains nearby versus disperses far away. A smaller home range relative to the scale of the systems implies that more growth will be maintained in or near a given patch.

To determine these values, we rely on life history parameter data from Green et al. (2014) and species-specific information compiled by the SFG (2014). The local dynamics of dispersal and adult home range numbers from the literature review are not perfectly accurate, however, and they can range within a family and across locations significantly. Specifically, site fidelity differs among species and larval dispersal is commonly measured in days, and therefore cannot be accurately converted to meters with without knowing specific oceanographic measurements (current speed, water movement, etc.). In using adult home range, we are able to include a greater quantity of species for our model. Adult home range information, measured in linear meters, is useful in determining the size of a TURF-Reserve depending on the prioritized species (Green et al. 2014). Incorporating local knowledge into the model provides greater accuracy and should be used when the information is available.

VI. Price and Cost

In order to determine discounted profits over the life of the TURF-Reserve, the model uses Philippine pesos per unit of harvest (kg) for both price and cost. These parameters are obtained through the PCRA (2013) and Bio Os Marine Sanctuaries Pride Campaign Management Plan (2011). A trained model user is able to alter both price and cost to accurately reflect market pricing. For any species not listed, the user should select a similar species of fish from a drop down list for which data is available.

In many instances, the gear type used affects price, and fishers do not rely solely on one gear type, but rather incorporate various methods to harvest fish. To account for this variability, we set an average price for each species based on our literature review. Gear-based pricing can be included in future iterations of the model to improve price accuracy.

The main costs to fishers are a function of the effort used per trip. Costs vary across fisheries and regions, and data regarding the number of trips and time-related costs were not available, therefore we only considered the cost of fueling the boat. Based on information from the Bio Os Marine Sanctuaries Pride Campaign Management Plan (2011), we fix this cost at 300 Philippine pesos per trip. When available, local knowledge obtained from fishers should be incorporated into total costs to provide a more accurate representation of an individual fishery.

VII. Catchability Coefficient

Catchability is the relationship between catch rate and stock size. The catchability coefficient, therefore, is the number of fish caught per unit of effort and is most commonly calculated using both effort and biomass. It is commonly used as a proxy for the efficiency of a particular fishery. Due to the lack of available data, however, we use gear type and catch per unit effort (CPUE) obtained from the PCRA to calculate a proportional amount of catch for each gear type. To do this, we set “Drift Longline” as the most efficient gear, and divide the CPUE (total kg/trip) for each gear type into the “Drift Longline” CPUE. “Tuna Longline” was excluded from the list due to the high home range of the species and its scarcity within most municipal fisheries. To determine this input, users are asked to identify the fishing gear type used via a drop-down menu, which then auto-populates into the model. The gear types and their corresponding catch coefficient are shown in Table 4.

Mean CPUE of Common Gear Types	
Gear	**Proportional CPUE**
Drift Longline	100.000
Bottomsete Gillnet	50.122
Drift Gillnet	95.265
Spear Fishing	29.224
Bottomset Longline	58.204
Fish Corral	42.449
Single Handline	28.000
Octopus Jig	36.327
Multiple Handlines	20.408

Table 1. Average estimates of CPUE of fishing gear used by fishers in Cantilan, Surigao del Sur. Gear types were determined from the PCRA (2013).

As catchability helps assess the efficiency of a particular fishery, the catchability coefficient can be improved by incorporating more detailed information regarding the specific fishery. Information regarding the behavior of fish species towards different gear types, the seasonality of harvest, the number of users per gear type, the number of fishers per trip, and the experience of the fishers would improve the accuracy of the catchability coefficient.

VII. Illegal Harvest

Illegal harvest represents the total percentage of catch that is obtained through illegal, unreported, and unregulated fishing activities. This includes international and domestic fleets contravening laws regarding total catch amounts, gear types, spatial restrictions, or seasonal restrictions, as well as misreporting or not reporting accurate catch data. Factors that affect illegal fishing include capability of enforcement (both actual and perceived), general awareness of laws, the perceived level of compliance among all actors, and community involvement in the development of fishing rules and regulations.

Due to the nature of the illegal, unreported, and unregulated fishing, it is very difficult to gain accurate estimates that reflect the total percentage of catch derived from these activities. Due to a lack of credible data and the challenges with measuring fishing activity in the high seas, illegal fishing numbers vary widely: 19% of total catch in sub-Saharan Africa (MRAG 2005), 25-30% of global catch (Pauley & McClean 2003), and 8-16% of total catch in the Asia-Pacific region (Palma et al. 2010).

To determine illegal fishing in the context of a TURF-Reserve design, we use a regional constant as our baseline extrapolated from the PCRA. The illegal fishing constant can range from 0.0 – 1.0, and is categorized as follows:

High	Medium-High	Medium	Medium-Low	Low
0.5 - 0.6	0.4 - 0.5	0.4	0.4 - 0.2	0.2 - 0.1

Table 2. Illegal fishing parameterization and their corresponding values.

While it is unlikely that illegal catch accounts for more than 60% of total catch, users can adjust these amounts to reflect information obtained from survey responses and interviews with local fishers.

VIII. Open Access Dynamics (Theta Value)

This input parameter determines the dynamics in the open access areas of designs, or areas that will not be managed as TURFs or Reserves. On one end of the spectrum, an open access area may be in a steady state where stock levels are relatively constant. On the other end of the spectrum, fishing pressure may be increasing and moving towards open access equilibrium (where effort increases until profits equal zero). We use the variable theta (θ), ranging from 0-1 to determine where on the spectrum a target fishery resides. If theta is set at zero, the fishery remains in status quo and stocks in the open access patches remain constant at year 1 levels. If theta is set at 1, the fishing mortality in open access areas will be set so that profits equal zero. At a theta of 0.5, for example, open access harvest will be midway between status quo harvest and open access harvest levels.

In order to help model users determine where along the spectrum the target fishery is situated, the user guide identifies several potential data sources that may serve as an indicator. The TURF-Reserve Design Survey and PCRA include a trend diagram section, where site managers may ask community members to chart the trend of time spent on the water or landings for example. In some locations, historical landings data may also be available. If such data is available on a species-specific level, trends may help a site manager determine whether fishing pressure or catch per unit effort is increasing and/or stocks are declining. These results would imply that a higher theta value is appropriate.

Additionally, there are resources that evaluate the intrinsic vulnerability of species to overfishing. The PSA is a resource available to site managers that uses indicators of productivity and susceptibility to determine overall species vulnerability to overfishing. Finally, Fishbase (http://www.fishbase.org) provides a vulnerability and resilience score for many species that may also be used to determine whether a species is likely to be overfished to open access equilibrium. The combination of a highly vulnerable or low resilience species and increasing fishing pressure (as indicated by trend analysis) would suggest that theta should be close or at 1.0.

The Interface

The model interface is designed to achieve "pervasive usability" as described by Fabio Paterno, so that model users can interact with the interface regardless of circumstances, even in varying environments (2005). We identify the appropriate interface design through an adaptive interface testing process loosely based on Paterno's "basic concepts" of design.

1) *Identify goals of the model*—TURFtools is designed to be a decision support framework for the relative comparison of various TURF-Reserve designs given local biological, spatial, economic, and social data.

2) *Identify and order the activities that must be performed to reach the model goal*s—All specific biological, spatial, and economic inputs for the model equations were categorized. A list of how and where this data would be obtained was also compiled.

3) *Design an abstract user interface that supports performance goals*—An initial prototype of the model, or alpha model, was designed in the Microsoft Excel platform that incorporated all data inputs, met the model goals, but did not provide a user-friendly interface.

4) *Create concrete interface*—TURFtools equations and data were connected to a Beta version of the model in which users were asked to interpret raw data into model inputs. This was conducted through a series of beta testing that also calculated the user-appropriateness of the interface.

5) *Design final user interface*—Incorporating the feedback from steps 1-4, a final user interface was designed. This interface accounts for usability, aesthetics, and site-specific output communication values that were revealed throughout the interface design process.

Points of User Interaction

To ensure the success and usability of the interface, we examine three points of user interaction: 1) data entry and inputs, 2) stakeholders and data output, and 3) the specific integration within Fish Forever.

1) Data Entry and Data Inputs

Data Managers: All data entry within the model is to be conducted by a designated data manager, also referred to as the model user. While this person will have received training on TURF-Reserve function and design, we do not expect he/she to hold extensive expertise in computer-based modeling.

Data managers are responsible for translating both local knowledge and local data into the model. Therefore, while community data will be integrated into the model, a single user controls the entry of this data, ensuring consistency throughout the model. A supplemental "Model User Guide" (See Appendix 1) instructs users through the interface so that all critical parameters are accurately and thoroughly considered.

Data Inputs: A key task of the site manager is the translation of local data into data that can be used by the model. To address this issue, the interface is designed to easily interact with already existing local surveying information, scientific data collection, and mapping exercises. Estimates of the available data are based on ongoing surveying in the Philippines from the Participatory Coastal Resource Assessment (PCRA). The PCRA has been adapted by Fish Forever and tailored into a more targeted *TURF-Reserve Design Survey,* which conducts community-based surveying to collect data specific for the TURF-Reserve design process. These data include classification of local resources and habitats, mapping exercises of habitat and areas of use, species trend diagrams, and local profiles of community demographics.

In circumstances where local knowledge and biological data is not available, quantitative model inputs may be determined by global database information. The decision to use either preset data found in global databases or local environmental knowledge obtained through survey interviews and community forums depends on the feasibility and accuracy of local data available.

Data entry into the interface is directed through a supplementary "Model User Guide" that leads data managers through the interface without requiring additional training. This series of instruction includes an orientation to TURFtools, the TURFtools model, and data entry and data visualization.

2) Stakeholders and TURFtools: The Outputs

Community participation is critical throughout the TURF-Reserve design process. Stakeholders provide not only important spatial, biological, and economic information, but social and practical constraints and/or limitations that may affect design. For example, areas of conflicting use among user groups may be more appropriately evaluated through facilitated community discussion rather than through TURFtools. However, accompanying these community discussions with qualitative and quantitative performance results from TURFtools will provide a more holistic view of design tradeoffs throughout the decision-making process.

Although the data manager generates the outputs, all relevant stakeholders must understand the model outputs as well (fishers, community members, government officials). With the exception of certain working groups, EDF, Fish Forever, or Rare staff members do not train most stakeholders participating in TURF-Reserve design decisions. We do not expect local community members to have an understanding of Microsoft Excel or tradeoff analyses, therefore it is important that the site manager represents data outputs in an easily understandable manner.

We maintain data visualization within the Excel interface to keep the model simple and the technology requirements minimized. The data outputs of the model are relative comparisons of expected TURF-Reserve performance over a 20-year period. However, because these are relative performance expectations and not diagnosed metered changes in harvest, profit, and abundance, data outputs must be communicated with caution so as to not convey unrealistic changes in fishing performance. Therefore, specific values have been removed for most output visualizations.

Beyond the interface itself, our goal is to foster a design process that encourages participation, incorporates diverse stakeholder perspectives, and successfully communicates the implications of design tradeoffs. Through the interface, varying stakeholder designs will be evaluated and compared. The manner in which this output is communicated to the non-technical community is critical, and further research into communication for behavior change, feedback from Fish Forever and EDF partners, and field tests of various options will be pivotal in informing the communication of model outputs. The TURFtools model does not provide recommendations for the implementation and monitoring of a TURF-Reserve, but only conveys tradeoffs between various designs. EDF, Fish Forever, and the Filipino communities will be tasked with the former actions.

3) Integrating the tool within the Fish Forever framework

The tool will be used in collaborative efforts between site managers and local fishers, community leaders, and other interested parties to collect model inputs and create and evaluate design options as part of the TURF-Reserve design process.

While TURFtools can be used as a standalone tool within a broader TURF-Reserve design context, the tool is designed to easily integrate into Fish Forever's already existing TURF-Reserve design strategy, including the "TURF-Reserve Design Toolkit" (Figure 3). To do so, we examined current Fish Forever strategy documentation and EDF's step-by-step guide for TURF and TURF-Reserve design to gain insight into recommended information-gathering and stakeholder involvement procedures. Two TURFtools team members visited the four Fish Forever prototype sites in the Philippines to gather feedback into the integration of the tool. Site visits to Inabanga, Cantilan, Tinambac, and Cortes were conducted during the initial phases of community engagement. Communities were highly receptive to data results from the PCRA, which included fisheries profiles in the form of bar graphs, pie charts, and maps. Site managers were responsible for compiling important information and walking communities through the results. This type of data communication serves as a baseline for TURFtools data communication.

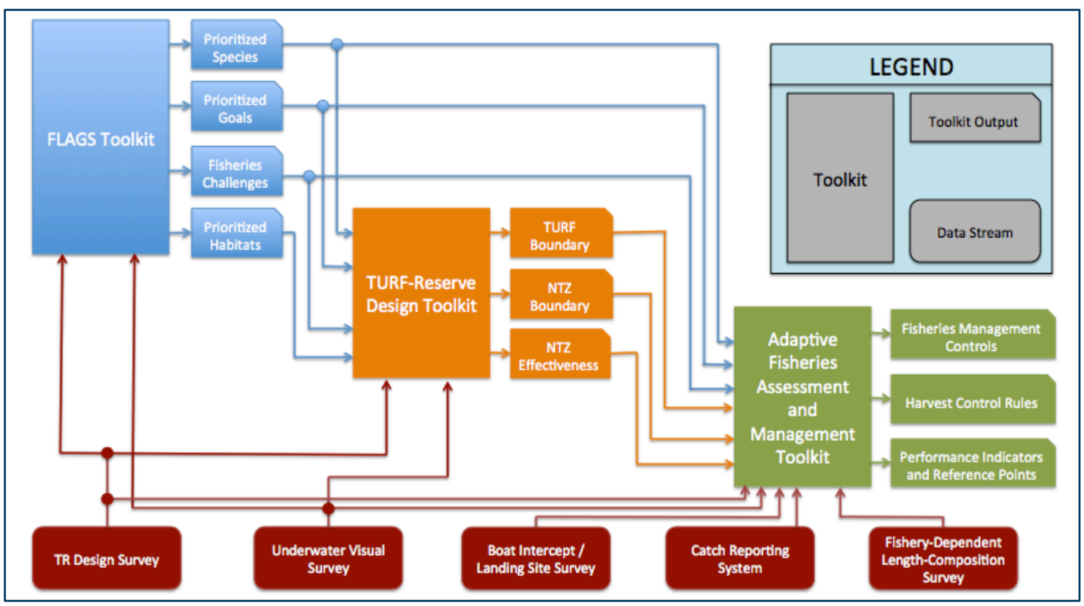

Figure 6. Draft schematic of working Fish Forever tools (SFG). TURFtools is incorporated into the "TURF-Reserve Design Toolkit".

Model Interface Adaptive Design Process

To ensure that the model interface and accompanying documentation is appropriate and effective both scientifically and for a larger, less specialized target audience, we conducted four stages of adaptive beta testing. Each stage of testing had strategic participants and goals.

PHASE 1: ALPHA TESTING WITH MESM STUDENTS — Initial testing was conducted with the goal of identifying areas of data entry that were unclear or not addressed due to oversight, as well as brainstorm ways of communicating outputs or tradeoffs.

Participants: All participants were Masters of Environmental Science and Management (MESM) students at UCSB's Bren School. The students were identified as well-informed individuals familiar with modeling and Excel, but not necessarily familiar with fisheries or fisheries modeling.

Materials: This stage used a preliminary Excel model without a user-friendly interface or "dashboard" and a basic Model User Guide.

Results: Students identified inputs that were unnecessarily time intensive, confusing, and scientifically unsound. Lists of potential output communication options were also compiled.

PHASE 2: DATA INPUTS AND THE USER MANUAL — Testing was done to determine the users' ability to input data into the model without the oversight of a TURFtools team member.

Participants: Representatives consisted of Fish Forever constituents from EDF, SFG, Rare, and the Bren School. All were familiar with the project, though not with the model.

Materials: This stage used an "inputs only" version of the Excel model (where outputs and results were hidden). Model User Guide, pre-selected species information, mock habitat map, mock "areas of interest" map, and mock TURF-Reserve designs.

Results: Participants provided notes on the User Manual as it pertained to data entry. Areas that were unclear in both the model and the user guide were provided. Improving the User Guide accessibility and the development of potential troubleshooting guide were strongly advised.

PHASE 3: OUTPUTS AND MODEL ASSUMPTIONS — This phase was an extension of previous testing. Using the input data from Phase 2, we focused on the model assumptions and outputs obtained from various the TURF-Reserve designs.

Participants: The same Fish Forever representatives from EDF, SFG, Rare, and the Bren School who participated in Phase II testing, in addition to two model specialists from both the Bren School and EDF, were surveyed in Phase 3.

Materials: This stage used the complete beta version of the Excel model, including the input data from stage one, a Model User Guide, pre-selected species information, mock habitat map, mock "areas of interest" map, and mock TURF-Reserve designs.

Results: Participants offered feedback regarding the aesthetics of the outputs to make them more readable and easier to understand. Participants also suggested offering guidance on how to interpret tradeoff results. This feedback was incorporated into the Model User Guide.

PHASE 4: FULL MODEL PRESENTATION – This phase was the first presentation of the model to the Philippines teams currently working with the prototype sites. It was also the first presentation that evaluated not just model usability, but also the model's capability to incorporate actual site data.

Participants: Phase 4 included the EDF Philippines staff, the EDF client, as well as select Rare staff working with the Fish Forever prototype sites for TURF-Reserve design.

Materials: Data from two prototype sites in the Philippines—Tinambac and Cantilan—were used to provide data inputs into two separate models.

Results: Participants identified how current local data collection (through the PCRA) could be incorporated and manipulated into the data inputs for the model. The Philippines team also identified current potential TURF-Reserve designs and looked at the outputs on various spatial scales.

[*]PHASE 5A: UPDATED MODEL PRESENTATION – This phase was similar to Phase 4 testing, however, feedback from Phase 4 was incorporated into the presentation. The presentation focused on the model's ability to evaluate TURF-Reserve designs based on updated information from the previous Tinambac example.

Participants: Participants included the EDF Philippines staff and Rare Philippines field staff. The Rare staff included members working with the Fish Forever prototype sites for TURF-Reserve design and those focused on the education and training of future site managers.

Materials: The TURFtools team presented a conceptual framework of the tool to the participants using updated data and TURF-Reserve designs from the previous Tinambac example.

Results: The following discussion focused largely around improving the communication of output analysis. Participants identified the importance of using the "Score Table" to guide discussions and output presentations to local stakeholders.

PHASE 5B: MODEL & USER MANUAL DEEP DIVE – Users were asked to complete a full run-through of the tool using sections of the User Guide, paying particular attention to User Guide clarity, model functionality, ease of data entry, and visual output manipulation and representation.

Participants: Participants included EDF and Rare Philippines field staff members focusing on model use and data analysis, and were assisted by TURFtool Group Project members.

Materials: Each member received a specific section of the User Guide, as well as a "clean" version of the model (no habitat mapping, species selection inputs, TURF-Reserve design options, etc.).

Results: Participants identified specific areas of improvement, including both aesthetic changes (ex. coloring and size of icons) and functionality improvements (ex. drop-down list alterations, improving habitat characterization). They also offered feedback regarding model structure, including the organization of the species list and increased transparency of model calculations.

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[*] The TURFtools team conducted Phase 5 testing on-site in the Rare Philippines offices. Testing was completed over a two-week period in March 2015 and was used to further refine and evaluate a beta-version of the TURFtool model.

PHASE 5C: RARE UNIVERSITY TRAINING – For the final phase of the adaptive design process, TURFtools group members presented a general overview of TURF-Reserve design principles and introduced TURFtools to future site managers with varying levels of knowledge and expertise in TURF-Reserve design.

Participants: Phase 5c participants included the Philippines 3 cohort Conservation Fellows and the Philippines 2 Prototype Fellows. Conservation Fellows will play a large role in the TURF-Reserve design process and implementation.

Materials: All participants received a sample habitat map and 4 varying TURF-Reserve design maps. TURFtools group members created TURF-Reserve designs in order to highlight how different design parameters (e.g. reserve size/location & TURF size) affect the outputs.

Results: By presenting the tool to a group relatively inexperienced with TURF-Reserve design, the final phase allowed us to gauge the accessibility and applicability of the tool. It also served to create buy-in and demonstrate how local knowledge and scientific data can be combined for effective design.

ADAPTABILITY OF THE MODEL

TURFtools is designed to capitalize on current Fish Forever design and implementation occurring in the Philippines as a means of grounding the tool in an applicable field context. However, the interface is designed to be adapted to any near-shore small-scale fishery as long as the necessary data and mapping is available.

DATA COLLECTION

The foundational data requirements for TURFtools are guided by the TURF-Reserve Design Survey, which gathers spatial maps, community demographic data, and species/habitat trends. This surveying process is recommended for its robust data collection, while simultaneously acting as a catalyst for community engagement in the TURF-Reserve design process. If the TURF-Reserve Design Survey is not available or is not the appropriate means of data collection for a given community, or other community data collection is already underway, other local data can be used. All community data should go through a verification process, or "ground truthing", in which local knowledge is cross-reference and paired with historic and/or scientific documentation. This process ensures that the data being contributed is as accurate as possible.

DATA ENTRY

TURFtools is pre-populated with a Philippines specific dataset that includes biological and economic information for a list of the most commonly fished species in the region. The interface has been designed to easily manipulate biological, economic, spatial, and other pertinent inputs. Therefore, as long as pertinent data is available, TURFtools can be adapted to any region.

Each point of data entry within the model can be customized to fit site-specific goals, data, and needs. These include habitat types, important areas of interest, target species bio-economic data, and TURF-Reserve design options.

Habitat manipulation can be conducted within the model interface to match the important habitats that were identified in community mapping. The habitats themselves are not associated with specific values, but rather are used to identify areas where the target species are found and to what degree. This input affects the carrying capacity of a species and will change for different habitat types. Therefore, habitat names can easily be changed without requiring additional training to manipulate model inputs (See Appendix 1, TURFtools User Manual, Steps 2 & 4.E).

Mapped areas of interest can be easily customized within the interface to display site-relevant parameters for the community. Examples include important life-cycle areas (spawning grounds, nursery grounds, etc.) or social parameters (overlapping fishing grounds by community members). These areas will be used in the final comparison of designs. Identifying the most important areas to the community can provide valuable insight into how various TURF-Reserve designs overlap with these regions and can also be useful for identifying potential conflict areas (See Appendix 1, TURFtools User Manual, Step 3).

If the TURFtools model will be used at multiple sites within one region, an appropriately trained data manager can replace the entire data set with species information that is relevant to the site (See Appendix 1)**.** If changes to a specific biological or economic parameter of a given species need to be altered, the model user can do these so manually within the interface. In lieu of using the built in bio-database, general biological knowledge of the target species, along with the spatial distribution of local habitat coverage, may also be used to associate certain biological parameters with site-specific habitat type.

Lastly, the data manager will prescribe the size and scale of the site's mapping area. This can be changed to fit the spatial needs of each site. Currently, the model provides projected performance outcomes of various TURF-Reserve designs using the spatial information provided. Therefore, the larger the mapping area, the "coarser" and less detailed the resolution of spatial data, and the less detailed the projected outcomes. The smaller the mapping area, the more detailed the outputs will be. For example, each site will have a designated scale to which all of the site-specific mapping exercises are set. Overlaid on each map will be a 10 x 10 grid of any size. However, each patch of the 10 x 10 grid is limited to 1 habitat type, 1 area of importance, and 1 management zone (TURF, Reserve, open access). Small-scale variations of habitat, use, or design that occur within a single patch are not captured in the model outputs. While size and scale of these maps can be changed to fit the site, data managers should be aware of the effects of increasing or decreasing the resolution (See Appendix 1, TURFtools User Manual, Page 7).

The Outputs

The overarching goal of the TURFtools model is to provide users with information that helps them evaluate tradeoffs between multiple TURF-Reserve designs. Ultimately, this information will aid stakeholders in the final TURF-Reserve decision. The outputs – percent change in abundance, percent change in harvest, and percent change in profits – mirror the formatting styles currently used by EDF and its partners (Figure 4). All icons are colored uniformly across the model to maintain consistency throughout the process. These particular outputs were chosen based on feedback from EDF, Fish Forever, and local site managers. After users successfully complete the INPUT phase and save their TURF-Reserve designs, the outputs will be displayed in an easy-to-read dashboard within the TURFtools Excel file.

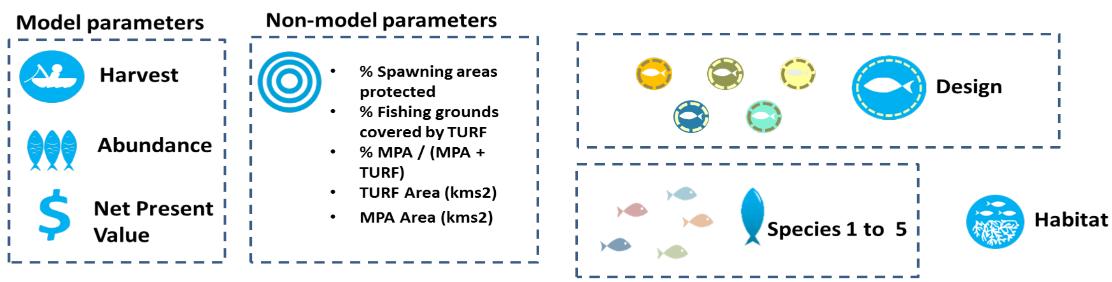

Figure 7. Design icons for TURFtools model outputs. These icons are currently being used by EDF and Fish Forever and were chosen to maintain continuity with the "TURF-Reserve Design Toolkit".

As mentioned earlier, the TURFtools model is not a decision making tool, but rather provides tradeoff analysis between various designs. It does not provide users with an optimal design, and stakeholders should be made aware that the tool is merely one piece of a much larger decision framework. The outputs, therefore, are not an endpoint, but rather a way to enhance dialogue between site managers and community members.

While the process of generating multiple TURF-Reserve designs is informative in and of itself, users need to be able to evaluate which scenarios perform better to help them achieve their goals more quickly. Leslie et al. (2003) concluded that multiple iterations of the conservation goal in the initial stages of planning a network of marine reserves would allow stakeholders to gain a visual sense of how different goals affect potential network designs and their implementation strategies. It is in this process that the TURFtools model outputs is most effective.

Feedback from our client and various working groups consistently stress the importance of not assigning numerical values to the outputs. Doing so would create unrealistic expectations that, if not met, could negatively affect the buy-in process. There are also other factors (ex. the total number of fishers, level of enforcement) that are not considered in the model that may influence results. To this end, we chose to use icons that vary in size to relate the percentage change in abundance, harvest, and profits between designs rather than rely on quantitative values. Depending on which parameter a user is interested in, the user may choose among the six options that the tool provides.

Understanding Tradeoffs

Alternative designs help users comprehend the range of different outcomes that they can expect and their potential implications. Providing multiple ways to communicate the outputs is a valuable resource to compare TURF-Reserve design scenarios, but site managers must be clear that the results do not guarantee a particular outcome to minimize the risk of confusion and loss of credibility (See Appendix 2 for visual representations of each output chart).

The outputs compare designs via different combinations of model and non-model parameters, so each chart communicates slightly different information. For further clarification, Table 6 provides an initial description of the types of information each output chart or table provides.

<table>
<tr><th>Level</th><th>Chart number</th><th>Type of Analysis</th></tr>
<tr><td>Single species Analysis</td><td>Chart 1a- c</td><td>• Compares performance of a single-species across multiple designs
• Evaluate different tradeoffs between 2 model outputs</td></tr>
<tr><td rowspan="3">Multi-Species analysis</td><td>Chart 1a-c
Chart 2</td><td>• Compares performance of multiple species across all designs
• Takes into account 1 non-model parameter</td></tr>
<tr><td>Chart 3</td><td>• Compares a model output for all species against a non-model parameter</td></tr>
<tr><td>Scores</td><td>• Allows the users to see all information at once and see which design is performing better
• Provides a scaled summary of results</td></tr>
</table>

Table 3. Chart identifications and a summary of information provided.

Model Outputs and Non-Model Parameters

TURFtools outputs are divided into two categories, which we have identified as model and non-model outputs. Model outputs relate to the bio-economic population dynamics model and include abundance, harvest, and profits and are communicated through the use of the symbols in Figure 3. Non-model parameters can be changed by the model user based on areas of interest identified by community members (See Appendix 1 for instructions on how to change these outputs).

The output charts are designed to compare tradeoffs between model outputs while showing the differences in the non-model parameters across each design. For example, Output Chart 1.b plots two model outputs on the x- and y-axes, while the icon size changes for each design based on the non-model parameter chosen. We constructed the "Outputs" tab within the Excel model so that charts can be printed individually to facilitate information sharing.

I. Abundance

One of the main conservation goals of implementing TURF-Reserves is to increase the abundance of marine organisms, especially those targeted by fishers. Various studies show that the implementation of TURFs helps to achieve this objective (Alcala & Russ, 2006; Sala et al., 2013; Hilborn, 2004). Lubchenco et al. (2003) demonstrated that marine reserves have a similar impact.

The percent change in total stock for all patches helps determine the impact of various TURF-Reserve designs on fish populations. To determine this output, we first determine the total abundance of the design in in (t) across all patches:

$$N_D = \sum_{i}^{p} N_{i,j,t}$$

Calculated similarly, the total abundance in Status Quo in time (t) across all patches is

$$N_{SQ} = \sum_{i}^{p} N_{i,j,t}$$

Next, we calculate the total abundance of a design for all years across all patches:

$$N_D = \sum_{t=1}^{T} N_{i,j,t}$$

And the total harvest of the Status Quo for all years across all patches:

$$N_{SQ} = \sum_{t=1}^{T} N_{i,j,t}$$

Lastly, we determine the percentage change in stock:

$$\%\ in\ Abundance = \left(\frac{Total\ Abundance\ in\ Design - Total\ Abundance\ in\ Status\ Quo}{Total\ Abundance\ in\ Status\ Quo}\right) * 100$$

II. Harvest

The percentage change in harvest over the 20-year timeframe helps communities weigh the various TURF-Reserve designs. It represents how much harvest occurs in each design when compared with the Status Quo.

To determine the percentage change in legal harvest, we first determine the total harvest of the design in time (t) across all patches:

$$H_{D,j,t} = \sum_{i}^{p[TU+OA]} H_{i,j,t}$$

Calculated similarly, the total harvest in Status Quo in time (t) across all patches is

$$H_{SQ,j,t} = \sum_{i}^{p[SQ]} H_{i,j,t}$$

Next, we calculate the total harvest of a design for all years across all patches:

$$H_{D,j} = \sum_{t=1}^{T} H_{D,j,t}$$

And the total harvest of the Status Quo for all years across all patches:

$$H_{SQ,j} = \sum_{t=1}^{T} H_{SQ,j,t}$$

Lastly, we determine the percentage change in total harvest:

$$\%\ Change\ in\ Legal\ Harvest = \left(\frac{Total\ Harvest\ Design - Total\ Harvest\ Status\ Quo}{Total\ Harvest\ Status\ Quo}\right) * 100$$

III. Net Present Value

A main objective for fishery managers, fishers, and community members is to increase profits within a fishery. The TURFtools model uses NPV calculations to normalize comparisons between year 1 and year 20. Users have the option to choose Net Present Value as a tradeoff criterion in each chart to aid in the differentiation process among designs.

To determine the percentage change in profits, we first determine the total profits of the design time (t) across all patches:

$$\pi\left(H_{D,i}\right) = P_j \sum_{i}^{p[OA+TU]} H_{i\ldots P,j,t} - \left(\frac{c_j \sum_i^{p[OA+TU]} H_{i\ldots p,j,t}}{q_j \sum_i^{p[OA+TU]} N_{i\ldots p,j,t}}\right)$$

Calculated similarly, total profits in Status Quo in time (t) across all patches is:

$$\pi\left(H_{SQ,i}\right) = P_j \sum_{i}^{p[SQ]} H_{i\ldots P,j,t} - \left(\frac{c_j \sum_i^{p[SQ]} H_{i\ldots p,j,t}}{q_j \sum_i^{p[SQ]} N_{i\ldots p,j,t}}\right)$$

Next, we calculate NPV of the design for all years across all patches:

$$NPV_D = \sum_{t=1}^{T} \rho^t * \pi_{D,j,t}$$

And NPV of the Status Quo for all years across all patches:

$$NPV_{SQ} = \sum_{t=1}^{T} \rho^t * \pi_{SQ,j,t}$$

Lastly, we determine the percentage change in profits:

$$\%\ Change\ in\ Profits = \left(\frac{NPV\ Design - NPV\ Status\ Quo}{NPV\ Status\ Quo}\right) * 100$$

DISCUSSION/FUTURE WORK

MODEL VALIDATION

In order to validate our model results and better understand input sensitivities, we coded the system of equations in R Studio. We then ran the same design and input parameters for 1 species in Excel and in R Studio to confirm consistent results in percent change in harvest, abundance, and profit. Resulting abundance, harvest, and net present value scores were the same in the two platforms, with differences of less than 0.5 due to significant figure use differences between the platforms. Given this verification of the model, we proceeded to use R Studio to perform sensitivity analysis.

INPUT RANGE AND PRECISION

I. INPUT RANGE SENSITIVITY

By testing a range of values for each parameter, we are able to see if there are ranges of inputs for which the results change drastically. It also verifies that the model functions logically under a range of inputs. To conduct this analysis, we ran the model for 100 values of each input and graphed the resulting model outcomes. In this analysis, the code identifies the optimal TURF policy for each value of the target parameter.

II. INPUT PRECISION SENSITIVITY

The sensitivity analysis also addresses what happens when input parameterization is not precise. For this test, the model similarly ran 100 values of a target parameter, but maintained a singular TURF harvest policy optimized for one baseline variable value.

All the sensitivity analyses utilize a set of baseline parameters and considered mid-range values for each variable. Each analysis is based on a uniform mixed TURF-Reserve design containing 58% TURF, 16% reserve, and 26% Open Access patches (For complete results of the sensitivity analysis, see Appendix 3).

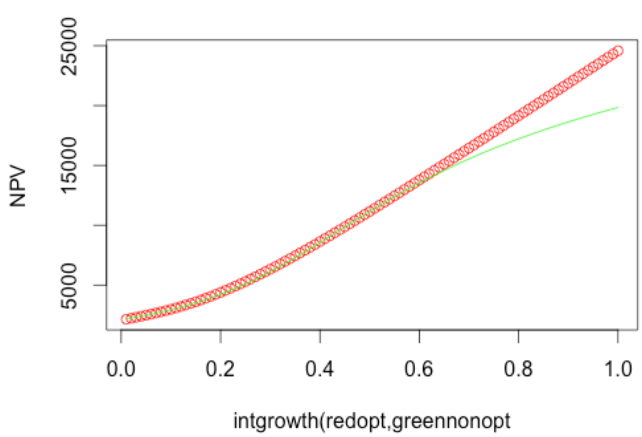

Figure 8. Intrinsic growth rate sensitivity analysis.

This analysis identified the parameters most 'sensitive' in terms of range and precision uncertainty. Intrinsic growth rate is one such input parameter. Net present value of the tested design increased over 5-fold over the tested input range. To the user, this implies that seeking the best available data for the input is critical. Precision sensitivity of this input becomes important at higher intrinsic growth values where greater net present value is lost when harvest policies are optimized for a lower value. However, growth rates above 0.8 are likely irrelevant to TURF species as they are more commonly associated with pelagic species such as sardines.

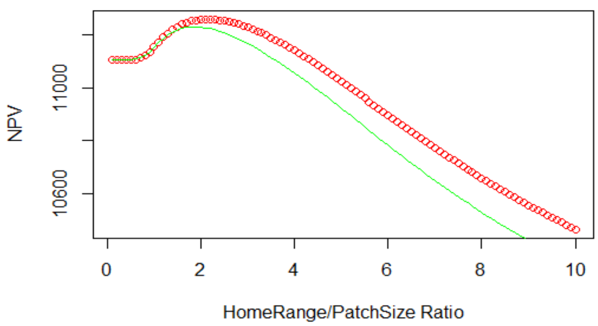

Figure 9. Home range to patch size sensitivity analysis.

Home range as a ratio of system size is a parameter we found to be far less critical to model outcomes, as net present value ranged only around 10% under the tested parameter range. This implies that users do not need to focus as much on obtaining precise inputs. However, even for the most uncertain or sensitive species parameter inputs, the input is constant across all designs. The goal of the tool is to provide relative performance evaluation. As long as the input range does not affect relative design performance "rankings" for a given species, the end goal may still be achieved. In order to ensure that input parameter sensitivity would not affect relative design performance ranking, we select the three most sensitive input parameters (intrinsic growth rate, carrying capacity, and stock status) as determined by our prior sensitivity analysis. Figure X demonstrates that despite varying trajectory sloes and values, the relative ranking of the designs remains the same.

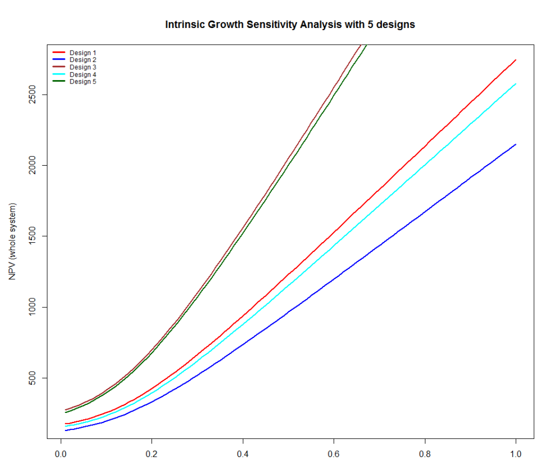

Figure 10. Relative ranking of designs for intrinsic growth rate sensitivity analysis.

TURF VERSUS OPEN ACCESS PERFORMANCE

In order to confirm that TURF patches outperform Open Access patches, we analyzed 100 intrinsic growth rate values against total TURF profit NPV minus Open Access Profit NPV by first running an all-TURF design, then running an all-Open Access design. We chose intrinsic growth rate as the variable to manipulate due to preliminary sensitivity analysis results above that demonstrate the significant impact variability this parameter has on model outputs. Given a relatively stable fishery at year zero and high illegal fishing in a TURF area, we were concerned that the Open Access patches may outperform TURF patches. We therefore ran the analysis under the baseline 40% illegal fishing level in the TURF and a 90% illegal fishing level in the TURF (Figure 12). In both cases, TURF designs outperform Open Access designs in terms of net present value, showing that the model optimization policy brings more economic benefits than any open access policy for the range of intrinsic growth rate values we analyzed.

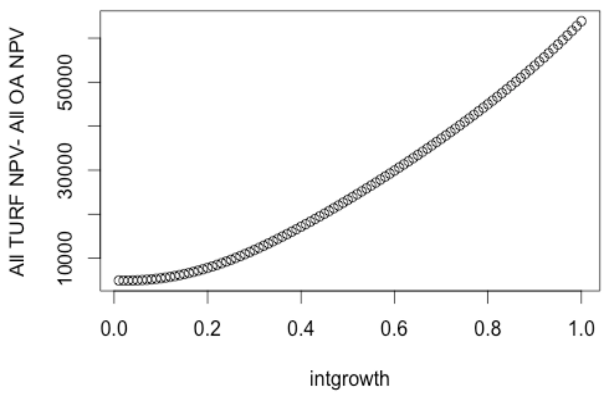

Figure 11. Intrinsic growth rate sensitivity analysis: Open Access versus TURF with 40% illegal fishing.

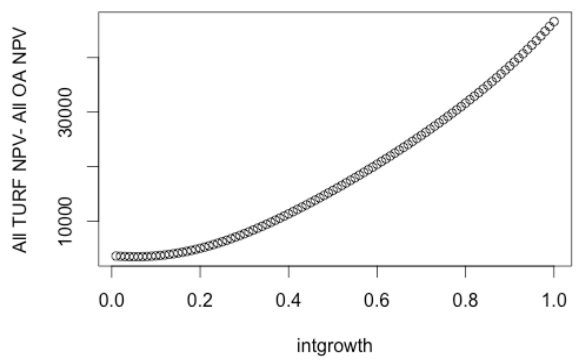

Figure 12. Instrinsic growth rate sensitivity analysis: Open Access versus TURF with 90% illegal fishing.

LIMITATIONS

The design of the model was constrained by three key limitations:

- Data availability
- Access to technology and limited internet accessibility
- Maintaining consistency with software programs currently in use (i.e. Microsoft Excel)

Given these limitations, we construct a model that could evaluate differences between performances of distinct TURF-Reserve design options. Excel is the chosen platform to build the model because of its universality and limited technological and expertise barriers. Consequently, we have created a model as simple and intuitive as possible that could reflect differentiated spatial outcomes. We utilize a logistic growth model because it tracks changes on population numbers each year with simple inputs. Derived from this, we add harvest and profit calculations. As the data availability in our applied Philippines context is generally poor and qualitative, we needed a way to transform the inputs in a precise enough way so that the logistic growth function could generate different responses given different inputs. We choose categorical input classifications based on literature review and available datasets to try to capture as much variability in the inputs as possible while preserving simplicity for the user.

Future Work

Although simple in structure, the model is sensitive enough to provide different outcomes even with similar inputs. This model is a great starting point, but several key revisions to the current tool could be made when more precise data are available. Some of these revisions could be made in the same Excel platform, but others would require more powerful modeling programs, such as RStudio or MatLab.

I. Increase the Number of Patches to Achieve a Higher Resolution Potential

A higher resolution allows users to account for greater habitat differentiation and non-model habitat characterization specificity (i.e. spawning areas, fishing grounds, etc.). It may be necessary where TURF-Reserve areas are expansive and/or habitat is highly variable, but it will also require a more time intensive mapping input. Ideally, the tool would have a variable number of patches (n) depending on the size of the site to be implemented, the mapping capacities of the communities, and the species involved. In order to do this, other modeling platforms might be needed.

II. Explore Other Bio-Economic Model Structures

There are myriad model structures that may be used to understand bio-economic fishery dynamics. A commonly used model is the age structure model, which accounts for species demographics and uses a distinct set of inputs from the logistic growth model. A middle step between this age-structure model and the logistic growth model currently in use is the delay-difference model, which keeps track of both larvae and adult production in every patch (Sala et al. 2013). This model might be a better fit to improve the precision of this tool given the constraints mentioned above.

Another means to increase certainty of the model would be to incorporate habitat inter-relations through the methods summarized by Foley et al. (2011). The extent of revisions necessary to the current structure of the Excel model depend on the equations themselves, and, for some changes, may require extensive changes to the file structure. For a more complex age-structure model, Excel might not be the appropriate platform and other programs would be required.

III. Add a Dynamic Illegal Fishing Module Based on Profit and Effort Dynamics

The current model structure uses a constant illegal fishing effort level as a percentage of the TURF harvest policy. To better reflect potential changes in effort and location of illegal fishing, a module could be added to direct illegal fishing to areas with greater profit potential. Given a paucity of local data on relative effort and a scope that does not include management advice, we refrained from such an addition. However, it would be a feasible addition to the scope of the tool.

It is important to note that model accuracy improvements also necessitate improved local data. Age structure models, for example, provide more complex dynamics than the logistic growth model, but they also require more species-specific data. Literature review, historical landings data, and/or underwater surveys are all possible sources for such data. In the case of the Philippines, it is not certain that such data is available at all sites, and we designed our model to accommodate the most data-poor scenarios. When adapting the tool for application in a new context, we recommend model users carefully consider the availability and quality of local data. We have worked with the future users of the model to revise habitat mapping and data collection methodologies to more readily sync with the model input process. In any application of the model, it is preferable to consider both the model structure in terms of local data availability and local data collection in terms of model input procedures.

IV. Explore Alternative Communication Methods (web-based tools, Software Applications, etc.)

Another means to achieve more sophisticated modeling and interface capability is through the utilization of a platform other than Excel. We chose an Excel interface because of its suitability to the Philippines context. Mainly, it does not require an Internet connection and is familiar to Philippines site managers likely to use the model. If Internet availability is not a concern and/or users have some familiarity with modeling software such as R Studio there are numerous interface options:

1) Shiny by RStudio/Matlab/Python/etc.
2) Seasketch, or another geographic information system interface
3) Mobile App or other web-based tool

Each of these interfaces could be developed using the current set of equations and inputs to be utilized under the same general user procedure.

CONCLUSION

Roughly 3 billion people rely on seafood as their primary protein source (FAO 2012), and, as populations continue to rise, increased harvest levels will be needed to meet this demand. In order to provide sustainable yields for future generations and ensure both the health and livelihoods of small-scale artisanal fishing communities, fisheries must employ alternative management regimes to prevent overfishing. TURF-Reserve systems provide fishers with exclusive access to defined fishing areas, thus transferring responsibility to those intimately involved with the fishery, and they have recently become an increasingly popular solution to stem the threat of overfishing. When managed and enforced correctly, fisheries have seen increases in productivity and profit (Alcala & Russ 2006; Sala et al. 2013; Hilborn 2004), providing a stable source of food and employment.

The Fish Forever partnership between Environmental Defense Fund, University of California, Santa Barbara's Sustainable Fisheries Group, and Rare is currently working in five countries, implementing TURF-Reserve systems through a multi-faceted approach involving community buy-in, science-drive fisheries modeling, and policy advocacy. To advance these efforts, the TURFtools team has created a highly adaptable bio-economic, spatially explicit model. Designed for the Philippines context, the model can be manipulated for implementation in other countries.

Integrated into the larger "TURF-Reserve Design Toolkit", TURFtools provides users with the ability to create multiple TURF-Reserve designs and analyze various tradeoff scenarios for different target species. The model, designed for use in extremely data-poor scenarios, also has the ability to incorporate local ecological knowledge to provide more accurate results for individual communities. Once all relevant data has been collected and input into the model, users will be able to compare designs across changes in abundance, harvest levels, and profits. Although the model is not intended to act as a final decision-making tool, it serves an important role in the end-process by engaging local stakeholders, providing visual representations, and communicating outputs relative to each TURF-Reserve design.

As small-scale artisanal fishing communities prepare to meet the challenges of overfishing, climate change, and population growth, TURF-Reserves offer a creative solution to these complex problems. TURFtools provides a basis for understanding the effects of various spatial designs and aids in the implementation of effective, productive TURF-Reserves. Future iterations and improvements to the model will ensure more informed fishery designs and help create healthier ecosystems, fisheries, and communities around the world.

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TURFtools: A TURF-Reserve Design Tool

TURFtools: A TURF-Reserve Design Tool

Part 1: Understanding TURFtools & the TURFtools Model

What is TURFtools?

TURFtools is a TURF-Reserve design tool that helps communities decide among spatial TURF-Reserve design options by assessing the relative performance of designs based on both scientific and social information. The design tool is used alongside the TURF-Reserve design process described in the Fish Forever design curriculum material.

The tool is an Excel based model that uses biological, economic, social, and spatial information that comes primarily from the TURF-Reserve Design Survey and the TURF-Reserve species selection, as well as secondary sources where needed.

The TURF-Reserve design tool comprises of 5 steps.

1 **Collect data**—the TURF-Reserve Design Survey and supplementary biological species data act as the main sources of spatial, economic, and biological data

2 **Develop TURF-Reserve design options with stakeholders**—using the TURF-Reserve design guidelines, stakeholders develop design up to 5 alternative TURF-Reserve designs on a gridded map that is consistent with the scale of the community maps

3 **Input data into the tool**—all spatial, social, economic, and biological data from the data collection process is entered into the excel document

4 **Enter design options into the tool**—designs are entered into the model and the model is run

5 **Evaluate projected performance of design options**—the tool provides a comparison of the expected performance of different design options to help weigh the pros and cons between designs

Significance of the Tool

TURF-Reserves are only effective in meeting defined goals if they are designed effectively. Stakeholders designing TURFs are faced with many technical decisions, such as which species to manage in the TURF and where boundaries should be located. These decisions depend on a variety of factors, including important fishing areas, movement patterns of target species, number of fishermen, the location of key habitats, and complex social factors such as the way fishermen are organized (Poon & Bonzon 2013). In this design process, local site managers and stakeholders will need to weigh trade-offs and make design decisions based on available biological/ecological data and socioeconomic factors.

This TURF-Reserve design tool will support effective fishery management by providing a technologically simple, easy to use framework for site managers. The results and visualizations from the tool can facilitate informed design discussion with fishermen, fishery managers, scientists, and other stakeholders when comparing different TURF-Reserve designs. Comparison will be measured in terms of relative changes to harvest and biomass, and profit, as well as a variety of non-model parameters including: percentage cover of the reserve, percentage cover of important habitats like nursery grounds or spawning areas, and other customized outputs.

The Model

TURFtools uses Microsoft Excel as the primary platform for translating community information and TURF-Reserve design options into a visual and analytical output to help weigh tradeoffs between designs. The Excel model is used in steps 3-5 listed above.

The model has been designed with an interface to use under extremely data poor circumstances, though it can also be adapted to data-rich environments as well. The data inputs for the model are those that can be collected primarily from communities, fishermen, and local ecological knowledge. There are often qualitative prompts for spatial and species-specific information that are translated into quantitative parameters via 'behind the scenes' tabs stocked with values. For every such input, a trained model user may manually adjust these values if there is local data available.

How the Model Integrates into the Design Process

While it is possible to design TURF-Reserves in the absence this model, this design tool provides explicit and transparent technical guidance on the social, economic, and ecological tradeoffs associated with proposed TURF-Reserve design options. TURFtools is used alongside the design process, though the model's information gathering process (the Design Survey) provides data that is useful throughout the course of TURF-Reserve development. The model will allow decision makers to weigh trade-offs between design options based on the characteristics of the fishery.

How to Use the Model

The facilitator of the TURF-Reserve design process can follow the step-by-step instructions for the model as outlined in *Part II* of the *TURFtools Guides* to input data into the Excel model. He/she will enter known site-specific information or choose the best option from the pre-entered data already in the model.

Up to five (5) pre-selected TURF-Reserve spatial design options (from the design process) are entered into the model. These are differentiated by their varying spatial placement of the

Open Access, TURF, and Reserve areas. The result of the model will be visual representations of the tradeoffs between the design options, which will be used in the discussion of choosing a TURF-Reserve design.

Capabilities of the model

The TURFtools model is used within the design process to help facilitate data-driven, quantitative and qualitative discussions about various TURF-Reserve designs. Design teams can anticipate using the model to help:

- *Account for site-specific spatial, biological, and economic information:* TURFtools utilizes available local data for target species, habitat type and quality within the potential TURF-Reserve range, as well as local prices and costs of fishing, and incorporates them into the model to give a more robust comparison between design types. The more accurate and specific the data, the more detailed the trade-off analysis will be.

- *Assess tradeoffs of design:* The model is used for the relative comparison of TURF-Reserve design options by weighing trade-offs between varying spatial designs. These trade-off analyses will aid decision-makers by providing qualitative results for informed discussions.

- *Visualize design tradeoffs:* The trade-off analysis will be depicted in various charts and graphs that can be used to visualize to outputs and used to communicate these results to stakeholders.

- *Facilitate in the design process:* TURFtools is not a stand alone tool, but instead a tool that can be used alongside the design process to weigh trade-offs between current designs.

Limitations of the Model

The outputs of the model are limited by both the type and quality of data. Therefore, the model has some limitations as to its application and scope.

- *Comparison of Designs versus Optimal Design:* TURFtools will not act as a "deciding factor" to determine the "best" TURF-Reserve design, as design suitability will also be dictated by the goals, objectives, and constraints of each specific community.

- *Not an Enforcement and Regulation Tool:* TURFtools is not a management design tool, and will not provide information on how to enforce or regulate TURF-Reserve areas. While TURFtools does incorporate illegal fishing pressure and comparative harvest policies in managed and open access areas, it does not reflect actual local policies and any changes in management and use over time.

- *Limited Spatial Variation:* Spatial variation (of both habitat and areas of importance) is limited to the resolution of the TURF-Reserve area and surrounding areas of importance. Each area will be mapped on a 10 x 10 grid, so the larger the area the coarser the resolution of the map. Each square, or "patch", of the 10 x 10 grid is limited to 1 habitat type and 1 area of importance. Small scale variations of habitat, use, or design that occur within a single patch will not be captured in the outputs of the model

- *Conflicting Areas of Use and Prioritization:* The model consists of three matrix maps; one for habitat, one for areas of interest (ex: spawning area, nursery ground, tourism zone, etc), and one for designated use (reserve, TURF, open access). Patches with multiple habitats, multiple areas of interest, or multiple uses may have to be prioritized at the discretion of the user.

- *Social Limitations:* The social and practical constraints/ limitations that affect the size and space of the TURF will also be incorporated throughout the design process though may not be captured in TURFtools. For example, areas of conflicting use among user groups may be more appropriately evaluated through facilitated community discussion. Depending on the scale of the area, the TURFtools may or may not be useful in depicting these conflicts.

TURFtools is best used as a supportive tool in a broader stakeholder-driven design process. The deficiencies of the tool can be minimizes through the use of the accompanying tools in the "Fish Forever Tool Box", as well as community discussion and communication.

TURFtools: A TURF-Reserve Design Tool

Part 2: The Materials

The information required to run the TURFtools model comes primarily from data collection already being conducted in communities. The materials required for the model include:

- PC computer with Excel & Solver plug-in
- Community maps
- List of target species
- Supplementary biological data for target species
- TURF-Reserve design options

PC Computer with Excel

TURFtools is formatted for a PC computer. Some error messages may result from using a Mac/ Apple computer.

Community Maps

Community maps provide the model with site-specific spatial variation that is integral for evaluating the projected performance of various design options. Therefore, the more detailed the maps the more comprehensive the trade-off analysis.

Types of Maps

1) Habitat Maps: These maps should include all critical habitats for the selected target species as well as surrounding habitat types. Up to 12 habitat characterizations can be input into the model.

2) Areas of interest: Three (3) categories of areas of interest can be mapped in the model. Depending on the goals of the community, these areas of interest can vary. Some examples include: spawning areas, nursery grounds, fishing areas, tourism zones, etc. These should be included spatially on either the habitat map, or a separate map that is on the same scale as the habitat map.

Scale + Grid

Maps should be conducted on a 10x10 grid with the same scale across all maps for a given site. If a grid was not in place during the mapping workshops, a grid can be overlaid after mapping is complete.

The spatial resolution of the mapping area is extremely important for TURFtools. The model provides projected performance outcomes of various TURF-Reserve designs using the spatial information provided. The larger the mapping area, the "coarser" and less detailed the spatial data will be. The smaller the mapping area, the more detailed the outputs will be.

The size of the mapped area will change from site to site. However, maps should be scaled to include the largest potential TURF-Reserve site, as well as a portion of the unmanaged, open access areas. We suggest having one "row" of open ocean as the perimeter of the grid.

The grid does not need to be square; it just needs to be a 10 x 10 grid. Each one of the cells of the grid can be tall or long rectangles, or squares. The most important part, however, is that the area of the map in linear kilometers be known so it can be entered into the map.

List of Target Species

Communities should have already selected the target species before beginning to use TURFtools. Up to five (5) target species can be entered into the model, though you can you can use as few as one (1) depending on desired outputs.

Supplementary Biological Data for Target Species

The model has a database of pre-input data for certain species. These average values are based on literature review of biological information. If, however, more specific biological information for the target species is available at your site, this information should be used in place of the pre-populated information.

Biological data includes:

- Home range
- Intrinsic growth rate
- Overall stock status of the target species
- Habitats use

Social and economic information

- Price of target species
- Cost of fishing
- Rate of illegal harvest as a percent of total catch
- Primary type of fishing gear used to catch target species

This information can be obtained through literature review of scientific papers conducted in the region, from scientific studies at nearby universities, papers, censuses, and community surveying.

TURF-Reserve design options

Up to five (5) TURF-Reserve designs can be evaluated in the model. These design options should also be transferred to a 10 x 10 grid on the same scale as the mapping. Therefore when they are transferred into the model, the spatial data correlates to information gleaned from the community mapping process.

TURFtools: A TURF-Reserve Design Tool

Part 3: Model Instructions

This document will guide ***site managers (or model users)*** through the process of using the TURF-Reserve Design Tool and its application.

Goals of this Document

- Create and save a site-specific design model in Excel
- Translate spatial data (habitat maps, spatial areas of importance, and TURF-Reserve design options) into the TURF-Reserve Design Tool
- Select species of interest and site-specific parameters
- Compare and evaluate performance of TURF-Reserve design options

Materials and Data Needed for the Model

- [ ] Community maps on 10 x 10 grid, which includes:
    - Spatial habitat characterization on 10 x 10
    - Critical habitat (spawning areas, nursery grounds, etc)
    - Other areas of interest (tourism areas, fishing grounds, mariculture, etc)
- [ ] TURF-Reserve design options
    - Up to five (5) design options of TURF, Reserve, and Open Access
- [ ] Any supplementary site-specific biological data for target species

<u>Definitions:</u>

- **Matrix**: synonymous to the "grid" of the 10 x 10 maps
- **Tab**: Current worksheet that is being displayed within Excel. The worksheet, or tab, can be changed by selecting an alternate tab at the bottom of the Excel screen

USER REQUIREMENTS:

- **You <u>must</u> use a PC computer**—the model is formatted for **a PC**. Using an Apple/Mac will result in error messages
- **You <u>must</u> have "Solver" installed on Excel***—Solver is an optimization tool that Excel offers as an "add-in" and must be installed before the model can run
- **You <u>must</u> "enable macros"***—when prompted after opening the model, click "enable macros" so all features of the model can be run

*This will be discussed in STEP 1

STEP 1: Preparing the model

To successfully run the model, a few steps of preparation are required. This model is read-only. By saving the model with your new site name, both your site-specific model and the original file will be easily accessible.

Instructions

1. Open the model on a PC computer
2. Enable macros
   - A pop-up window will prompt you "This workbook contains macros. Do you want to disable macros before opening the file?"
   - Select "Enable Macros" to continue
3. Install the "Solver" add-in

> **Installing Solver:**
>
> 1. Go to the **File** toolbar and select "Options", and then "Add-ins"
> 2. In the pop-up Manage box, click "Excel Add-ins" and then select "Go"
> 3. An "Add-ins available" box will popup. Check the "Solver Add-in" box from the list. (if Solver is not listed, select "browse" and look for Solver.xlam)
> 4. Solver should now be listed in the "Analysis group" under the Data tab

4. Save the model. This model is read-only. By saving the model with your new site name, both your site-specific model and the original file will be easily accessible.
   - Go to **File** toolbar and select "Save As" from the pull down
   - Select the location on your computer where you wish to save your model
   - Save the model with your site name and date, using an underscore for spaces
     - Ex: *Inabanga _Dec2014*

STEP 2: Input the Habitat Characterizations for your TURF-Reserve site

This step will translate spatial habitat mapping information (seagrass, mangroves, coral reefs, etc) to the computer model.

> **Excel Tabs Needed:**
>
> - Habitat Characterization (*GREEN)*
>
> **Materials Required:**
>
> - Community maps of habitat gridded to 10 x 10 matrix collected during the PCRA

HABITAT TRANSLATION KEY:

Habitat types are coded by both color and numbers. Mapping may vary per site, so double check mapping legends before translating data.

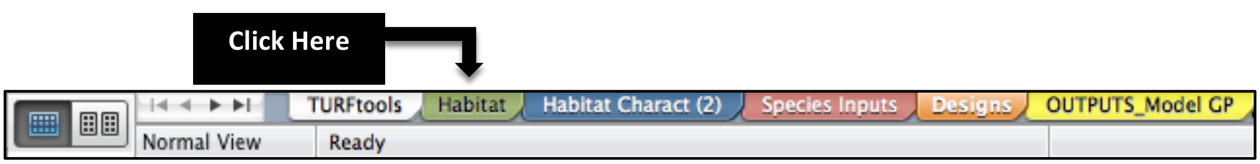
The default habitats and colors are:

1) Mangrove—DARK GREEN
2) Degraded Mangrove—LIGHT GREEN
3) Coral Reef—RED
4) Degraded Coral Reef—PINK
5) Seagrass—ORANGE
6) Sandy Bottom—YELLOW
7) Mudflats/ Estuary—PURPLE
8) Open Ocean/ Channel/ Pass—BLUE
9) Mariculture—LIGHT BLUE
10) Rocky Shoreline—BROWN
11) Land—TAN
12) Other—LIGHT BLUE

1. Mangrove	**2. Degraded Mangrove**	**3. Coral**	**4. Degraded Coral**	**5. Seagrass**	**6. Sandy Bottom**
7. Mudflats/ Estuaries	**8. Open Ocean/ Channel**	**9. Mariculture**	**10. Rocky Shoreline**	**11. Land**	**12. Other**

Instructions:

1. Click on Habitat Characterization 1 tab (*GREEN)* on the bottom bar.



2. Make a list of up to 12 key habitats from the community mapping exercise. All important habitats for all target species should be included in this list. **If the default habitats match the listed habitats from mapping, skip to step 4.**
3. To change the habitat name: simply click on the cell you would like to change and type in the more appropriate habitat types/name (ie- local names for habitats).

Eg:

Kelp Forest	**Degraded Kelp Forest**	**Deep Rocky Reef**	**Tidal Rocky Reef**
1	**2**	**3**	**4**

Similarly, if different areas of the same habitat have significantly different characteristics that are relevant to the target species, those can be entered into the model as separate habitats.

Eg:

Coarse Branching Coral	Fine Branching Coral	Deep Water Soft Coral	Mounding Coral
1	2	3	4

★ ***FEWER THAN 12 HABITATS?*** *That's okay! If your site has fewer than 12 sites, click on the colored cells that are not being used and delete the habitats names. These cells can be left blank.*

4. Use your 10x10 gridded habitat map to guide you through translating habitat information into the model. Each square on your habitat map corresponds to one patch in the matrix.
5. For each patch in the matrix, assign the appropriate habitat number that corresponds to the habitat type from the community maps. Use the legend at the top of the page. To change the number, click on the cell, type the number, and press "enter".

★ ***MULTIPLE HABITAT TYPES IN ONE PATCH?*** *No problem! For patches with multiple habitats choose the habitat that covers the largest percentage of that patch. No patch can have two habitat types. If multiple habitats are evenly distributed within one patch, select the habitat that is most important to your target species.*

6. Scroll over to column O and column P to enter the "System Scale" in linear meters. The map does not have to be square, so enter the height and width used in the mapping. The total square meters and hectares will auto-populate.

Step 3: Input Areas of Interest maps

This tab is used to indicate areas of interest and/or importance to the community within the mapping area. These "Areas of Interest" are used in the comparison of designs and can include important zones (spawning areas, nursery grounds, etc) or areas of use (fishing zones, tourism areas, etc). Depending on these areas, it may be interesting for the community to see how various TURF-Reserve designs overlap with these regions. It can also be useful for identifying potential conflict areas.

Excel Tabs Needed:

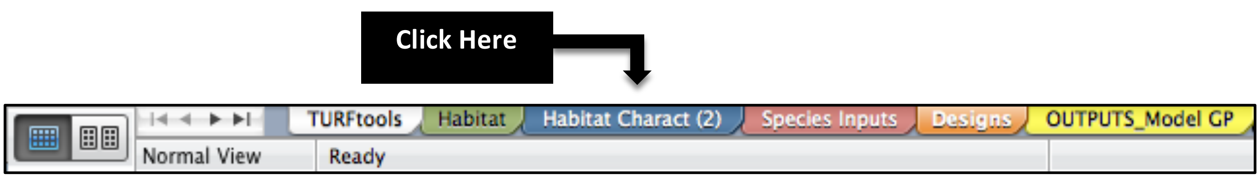
- Habitat Characterization (2) (*BLUE*) aka-areas of interest

Materials Required:

- Community maps areas of importance (spawning areas, nursery grounds, fishing grounds) gridded to 10 x 10

Instructions:

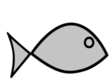
1. Click on the Habitat Characterization 2 Tab (*BLUE)*



2. Select the three most influential and important areas of interest to your community from the drop down menu.

HOW TO SELECT FROM A BUILT IN PULL DOWN MENU:

- Select the menu by first clicking on the desired cell.
- Cells with pull down menus will have a gray up/down arrow on the right of the cell.
- Click the arrows to display the drop down menu and make selection



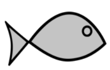
3. If a given area of importance to your community is not listed, simply click on the colored cell and type in the appropriate name.
4. Use your 10x10 gridded habitat map to guide you through translating "Areas of Interest" information into the model. Each square on your map corresponds to one patch in the matrix.

5. For each patch in the matrix, assign the appropriate number that corresponds to the area of interest from the community maps. Use the legend at the top of the page. To change the number, click on the cell, type the number, and press "enter".

Overlapping "Areas of Interest"? Let's discuss…

★ *If more than one characterization applies (eg: both nursery ground and spawning area), choose the characterization that is most important to the community when comparing designs. This is at the discretion of the inputter.*

Ex: Coral trout spawns in 5 different areas, but the nursery ground is only found in one area that overlaps with one of the spawning areas. To ensure that nursery grounds are represented spatially, the data site manager may choose nursery ground over spawning area for that patch.



Step 4: Complete the Species Inputs for each Target Species

Here, up to 5 target species for the TURF-Reserve site can be selected. Data inputter will answer questions about each species where information is known. If data is unknown, the model will supply average values.

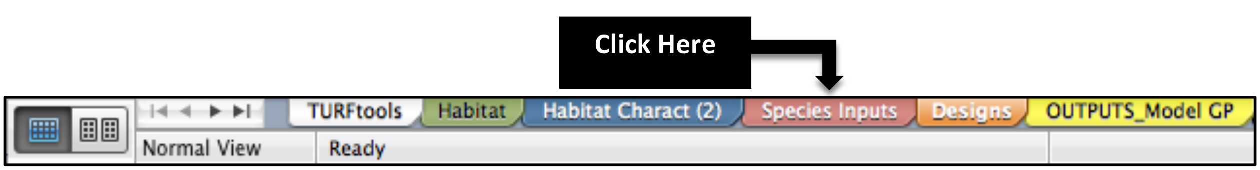
```
Excel Tabs Needed:

      •  Species Inputs (RED)
Materials Required:

      •  List of priority species at the site
      •  Biological information on target species (if known)
            •  Adult home range
            •  Growth rate
            •  Species' preferred habitat types
            •  Status of fish populations in important habitats
      •  Optional: FLAGS- Species selection and any related surveys,
```

Instructions:

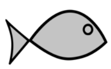
1. Click on Species Input tab (*RED*)



2. Complete the information in each colored column by following steps A-H below
3. Repeat for every selected target species (up to 5) in each subsequent columns

A) Species Selection (row 3): These are the pre-selected target species chosen by communities
   1) In the first *DARK BLUE* column (A), choose the site's first target species from the dropdown list in row 3. Species are listed alphabetically.

> ***IS MY SPECIES LISTED?*** *Maybe. Maybe not. But it's okay. Have a list of the target species in your area available with their scientific names. If it is listed, picking a species from the drop down menu will be helpful by automatically populating known biological data. A photographic list of local species may also be helpful when choosing species from the drop down.*



   2) If the species is not on the list, click on the cell (A4), and type the name of the target species in the column.
   3) The name of the target species will appear in several input categories, and for species for which there is stored life history data, values will auto-populate. (These categories include: home range, intrinsic growth rate, price, and cost).

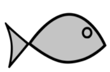
B) Adult Range (rows 7-8): Adult home range, or dispersal range, is the area in which a species lives and travels. This variable determines how much of species growth stays within a given patch versus disperses outward. Therefore, home range impacts how effective the size of the TURF-Reserve is in capturing the target species scale of movement.
   1) If you selected a species from the drop down menu, this information will auto-populate for steps B + C. SKIP TO STEP D.
   2) If the name of the target species was NOT on the list in Step A, select the species with the most similar adult home range to the target species.

C) Species Growth Rate (rows 10-12): The rate of population growth of the target species is indicated by the species' intrinsic growth rate. In the model, the growth rate determines how fast the population grows, influencing the number of new individuals entering the system. Growth rates have been provided for some target species.
   1) If you selected a species from the drop down menu, this information will auto-populate. SKIP TO STEP D.
   2) If the value does not auto-populate, the intrinsic growth rate cell (row 11) reads 'NA', or contrary site information is available, there are two options:
      - 1- Use the drop down menu to select the species with the most similar perceived growth rate (A11).
      - 2- If local data or literature-reviewed data provides a more accurate local intrinsic growth rate value, it can be manually entered by clicking on the cell (A12) and entering the value.

D) Overall Stock Status (rows 14-15): This value indicates the overall condition of the stock as compared to a pristine stock. Stock status helps determine the initial stock in year 1.

1) Choose a qualitative stock level from the dropdown menu in row 15 (pristine, high, average, low, depleted). To decide the status of the stock, consider how its current abundance and overall health compares to historical records. Potential impacts that may lower the stock status include overfishing, habitat degradation, and pollution, among others. Do not consider habitat preference at this point, but instead think about overall stock status in the entire mapped area.
    a. Pristine—no fishing is present and fish stocks are high
    b. High—fish populations are increasing in this habitat
    c. Average—fish populations are neither increasing nor decreasing
    d. Low—fish populations are decreasing
    e. Depleted—fish populations are much lower

NEED HELP DETERMINING YOUR STOCK STATUS? *There may be help available! See if your site has done any assessments of your target species over time. Trend diagrams from community surveying can be very useful*



E) Habitat Use and Stock Status: (rows 17-30):

- ***Habitat Use***—Understanding which habitat types are occupied (and to what extent) by each target species helps determine the maximum population size of the target species that a habitat can sustain indefinitely. This number will change for different habitat types. In the model, the habitat use helps determine the initial stock in a given habitat. It also affects how fast a population grows and limits its total growth.
- ***Stock Status***—Stock status is the state of target species populations in a given habitat relative to a pristine stock. Even though a species is living in its primary habitat, given fishing pressures or habitat health, the stock could lower than if it were in a pristine environment. Target species will have different stock status in different habitats given their biological characteristics. Stock status helps determine the initial stock in year 1.

1) HABITAT USE (column B for species 1)— Habitat types from Step 2 will auto-populate in rows 19-30. For any habitats applicable, select from the drop down menu how each habitat serves the target species using the following definitions.
    - Primary Habitat—habitat where the species is most commonly found as an adult
    - Secondary High—habitat where the target species is often found, but is not considered its primary habitat
    - Secondary Low—habitat where the target species is occasionally found, but less than 'Secondary High'
    - Transient/ Low Density—areas where species may travel through or reside temporarily or at low concentrations
    - Not Present—habitats where the target species is not found

WHAT IF MY SPECIES IS FOUND IN MULTIPLE HABITATS? *No worries! More than one habitat type can serve as a species "primary habitat" or "secondary high", etc.*

2) STOCK STATUS (column C for species one)— The stock status determined in Step D will automatically fill the status for each habitat. If it is known that there is significant variation in the status of a stock in a given habitat, then users may choose a different status for any given habitat. If the stock is not present, then ensure that 'Not Present' was selected for the habitat in 'Habitat Use' (see E1).
   - Pristine—no fishing is present and fish stocks are high
   - High—fish populations are increasing in this habitat
   - Average—fish populations are neither increasing nor decreasing
   - Low—Fish populations are decreasing
   - Depleted—fish populations are significantly lower or gone

F) Illegal Fishing (rows 32-34): This categorization estimates the amount of total catch/harvest of a target species that is caught illegally (by gear type, size, location, etc). In the model, this is calculated as a percentage of the total legal harvest in TURF areas (both in TURFS and reserves).
1) For 'Reserve' (row 33) and 'TURF' (row 34) choose the estimated extent of current or future illegal fishing relative to perceived average amongst other communities.
2) Choose illegal fishing extent using the following definitions:
   - High— There is more illegal fishing than the average community. Much of the total harvest from the area is due to illegal fishing (gear, location, encroachment).
   - Average—Illegal fishing is occurring in the area
   - Low—Illegal fishing is less than the average community (this may be due to effective enforcement and/or management, few number of fishermen, etc.)

G) Price (row 38): Understanding the local market price for which the target species sells will help inform the relative changes in profits.
1) If the target species was selected directly in the drop-down list in Step A, the price/kilogram ($PHP) will automatically load.
2) If the target species was not in the dropdown list, choose the species from the dropdown list with the most similar price per kilogram.
3) Additionally, if local data suggests a different price/kilogram (PHP), the price may be changed manually directly in the cell.

H) Cost (in Philippine Pesos) (row 42): Cost of fishing related to basic needs (gear, bait, gasoline) is set to $300 PHP/day.
1) If the target species was selected directly in the drop-down list in Part A, the cost/kilogram will automatically load.
2) If the target species was not in the dropdown list in Part A, choose the species from the dropdown list with the most similar cost per kilogram.

3) If local data suggests a different cost/kilogram (PHP), the price may be changed manually directly in the cell.

I) Primary Gear Used (Catch Coefficient) (row 45): Select the most commonly used gear for the target species. A value for the catch coefficient will then automatically load in the parameter tab based on the selection. This coefficient reflects the efficiency of the gear and how it affects profits.

J) Open Access Dynamics: This value explains the fishery trajectories of a target species in unmanaged (open access) areas. Fishing pressure in these areas may be increasing as profits decrease; or, if the fishery is stable it may continue at status quo. A stable fishery does not mean that it is a healthy fishery, but rather that stock levels are not changing. Where in this spectrum the fishery stands depends on an input from 0-1.
   - 1 – Enter zero if the fishery is well established and stock levels are stable, even if they are low or depleted. One way to determine this is to look at catch per unit effort (CPUE) trends if this data is available. If the trend is stable, it is a sign the fishery is in status quo. Another option is to consider the length of fish caught in the last ten years. If fishery landings are consistent in length this is also a sign that the fishery is in status quo. A value of 0 means the fishery is in perfect status quo and that stock levels are constant.
   - 2 – Enter 1 if the fishery is newly emerging and increasing in pressure. A value of 1 will result in an open access situation, in which stocks are harvested until profits equal zero. If fishing pressure is increasing (CPUE is decreasing and/or length of fish caught is declining); or, if the species is determined to be highly susceptible to overfishing in the PSA, this is a sign that the fishery should be considered open access.
   - 3 – If the fishery is somewhere in between, choose an approximate relative value between 0.0-1.0.

STEP 5: Input Your TURF-Reserve Design Options

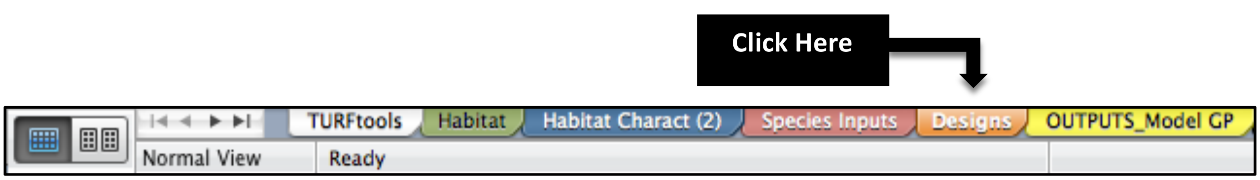
```
Excel Tabs Needed:

   • Designs (ORANGE)
Materials Required

   • Dimensions of the TURF-Reserve system included in the 10x10 map.
   • Community TURF-Reserve designs (could be pre-designed on
     community maps or designed on the spot)
```

Instructions

1. Click on "Designs" tab at the bottom of the page (*ORANGE)*



2. Assign the total length and width of the gridded map in linear kilometers.
3. Insert pre-determined TURF-Reserve designs into the 10x10 grid. These designs should be on the same spatial scale and map as the habitat mapping
   - Assign each patch a number according to the desired design where 1 is open access, 2 is reserve, and 3 is TURF.
   - After the first design has been entered, save the design by pressing the 'Save Design 1' button.
   - Repeat the process for up to 5 designs, each time saving by pressing 'Save Design 2,' 'Save Design 3,' 'Save Design 4,' and 'Save Design 5'

> ***WHAT IF MY PATCH HAS MORE THAN ONE MANAGEMENT USE?*** *For patches with multiple management designations (reserve, TURF, OA) on a map, select the management type that covers the largest percentage of that patch.*

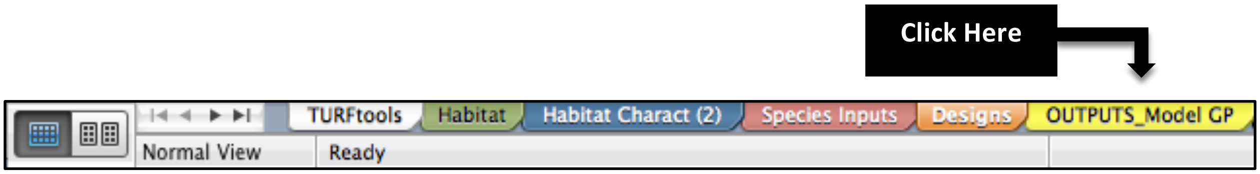
STEP 6: Compare Designs

> Excel Tabs Needed:
>
> - Outputs (*YELLOW*)
>
> Materials Required:
>
> - None

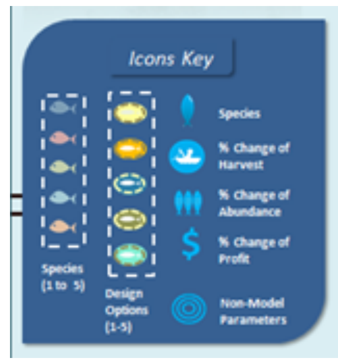
> ***REMEMBER!***
>
> *Think carefully what you want to communicate. As with any communication tool, it is important to select the appropriate information and/or visuals for your community. These combinations of outputs can be used to support the decision-making process.*
>
> *You may find more than one option to compare between species, designs, or both.*

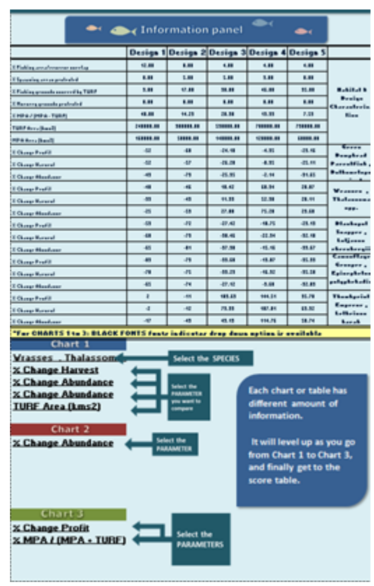
Instructions

1. Select the Outputs tab at the bottom of the page (*YELLOW)*



2. Familiarize yourself and your external audiences with the icons key that is provided in the dashboard.





3. Locate the "**Information Panel**". Here you will see the information available to be displayed in the charts and table. These raw numbers are not meant for sharing with external audiences. They are not specific forecasts, just general performance values.

   The lower half of the Information Panel contains the "**Chart Display Options**" with drop down menus. Return to this menu to make changes on output displays.

4. Since the charts display different "levels", or complexities, of information, we suggest to guide the outputs' evaluation with the user/participants using the following framework:

LEVEL 1: Output per single species

Instructions and questions guideline	Chart to look at:
In the Information, Panel choose 1 species (from the 5 you selected in the input section) from the SPECIES drop-down list. Question: How do the designs (per species) perform for each parameter?	**CHART 1.a** The spider webs, or radar charts, show the values of each parameter (i.e. harvest) for each one of the designs along a separate axis. The value will be higher as it reaches the outer ring.
Choose 1 species from the drop down menu. Question: What are the tradeoffs (per species) under different parameters?	**CHART 1.b** The graph will show the tradeoff between the two parameters that were chosen. The size of the circle will reflect the size or amount of the NON-Model Parameter chosen.
In the Chart 1 section of the Information Panel, choose a Non-Model parameter that you want to display Question: How do the designs perform for a single species regarding : Change in Abundance, Change in Profit, Change in Harvest and the NON-Model Parameter selected.	**CHART 1.c** The bubble graph allows you to compare different parameters across designs (for a single species).

LEVEL 2: ALL species – 1 parameter OUTPUT

In the Information Panel (Chart 2 section) choose a NON-Model parameter to be evaluated. Question: How do the designs perform, for ALL species, regarding different parameters?	**CHART 2** The chart shows how the parameter selected (y-axis) perform in each design across all species. You may notice that a parameter may perform similarly, or not, across different species.

LEVEL 3: ALL species / 1 parameter / 1 NON- Model Parameter

In the Chart 3 section of the Information Panel, choose 1 parameter and 1 NON-Model parameter that you want to be evaluated. Question: What is the tradeoff between a model parameter and a non-model across all designs and all species?	**CHART 3** This chart can display which species benefit under different combinations of parameters and design selection. This graph can be complex due to the amount of data represented, so should be used depending on the audience.

The table in the Information Panel is linked to the score table. There is no need to select any parameter. Question: Which design performs better across all species?	**SCORES** The score table shows the performance of each design for all species. The color scale ranges from light to dark, with darker values representing higher percentages or amounts values.

Extra!! Take-home OUTPUTS

From our experience, participants find useful to take-home some of the results from any workshop, meeting, or in this case, decision-making process.

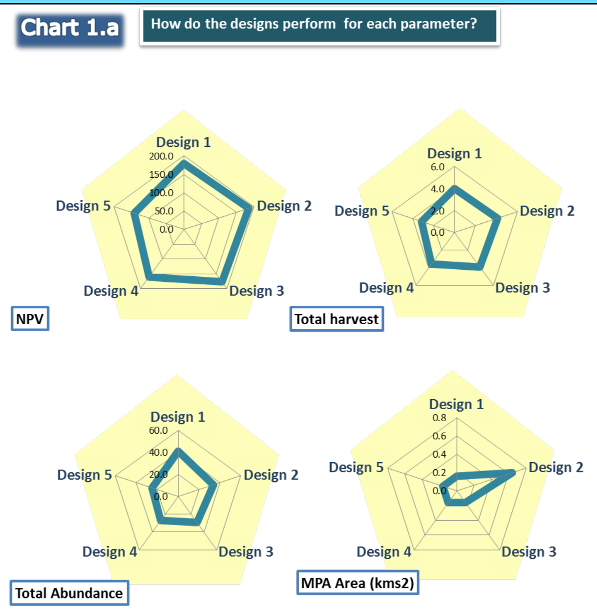
Instruction

1 – If you click on "VIEW" and then "Page Layout" you will see that the outputs are arranged in a way that can be printed and shared.

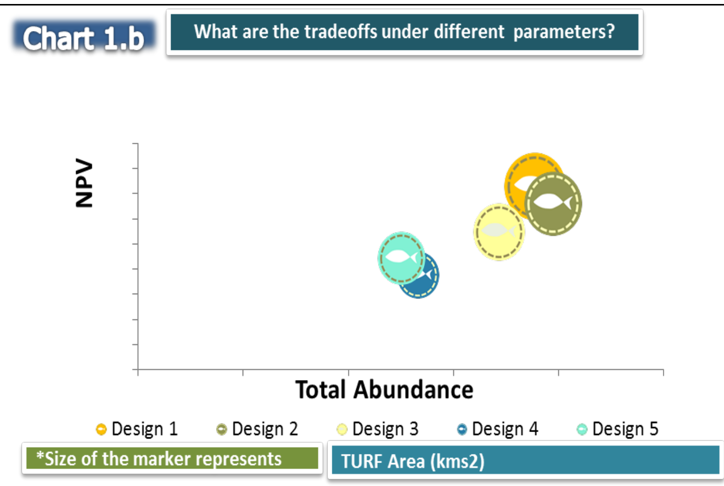
*** Be sure to communicate that the printed material is not a final decision, it is just information that was used to discuss the different options of designs. ***

APPENDIX 2: OUTPUT VISUALIZATIONS

The following figures show output charts and their corresponding plotted parameters. Only those parameters used in the figure are mentioned in the second column.

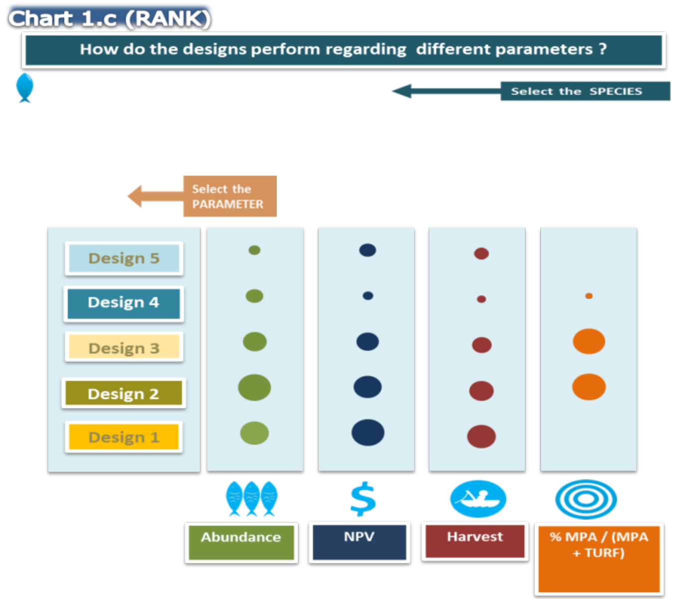
<table>
<tr><th>Chart Number & Visual Representation</th><th>Parameters Plotted</th></tr>
<tr><td>
</td><td>

Model Parameters
- Abundance
- Harvest
- Net Present Value

Non Model Parameters
- MPA Area (km^2)</td></tr>
<tr><td>
</td><td>

Model Parameters
- Abundance
- Net Present Value

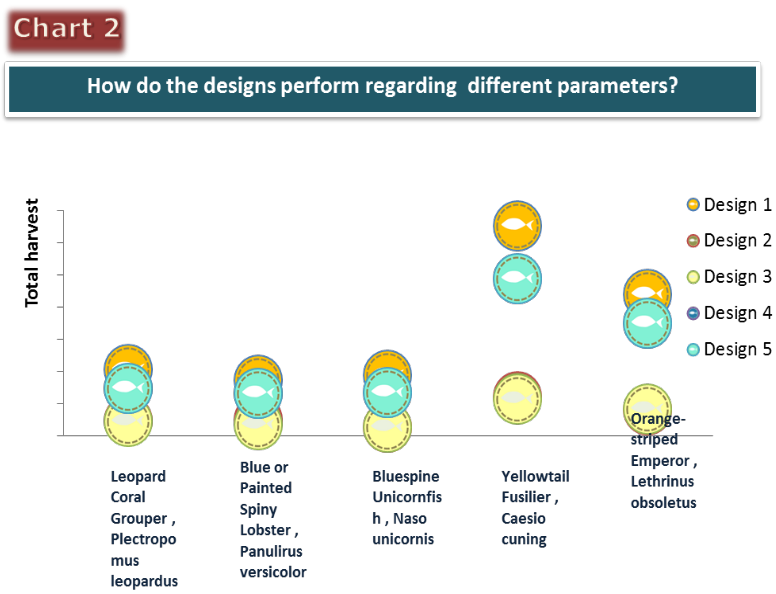
Non Model Parameters
- TURF Area (km^2)</td></tr>
</table>

<table>
<tr><th>Chart Number & Visual Representation</th><th>Parameters Plotted</th></tr>
<tr><td>


</td><td>

Model Parameters
- Abundance
- Harvest
- Net Present Value

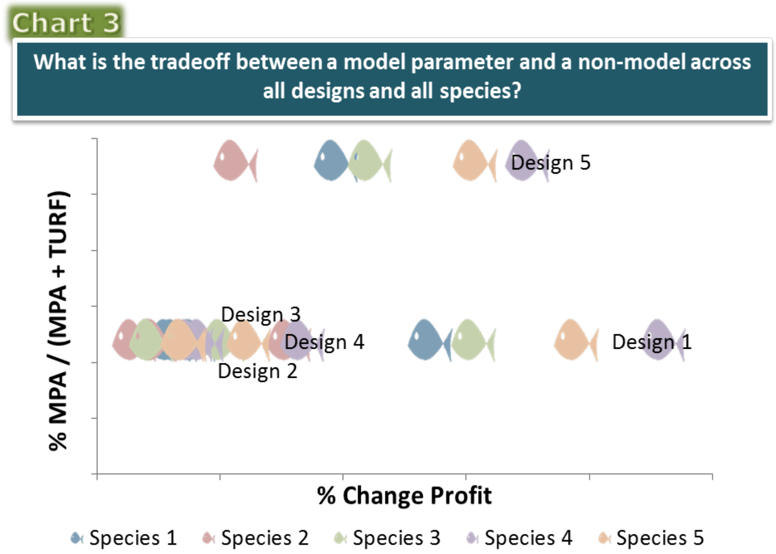
Non Model Parameters
- % MPA / (MPA + TURF)
</td></tr>
</table>

<table>
<tr><th>Chart Number & Visual Representation</th><th>Parameters Plotted</th></tr>
<tr><td>


</td><td>

Model Parameters
- Harvest

Species
- Leopard Coral Grouper
- Blue or Painted Spiny Lobster
- Bluespine Unicornfish
- Yellowtail Fusilier
- Orange-striped Emperor
</td></tr>
</table>

Chart Number & Visual Representation	Parameters Plotted
	**Model Parameters** - Percentage Change in Profit (Net Present Value) **Non Model Parameters** - % MPA / (MPA + TURF)
	**Model Parameters** - Abundance - Harvest - Net Present Value **Non Model Parameters** - % Fishing area/reserve area - % Spawning areas protected - % Fishing grounds covered -% Nursery ground protected - % MPA / (MPA+TURF) - TURF area (km^2) - MPA Area (km^2) **Species** - Leopard Coral Grouper - Orange-striped Emperor - Daisy Parrotfish - Streamlined Spinefoot - Indian Mackerel

APPENDIX 3: SENSITIVITY ANALYSIS

Baseline Parameters

The following baseline parameters were used in all sensitivity analyses. They reflect common mid-range input values in the context of the Philippines.

Home Range	100	Discount Rate	5%
Illegal Harvest in TURF	40%	Patch Length (x-coord)	100
Illegal Harvest in Reserves	40%	Patch Height (y-coord)	100
Cost	52	Catch Coefficient	60
Price	100	Closed System	Yes

Input Sensitivity Analysis

In the following sensitivity analysis, we sought the answer to two distinct questions:

1) How do model outcomes change based on the range of an input, and are there ranges for a given input that drastically change the outcome?

Answering this question helped us understand the implications of our input ranges and ensure that the model is performing in a logical manner. To execute the analysis we ran the model for a range of 100 values of a target input. For each of the 100 values, the TURF policy is optimized. We refer to this analysis as the 'optimized' run.

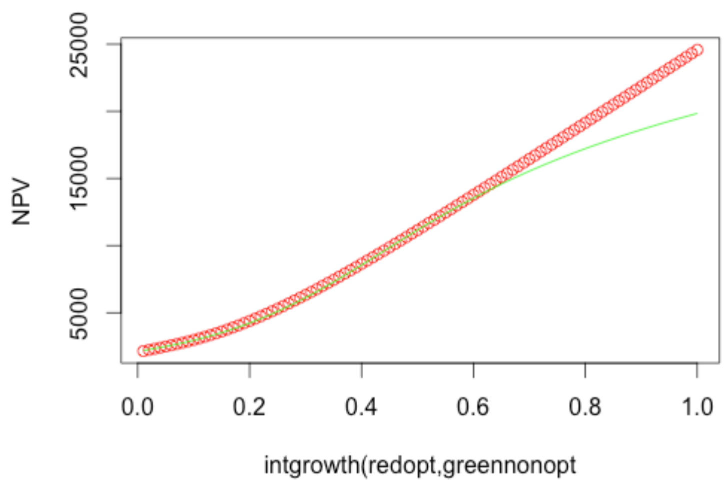
2) How does the precision of inputs change the model outcomes?

Given the data poor environment in which we contextualized this model, there are high levels of input uncertainty. This analysis provides the opportunity to quantify the impact of estimated variation for key inputs. This analysis will help determine for which inputs greater effort to accurately quantify model parameters is more valuable. To execute the analysis we ran the model with the same 100 values for each target input. However, we maintained the optimal TURF policy from the baseline parameters (defined above). We refer to this analysis as the 'non-optimized' run. Each analysis is based on a uniform mixed TURF-Reserve design containing 60% TURF, 12% reserve, and 20% open access (For complete results of the sensitivity analysis, see Appendix 3).

For each input presented below, the results of both analyses are plotted on the same graph versus TURF profit net present value (NPV). The red dots represent the first sensitivity analysis (S.A.) in which the TURF policy is optimized for each value tested. The green line reflects the S.A. results in which a TURF policy determined by the baseline parameters is maintained constant for each value of the input tested.

I) Intrinsic Growth Rate

Figure 1: Intrinsic Growth Rate Sensitivity Analysis



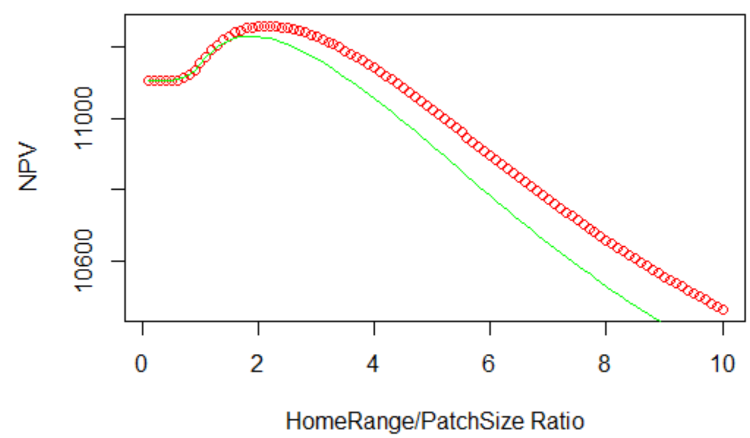
The intrinsic growth rate values in the life history species database included in the tool range from approximately 0.1-1.3. This range may change slightly in different locations, but we expect the majority of species to fall within a similar range.

The intrinsic growth rate S.A. logically features an upward sloping line. This is because greater intrinsic growth rates reflect species populations with faster population growth, and therefore greater ability to grow even under high fishing pressure. Since the populations grow more quickly, there is a higher optimal harvest policy for TURF areas. The second S.A., reflecting an inaccurate intrinsic growth rate input has a similar NPV trajectory, with increasing profit losses for higher intrinsic growth rates. This is logical as well because growth curves are not linear, and faster growing species present increasingly greater optimal harvest policies.

This implies that model users will see greater discrepancy in model outcomes when underestimating the growth rate of very fast growing species. However, we do not expect that species with growth rates higher than 0.80 will commonly be targeted as TURF species because such high growth rates are more common to smaller, pelagic species such as sardines. The key take-away for the model users regarding this input is that it is a key driver of model outcomes and therefore care should be taken to seek the best available data source for a given target species. When possible, local life history studies or catch-MSY deduced intrinsic growth rates from historical landings would provide the most robust input value.

II) Home Range:Scale Ratio

Figure 2: Home Range:Patch Size Sensitivity Analysis

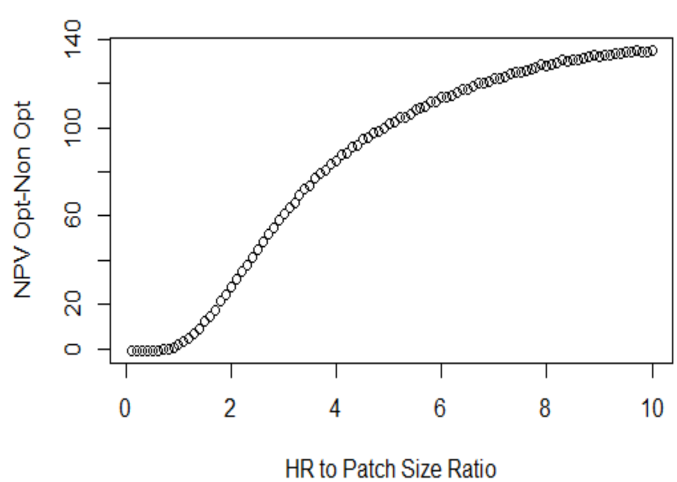


Home Range and Matrix Scale are inherently connected inputs because the scale of a home range matters only relative to the scale of the system. For instance, if a species home range is 1,000 meters and each patch is 1,000m across, the species is disperse in and out of the system at a different probability than if each patch were 1m across. Testing one without the other would provide an incomplete picture of the potential system dynamics. For this reason, we evaluated potential home range:patch size ratios.

The adult home ranges of the species we expect to be targeted in TURF management range from 1,000 to 50,000 linear meters based on literature review. The baseline ratio for this analysis is 1, but within a given TURF-Reserve design area ratios for different species may vary widely. However, it is not likely to be beyond 0-10.

The expected NPV is nearly constant at ratios of 0.5 or lower under both S.A. This is because at such low home range scales, there is not significant dispersal between patches. As the ratio increases, NPV profits increase due to the benefits of dispersal from reserves. The optimal home range to patch size ratio (for the given set of biological and economic baseline parameters) is found at 2.1 in the first analysis when the TURF policy is optimized for each ratio value. The optimal ratio is 1.9 for the second sensitivity analysis, but the maximum NPV is lower. From the maximum NPV point (Figure 4), both S.A. see a decline in NPV, with the non-optimized trajectory declining more sharply. When the home range grows much larger than the patch size, dispersal acts more as common pool than Gaussian, meaning growth is distributed equally among all 100 patches. Therefore, spillover from the well-managed TURF patches and unfished Reserve patches are shared relatively evenly among Open Access patches. Consequently, the TURF patches lose

Figure 3: NPV lost with Estimation Error in Home Range:Patch Size Ratio



more of the benefit of increased stock levels from implementation of an optimal harvest policy. The non-optimized trajectory suffers a greater decline, and Figure 5 demonstrates the increasing impact of a high home range:scale ratio coupled with an optimal harvest policy based on the baseline parameter of a 1:1 ratio. However, overall the loss under the non-optimized NPV in S.A. 2 is not very high relative to the total NPV (Figure 4.).

Given the ability of model users to obtain actual system scale measures through community mapping and zoning workshops, the extensive database of home range values from recent published literature, and the insensitivity of the model outcomes to the input range, these parameters require less caution than other, more sensitive inputs.

III) Price:Cost Ratio

Similar to the home range to scale ratio, price and cost are inputs that necessitate joint analysis. If price and cost each go up, there is a different result than if just one of the two inputs go up.

The resulting trajectory for both S.A. appears positive and linear. This is a logical result because NPV is a reflection of total profits over 20 years and profit is constant per unit of harvest. The difference between the optimized (S.A. 1) and non-optimized run (S.A. 2) is difficult to see in Figure 6, but is clearer in Figure 7 where the difference in NPV between the two S.A. analyses are graphed for each price:cost ratio. The difference between NPV increases as the ratio increases because the losses from not optimizing are more accentuated. It is important to note that the differences in NPV are not very large, which means that precision in this input is not essential for the results of the model. As in S.A. 1, NPV lost due to a sub-optimal harvest policy is linear because the price:cost ratio is constant per unit harvest.

Figure 4: Price:Cost Ratio Sensitivity Analysis

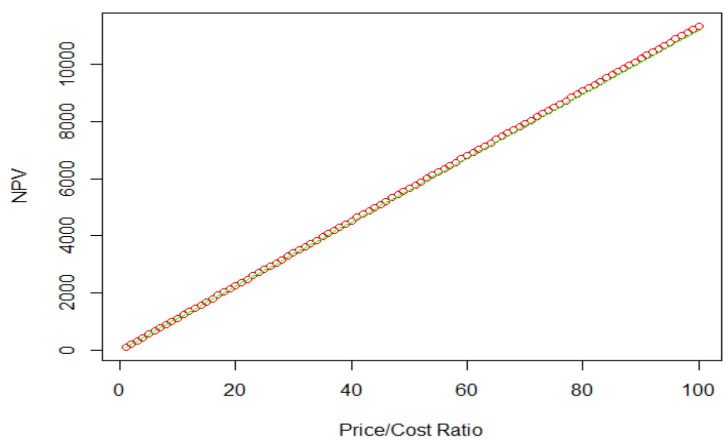
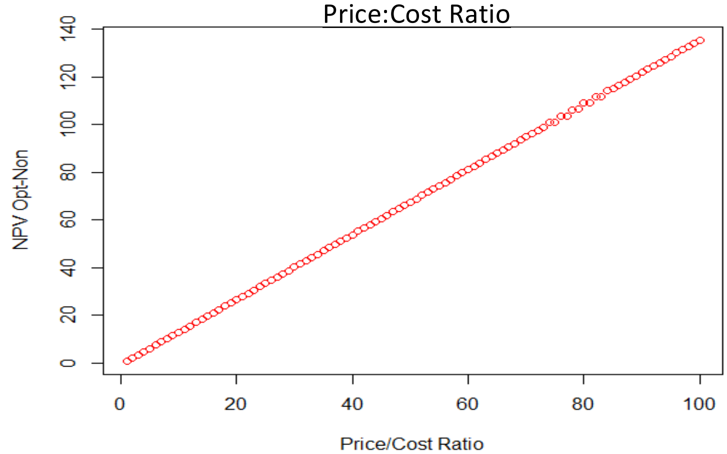


Figure 5: NPV Lost with Estimation Error in Price:Cost Ratio



Similar to system scale, we expect price and cost information to be relatively certain and robust inputs given their inherent quantitative value and relevance to local community members. This nature of the inputs, along with the linear relationship to profit outcomes, makes this parameter of less concern for model users.

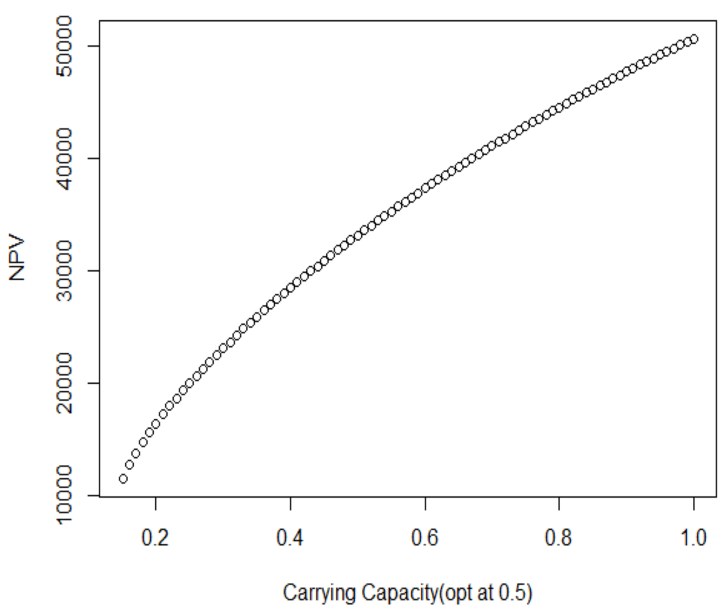
Sensitivity Analysis of Habitat Driven Parameters

In this model, carrying capacity and stock levels are determined by habitat-specific characterizations. For each habitat, one of five (5) carrying capacity and stock level values are chosen. Therefore, for each of the 100 patches there are five (5) potential values for the carrying capacity and stock level, respectively.

I) Carrying Capacity

To better understand the sensitivity of carrying capacity, we ran an all-TURF design with a consistent carrying capacity and initial stock of 0.5 to find an optimal policy. We then ran the same design with 100 carrying capacity values ranging from 0.0-1.0.

Figure 6: Carrying Capacity Sensitivity Analysis



In this case, there is an upward trajectory of NPV. The stock level cannot increase beyond the system carrying capacity and thus profits will always be limited by this factor. For carrying capacities above 0.5, although the harvest policy is not optimized correctly, profits are still increasing because the system has higher stock capacity and is under-harvesting.

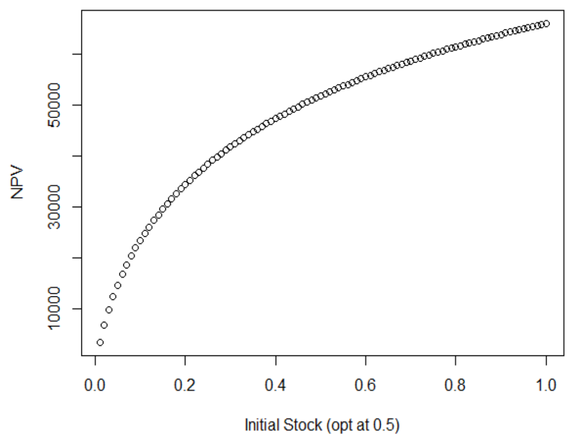
This analysis shows that precision in this input is necessary, as changes in this value have important repercussions in the model response (NPV). It can also be seen that the response is almost linear, therefore under or over estimating this number has similar consequences.

II) Stock Status

As in the carrying capacity analysis, we ran an 'All TURF' design with a stock status of 0.5 across all patches to determine an optimal policy. We then tested 100 values of stock status using the same optimal policy.

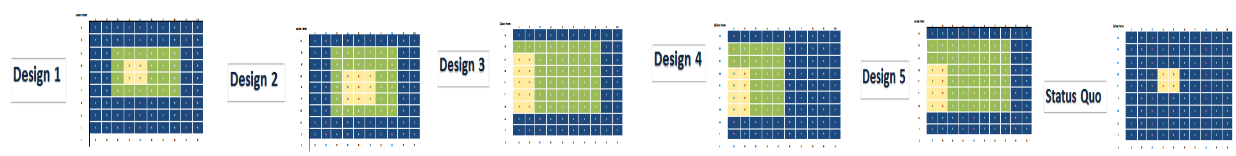
There is also an upward trajectory of NPV values, but the slope changes more significantly than with the carrying capacity analysis. This means that when overestimating the stock status (harvest decisions based on an artificially high stock status), relatively more NPV is lost per incremental error than when underestimating the stock status. This result is expected because an excessive harvest policy will deplete stocks over time and decrease harvest in the long runThe results of the analysis for both stock status and carrying capacity demonstrate the important influence of the inputs on model outcomes. This is particularly challenging because these inputs are parameterized on a relative scale given the intensive data collection requirements to determine true spatial values for these factors in a given system. We suggest users incorporate the most local data possible when considering the qualitative categorization of these variables, particularly stock status. The user guide suggests supplementary data sources to help guide users to an appropriate categorization.

Figure 7: Stock Status Sensitivity



Input Sensitivity across Outcomes

The first two sensitivity analyses (input range and precision) helped us identify the most influential and precision-sensitive parameters. This helps inform users which inputs merit most careful parameterization. However, the primary goal of the tool is to inform users of relative outcomes across different designs. Therefore, as long as the relative ranking of designs remains constant across a range of inputs, the overall results will not change, particularly because all outcome values are normalized relative to a uniform status quo scenario. We selected the three most sensitive input parameters: carrying capacity, intrinsic growth rate, and stock status and ran the model under five designs:



The results demonstrate that while designs affect the trajectory and scale of the model outcome variation for these parameters, the overall 'ranking' of designs does not change. Where outcomes between designs are similar, this will be demonstrated in the model output charts and score table. Therefore, we believe that despite the uncertainty and sensitivity of these parameters, the users may still consider the relative performances and tradeoffs.

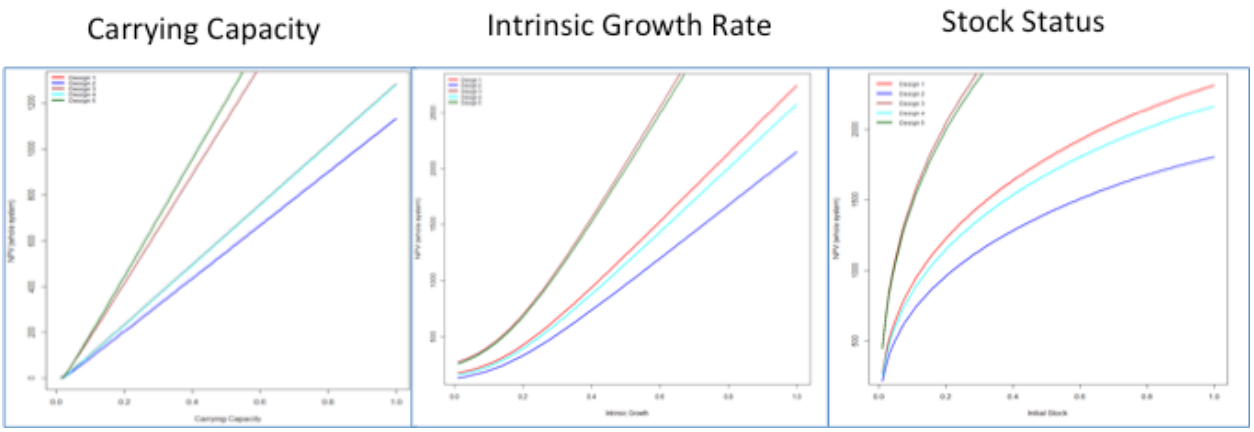


Figure 8: Performance of Carrying Capacity, Intrinsic Growth Rate, and Stock Status under Five Designs.

Other Parameter Testing Results

The following sensitivity analyses were performed only under the optimized scenario (in which an optimal harvest policy is calculated for each value of the input tested). No further tests were executed due to the more simplistic dynamic of the target variable.

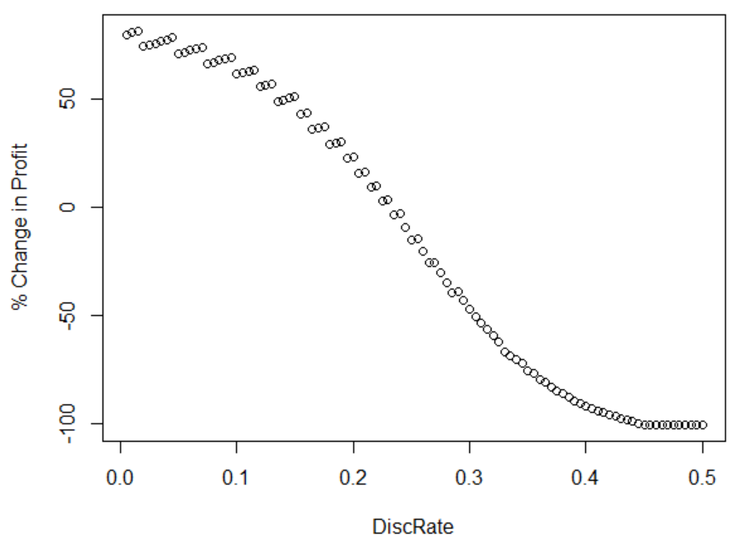


Figure 9: Discount Rate Sensitivity Analysis

I. Discount Rate

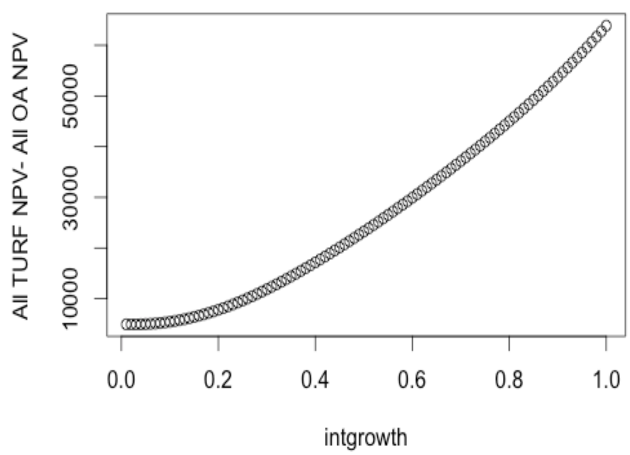
The discount rate reflects the time value of money and the intensity of preference for profits in the near term versus the long term. The higher the discount rate, the greater the preference for profits now. Therefore, we would expect that at higher discount rates, an optimal policy would be higher in order to maximize profits in the nearer term. The result of this single policy over 20 years may then deplete a stock. The S.A. results demonstrate this dynamic. The baseline value for the discount rate in the model is 5% (0.05). Although in a developing country a discount rate may be higher, we chose this baseline value in order to reflect the Fish Forever goal of long-term sustainable fisheries.

II. Catch Coefficient

Currently, the catch coefficient quantities provided in our model for the Philippine context begin at 20, and therefore this input does not affect profits to a significant extent relative to other inputs. In the case that catch coefficient values are ascertained to be under 20, the precision of this input parameter would become more consequential to model outcomes.

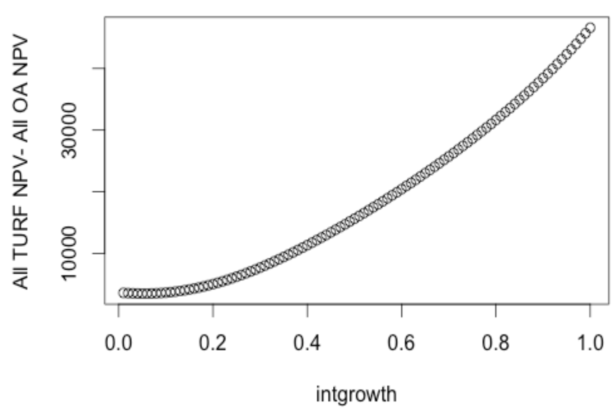
Using Intrinsic Growth Rate to Test Open Access (O.A.) versus TURF Design Performance

Figure 10: Intrinsic Growth Rate O.A. versus TURF with Illegal Fishing at 0.4



The model was run with an 'All TURF' design and an 'All Open Access' design. For every value of intrinsic growth (r), the optimal TURF policy was determined for the 'All TURF' design. For every value of r, the 'All TURF' design outperformed the 'All Open Access' design. This is an important verification for the model because if an Open Access design outperformed a TURF design, the model would present incongruent guidance with the other TURF-Reserve design tools and current theory on fisheries management.

Figure 11: Intrinsic Growth Rate O.A. versus TURF with high Illegal Fishing



In this analysis it is also important to note that the 'All TURF' design outperformed the 'All Open Access' design despite an illegal fishing level of 0.4 in the TURF. To see the effect of an extremely high illegal fishing rate we also ran the analysis with an illegal fishing rate of .9. Even at this extremely high illegal fishing pressure, the All-TURF design still outperformed Open Access in terms of Net Present Value.