Integrating Ecosystem Services into a Prioritization Model for Surf Protected Areas

Guarda do Embaú World Surf Reserve, Brazil; Photo: Kort Alexander

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UC SANTA BARBARA Bren School of Environmental Science & Management

CONSERVATION INTERNATIONAL

SAVE THE WAVES COALITION

Surf Conservation Partnership

A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Bren School of Environmental Science & Management

As authors of this Group Project report, we archive this report on the Bren School's website such that the results of our research are available for all to read. Our signatures on the document signify our joint responsibility to fulfill the archiving standards set by the Bren School of Environmental Science & Management.

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

____________________________________	March 2023
Advisor: Benjamin Halpern	Date

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Abstract

This project evaluated potential and priority locations for the establishment of Surf Protected Areas (SPAs) along the entire coastline of Brazil. To conduct this assessment, we 1) assessed the quality of Brazilian surf breaks using the established Surf Conservation Index (SCI) developed by the Save the Waves, a member of the Surf Conservation Partnership (SCP), and 2) expanded the SCI with the addition of two key ecosystem service assessments for mangrove carbon storage and coastal protection. This assessment created a list of top surf spots for priority conservation based on a ranking system including aspects such as wave quality, biodiversity, social, and economic significance. The addition of the ecosystem service assessment suggests that surf ecosystems in Brazil provide significant carbon storage and coastal protection and changed which sites were considered the highest priority for conservation. This result has significant implications for the management of surf resources. Additionally, we conducted a review of existing surf conservation projects to distill good practices in the field of surf conservation and management. Surfing will likely continue to be leveraged as a vehicle for conservation in the future; understanding broader implications of this work and developing clear guidelines is key for scaling up programs like the SCP.

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List of Acronyms

MPA	Marine Protected Area
SPA	Surf Protected Area
SCI	Surf Conservation Index
SCP	Surf Conservation Partnership
WSR	World Surf Reserve

Objectives

Establishing a surf protected area (SPA) or a network of SPAs first requires the identification and ranking of potential sites. To achieve this, the Surf Conservation Partnership (SCP), a joint program between Conservation International (CI) and the Save the Waves Coalition (STW), uses a tool called the Surf Conservation Index (SCI), which utilizes a pressure-state-response framework (Gallegos and Arroyo Rodríguez, 2021). This framework aims to conserve surf breaks that are relatively pristine, with low development pressure; contain important resources like high quality surf, biodiversity, and tourism infrastructure; and already have some level of environmental protection in place. This project aims to aid our client in developing SPAs in Brazil. To do this, we conducted the first ever country-wide study of the Brazilian coastline to identify and prioritize surf breaks for conservation. We also expanded on the client's existing SCI prioritization model by integrating a novel analysis of ecosystem services into the framework. The output of this analysis will support the broader work of our client to establish a global network of SPAs rooted in community- and ecosystem-based management.

Our project was executed with the following objectives:

1) Identify and rank priority surf breaks for conservation in four coastal administrative regions of Brazil.
2) Develop a reproducible method to quantify selected ecosystem services and incorporate them into the existing SCI.
3) Synthesize "good practices" for surf-based conservation across four primary research categories: surf resource identification, protection strategies, surf tourism management, and surf valuation.

Significance

Global Context

Surf resources, broadly defined as the breaking wave, land beneath the wave, and some of the surrounding marine, coastal, and terrestrial environments, often contain or are located in close proximity to important ecosystems and biodiversity hotspots worldwide (Reiblich, 2013). This connection of surf spots with natural assets, combined with surfing's global popularity and economic value, means that surfing is increasingly being leveraged as a vehicle for conservation.

Coastal ecosystems play an important role in regulating global temperature by sequestering carbon and protecting inland areas from erosion and sea level rise (Alongi, 2009). These ecosystems, as well as sensitive near-shore habitat like coral reefs, are strongholds of biodiversity that also provide a range of other services including tourism, recreation, and food provision. Yet these ecosystems are increasingly under threat from habitat destruction, pollution, overfishing, and other stressors (Reineman et al., 2021). Protection of coastal ecosystems will play an important role in mitigating impacts of climate change and preventing biodiversity loss around the world.

Considerations for ecosystem services, or the benefits people receive from processes in the natural environment, can be used to further enhance protection of coastal ecosystems. Mangroves and coral reefs are two habitats of particular interest that are assessed in this project. Mangroves are important for both climate change adaptation and mitigation. They can store three to five times more carbon compared to other tropical forests (Donato et al., 2011). Their intricate root systems stabilize sediments to prevent erosion while reducing wave action and providing nursery habitat for juvenile fish, crustaceans, and bivalves (Kazemi, Castillo, and Curet, 2021). A global analysis found that mangroves may provide $65 billion of flood protection benefits annually (Menéndez et al., 2020).

Coral reefs, which host one quarter of total marine biodiversity, provide some of the best natural defense against coastal hazards (Knowlton et al., 2010; Reaka, 1997). Reefs can absorb as much as 97 percent of a wave's energy, providing benefits comparable to man-made defenses such as breakwaters (Ferrario et al., 2014). While reefs are not net absorbers of carbon dioxide, they play an important role in supporting carbon sinks like mangroves and seagrass beds by sheltering against storms and waves. They can also form deep lagoons where carbon may be sequestered through sedimentation (Carlson et al., 2021; Guerra-Vargas, Gillis, and Mancera-Pineda, 2020).

Despite their importance, these ecosystems are disappearing at an alarming rate. Globally, corals have declined by roughly 14 percent since 2009 and mangroves are declining at a rate of 1 to 2 percent per year due to habitat destruction and fragmentation, pollution, overharvesting, and climate-related changes in precipitation, storm patterns, temperatures, and sea level rise (Goldberg et al. 2020; Ward et al. 2016; Almond et al., 2022). These losses, coupled with projected increases in global temperature, will intensify negative impacts to human wellbeing – driving further food insecurity resulting from sea level rise and increasingly variable and extreme weather patterns (Shivanna, 2022).

Proper protection and management of these ecosystems is essential for preserving the benefits they provide for biodiversity, carbon storage, coastal protection, and human wellbeing. Conservationists can take advantage of the overlap between surfing resources and priority conservation sites by leveraging support from the international surfing community to achieve wins for both coastal ecosystems and surf resources.

Why Surfing?

Surf conservation takes a unique approach to coastal ecosystem protection by recognizing surfing's engaged constituency and economic value as well as the social structures and cultural systems that exist in dynamic coastal zones. Conservation that addresses ecological, economic, and equity-based impacts is sometimes referred to as achieving the "triple bottom line" in conservation (Halpern et al., 2013).

Surf-based conservation has gained momentum over the past decade as surfers and environmentalists have made the connection between healthy coastal environments, vibrant local economies, and good waves. Global analysis of surf locations indicates that roughly a quarter of known surfing locations are within 5 kilometers of a key biodiversity area (KBA) but fall outside of existing marine protected areas (MPAs) (Figure 1). This highlights an opportunity for local communities to be engaged in the protection of coastal resources that support both their livelihoods and the environments they rely on (Reineman et al., 2021).

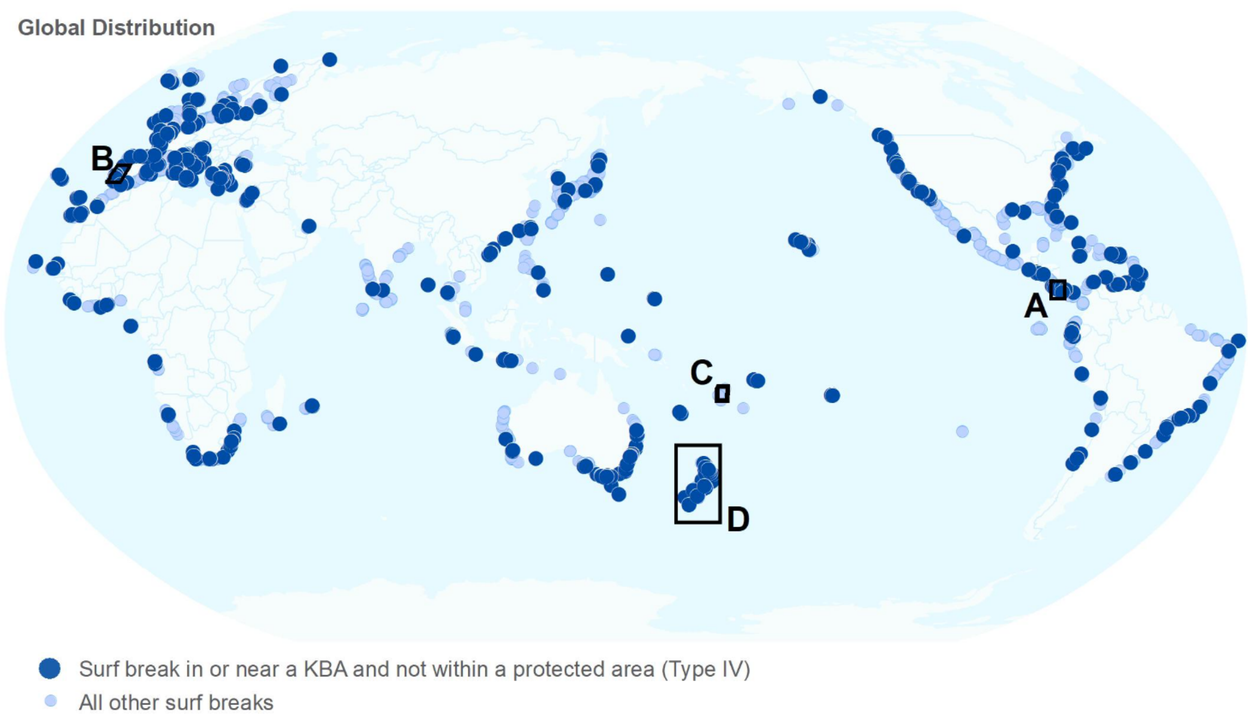

Figure 1. Global distribution of surf breaks. Dark blue dots represent surf breaks within 5 kilometers of a KBA but not within a protected area. All other surf breaks are represented by light blue dots (Reineman et al., 2021).

An SPA is different from an MPA in that protection of surf resources typically also includes direct protection of terrestrial aspects (e.g., freshwater systems, mangrove forest) that can impact the surf break and the features that shape them (Atkin, 2019; Reineman et al., 2021). The land-sea connection and emphasis on recreation access are the foundation of surf conservation. This necessitates a targeted approach to conservation that considers "cross-system threats" (Álvarez-Romero et al., 2011). This includes inland processes like deforestation and runoff from agriculture that can ultimately degrade coastal ecosystems and surf spots alike.

The increasing global surfing population puts additional pressure on surf resources, especially at premier surf locations that attract tourists (Mach and Ponting, 2021). This added pressure is a key reason why protecting surf breaks and the integrity of the coastal area they encompass is important in preserving the ecosystem services they provide. Increased usage can drive demand for investment in infrastructure and services that do not always align with the best interests of the local community or environment. Unchecked development and extractive activities can lead to the displacement of coastal communities, exacerbate poverty, and deepen both economic and environmental vulnerabilities (Reineman et al., 2021; Mach and Ponting, 2018). The stewardship of surfing resources through the designation of SPAs is an investment in natural capital that can yield significant and sustainable environmental, economic, and social returns when done mindfully (Ponting and O'Brien, 2014). SPA design is highly dependent on the goals of the people responsible for managing it and often does not involve restricted access or entrance fees. However, the creation of an SPA typically does require some level of community-led (or at least community-endorsed) management plans to ensure surf management meets the needs of both visiting surfers and locals (Mach and Ponting, 2018; Bennett et al., 2021; McGregor and Wills, 2017).

Practitioners acknowledge the fact that surf resources may not always contain the highest level of desirable conservation targets. What makes the surf conservation model effective is its support from a large, highly motivated international community with the shared goal of protecting coastal and marine ecosystems and their waves. This effort is also backed by the primary professional surfing organization, the World Surf League, which grants an additional level of visibility to this field (WSL, n.d.). The primary objective of this project is not to compare the efficacy of surf conservation to other forms of coastal protection or to assess its ability to meet conservation targets. Rather, it seeks to contribute to the growing consensus that surfing is an increasingly useful tool to raise awareness of and advocate for greater coastal protection.

Why Brazil?

Brazil is unique in that it is widely known as both a global biodiversity hotspot and as a wave-rich nation that has produced some of the world's best surfers. The Living Planet Index, a peer reviewed method for evaluating the state of the world's biological diversity, reports higher than average declines in the relative abundance of monitored species in Latin America relative to other regions over the past 50 years. The decline is primarily driven by changes in land and sea use including habitat loss and degradation (Almond et al., n.d.; Westveer et al., 2022). Brazil's seaboard – which accounts for 70 percent of its population and 80 percent of its gross domestic product – has experienced a high level of ecosystem loss. The Atlantic Forest, which once covered over 330 million acres of land in Brazil, has been reduced to just 12 percent of its original size. This is largely due to conversion into pasture and agricultural lands and expansion of urban and suburban areas. Along the coast in the Northeastern region the forest now exists as a thin strip, no greater than 40 miles wide. The forest has fared better in the south where it extends from the coast up to 200 miles inland. Even in its diminished state, the forest still harbors a biodiversity level equivalent to the Amazon Rainforest, yet is only protected across 2 percent of its area (Joly, Metzger, and Tabarelli, 2014; de Lima et al., 2020; Ribeiro et al., 2009; 2011; Tabarelli et al., 2005).

This project supports the protection of important coastal ecosystems by expanding the methodology used for evaluating and prioritizing SPAs to include coastal ecosystem services. The potential value of ecosystem services within these areas is not yet known but is likely significant (Beaumont et al., 2014). Specifically, we achieved this by quantifying the carbon storage and coastal protection provided by environments within a 10 km radius of each surf break in Brazil and integrating these values into the existing prioritization index. The inclusion of ecosystem services within a prioritization model for selecting SPAs presents a more holistic framework for surf break protection as practitioners look to scale programs. Our analysis considered the variations in ecosystems regionally within Brazil and used Brazilian states to bound our results (Figure 2).

Figure 2. Map of the states of Brazil. There are 17 coastal states, 16 of which contain surf breaks that are included in this analysis. The state not included in the analysis is Piauí. *Source: Wikipedia Media*

Surf Conservation Index

The Surf Conservation Index (SCI) carried out in this study has been deployed in several countries around the world, including Costa Rica, Mexico, and Fiji. The SCI is the first step in the process of identifying potential surf breaks for conservation. It analyzes anthropogenic pressure, biodiversity, characteristics of a break, and the response efforts in the areas surrounding a break (usually within a 10 km radius) to identify areas that meet criteria in support of SCP's goals of "conserving world-class waves and vital marine ecosystems that provide immense value to local communities" ("Surf Conservation Partnership", n.d.). Most recently, an

SCI was completed in Costa Rica and has been utilized to select a new area for a World Surfing Reserve (WSR). This is the first step to expanding the Surf Protected Areas Network. We hope to ("Surf Conservation Partnership" n.d.). Most recently, a SCI completed for the country of Costa Rica helped to identify and push for the designation of Playa Hermosa as a World Surfing Reserve (WSR), a first step in setting up a surf protected area network (SPAN) in the country. The results of our analysis will contribute to similar efforts to identify potential SPAs and establish SPANs along the Brazilian coastline.

Part 1: SCI and Ecosystem Services Analysis

Our analysis was split into two primary activities: 1) completion of a standard Surf Conservation Index (SCI) for Brazil; and 2) assessment of ecosystem services from mangrove carbon storage and coastal protection that was incorporated into a revised SCI. This process, and the resulting findings, are outlined in detail below.

Methods

Surf Break Identification

The first step to completing the SCI was to identify all possible surf breaks along the coast of Brazil. Once all surf breaks were identified and duplicate breaks were removed, surf breaks were grouped using Brazil's administrative regions to allow for regional prioritizations (Figure 3).

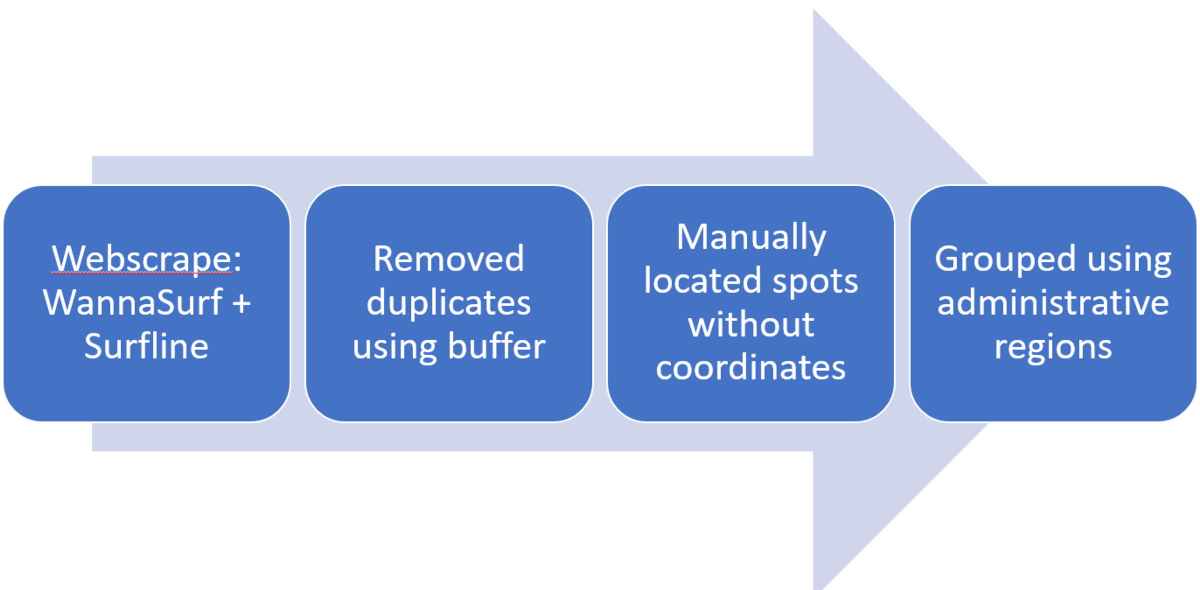

Figure 3. Surf break identification process. The above stepwise process was followed to gather and prepare surf break data to be used in the SCI.

To identify surf breaks, data were combined from two sources – WannaSurf and Surfline. The former is a public forum in which anyone can upload location and wave quality data for surf spots while the latter is a privately run surf forecasting company that maintains their own global surf database ("Brazil - WannaSurf, Surf Spots Atlas, Surfing Photos, Maps, GPS Location", n.d.; "Brazil Surf Report & Forecast - Map of Brazil Surf Spots & Cams", n.d.). Data was extracted from WannaSurf using web scraping code written and executed in the programming language R (version 4.2.2). Using this method, we gathered 317 surf breaks with and 95 surf breaks without exact GPS coordinate information. Thirty-seven of the 95 breaks were manually located and assigned geographic coordinates using the descriptions of the general location and names of the breaks. A total of 354 surf breaks were obtained from this process. Additionally, we received the locations of 333 surf breaks in Brazil from Surfline, courtesy of the Surf Conservation Partnership.

Next, duplicate surf breaks in the two datasets were identified and removed; WannaSurf locations were prioritized as they contain data on wave quality, direction, frequency, and experience level that Surfline locations do not. Buffers were drawn around all WannaSurf locations at three distances: 0.5 km, 0.75 km, and 1.0 km. After visual inspection in GIS software and consultation with surf experts and data managers at Save the Waves Coalition, 0.75 km was determined to be a reasonable radius to assume that a surf break appearing in both WannaSurf and Surfline datasets was a duplicate. Therefore, any Surfline locations within 0.75 km of a WannaSurf location were removed. 138 identified duplicates were removed using this method, resulting in 547 surf breaks that would be used in the analysis. Using a 1.0 km or 0.5 km radius would have identified 154 duplicates or 119 duplicates, respectively.

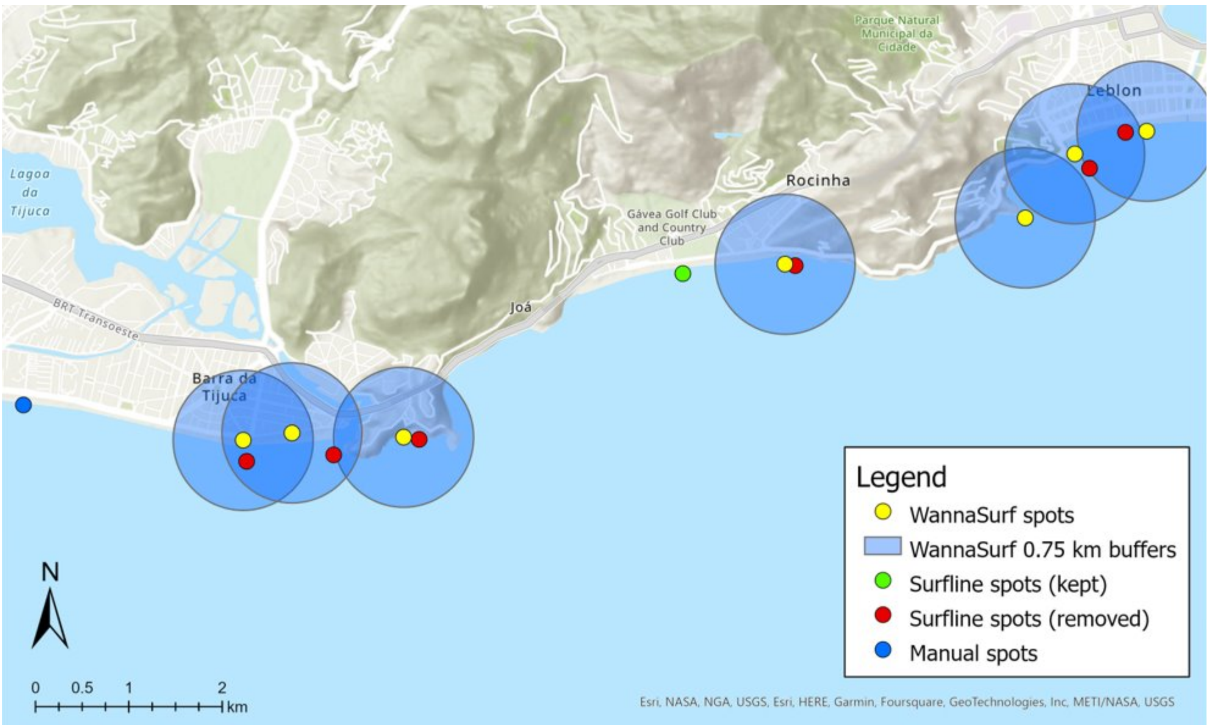

Figure 4. Removal of duplicate surf break locations among datasets. Surfline spots within 0.75 km radius (red) of WannaSurf spots (yellow) were removed. Surfline spots not within the 0.75 km radius of a WannaSurf spot (green) were retained. Surf breaks that were manually located are shown in dark blue.

Using the subnational administrative regions of Brazil as a guide, surf breaks were grouped into the following regions: North-Northeast, Southeast, and South. The breaks occurring in the North and Northeast regions were merged due to the small number of surf spots (n = 4) in the North. This grouping was done to enable regional-scale prioritizations in addition to the national prioritization.

Surf Resource Extent

To prioritize the surf breaks for conservation, we had to define the extent of the surrounding environment that would be considered as part of the “surf resource” to be evaluated. There are many ways to label the surf resource, with some practitioners, including the SCP, opting for “surf ecosystem” instead. This report uses “surf resource” as the operating term, defined as a combination of the break itself, submerged land and habitats beneath the wave, the offshore swell corridor that a wave must travel to reach shore and become a breaking wave, as well as near-shore terrestrial environments linked with beach access and the surfing experience. This holistic definition acknowledges that surf breaks are formed by physical features and processes that spatially extend beyond the immediate area where the wave is breaking. We defined surf resources as the area within a 10 km radius around each surf break. This definition does not incorporate the full extent of the processes that create waves but is meant to encompass a majority of the marine and terrestrial ecosystems that could affect or be affected by the surf break across all different types of spatial data that we used. To examine how buffer size affects prioritization, we modeled outcomes using 5 km and 1 km buffers and compared the results later in this report.

Surf Conservation Index

For our analysis, we used the same methods developed by the Save the Waves Coalition for previous SCIs (Sancho Gallegos and Arroyo Rodríguez, 2021; van den Berg et al., 2021). Using ArcGIS Pro (version 2.9.5), indicator values were calculated for three major indices: Pressure, State, and Response. The State Index is further divided into three subindices: Biodiversity, Surf, and Social. Altogether, each surf break receives a final SCI score from zero to one using the scores from each index – a higher score indicates greater priority for conservation, while a lower score indicates a lower priority for conservation. Diverging from prior SCI analyses, we chose to incorporate some indicators that had not been included previously, including terrestrial and oceanic priority areas (Biodiversity Subindex), marine species richness (Biodiversity Subindex), World Heritage Sites (Response Index), and United Nations Educational, Scientific and Cultural Organization (UNESCO) Biosphere Reserves (Response Index). These were added after discussion with Save the Waves and CI Brazil about gaps in previous SCIs and a desire to incorporate data unique to Brazil. All spatial data was transformed to the SIRGAS 2000 Brazil Mercator projection for analysis. The indicators, which index they belong to, and data sources can be found in *Appendix A*.

Spatial Data Analysis

For each index and subindex, models were created in ArcGIS Pro to find values for each indicator within each surf break buffer. Within the models, different tools were used for different kinds of spatial data. For point data such as ports, airports, and Bandeira Azul beaches, total number of points within each surf break buffer area was calculated using a *Spatial Join*. For line data like roads, we used *Summarize Within* to calculate the total length of lines within each buffer. For built area, priority areas for conservation, protected areas, world surfing reserves, wetlands of international importance (defined by the Ramsar Convention for the conservation and sustainable use of wetlands), UNESCO World Heritage sites, and UNESCO Biosphere Reserves, we used *Summarize Within* to calculate the total area of the polygons within each buffer. For census data like population change and employment, we took the mean value of all census districts that overlapped with each buffer using a *Spatial Join*. For raster data like land use change, species richness, and habitat cover, we used *Zonal Statistics as Table* to calculate the mean value of all cells contained within each buffer.

Surf Subindex Calculation

The Surf Subindex scores surf breaks on the following characteristics: wave quality, wave direction, wave frequency, experience level, and clustering. Wave quality is assigned an integer value from 1 (lowest quality) to 5 (highest quality). The value for wave direction is assigned based on whether a wave breaks in such a way that it can be surfed either left or right (1), or both directions (2) along the wave face. Wave frequency is determined by how consistently the wave breaks throughout the year and is assigned an integer value from 1 (lowest) to 4 (highest). For the experience level indicator, waves were rated based on the skill level needed to be able to surf the wave. For a wave with any specialized skills above beginner level or all surfers, those waves received a value of 0. Any breaks with a skill level of beginner or specified as a wave for all surfers received a value of 1. Each wave that had no experience level was given a level of 1 with the assumption that all individuals would be able to surf the wave. The value assigned to clustering was calculated by determining how many nearby breaks were found within the buffer surrounding one individual break. Where values were missing, null observations received the lowest values in each indicator scale for wave quality, wave direction, and wave frequency indicators.

Certain characteristics of waves are more important than others. For instance, wave quality is considered more important than the experience level needed to be able to surf the wave. Therefore, after normalizing all the indicator values, the indicators within the Surf Subindex (SSI) were weighted using the following equation:

$$SSI = \frac{\#\ of\ surf\ spots}{\#\ maximum\ surf\ spots} + \ Quality + \ Frequency + 0.5 * (Direction + Experience)$$

The value of the clustering indicator is determined by the fraction of the number of surf breaks included within a specific buffer compared to the maximum number of surf breaks found within a buffer (the first term in the equation).

Normalization and Prioritization

Normalization was completed in each index to allow comparison of surf breaks between indices, and to facilitate incorporation into the overall SCI. Indicator values were exported and read into R to calculate the normalized values. First, the maximum and minimum values for each indicator were identified. Then, each indicator was normalized from 0 to 1 by subtracting the minimum value from the indicator value for each spot and dividing by the difference in the maximum and minimum value for the indicator. For the Biodiversity Subindex, after adding the additional indicators for terrestrial and oceanic ecosystems and priority areas, the weighting between terrestrial and oceanic indicators was uneven. To create a more accurate representation of the marine and terrestrial biodiversity found within each surf buffer, we weighted the terrestrial priority areas together and the marine ecosystems together first, then weighted those with the oceanic priority areas and terrestrial ecosystems, respectively. With the marine and terrestrial biodiversity equally weighted, we were able to successfully normalize the indicators.

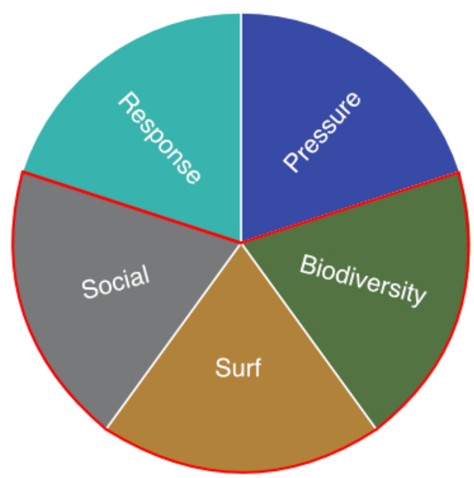

Figure 5. Pressure-State-Response Index framework for the Surf Conservation Index. State Index is split into 3 subindices: biodiversity, surf, and social.

Once normalized, indicators were added together for each surf spot and normalized again to give the result for each index and subindex. Then, the normalized indices and subindices were added together and normalized again to complete the SCI (Figure 5). Each index and subindex, as well as the completed SCI, was exported and reentered into ArcGIS Pro for mapping.

To calculate the values for each region, the indicator data was filtered to select by region and then normalized following the same steps above, ending with the SCI (see GitHub for complete code: link).

Ecosystem Services Assessment

As a major deliverable of this project, the team enhanced the SCI by adding a mechanism that evaluates surf breaks based on their ecosystem service potential. Specifically, a Climate Index was added to SCI's existing indices: Pressure-State-Response (Figure 6). This new index allows surf breaks to be scored higher and prioritized more if they provide more ecosystem services. Due to data and project timeline con-straints, the team focused on assessing two ecosystem ser-vices: mangrove carbon storage and coastal protection by natural habitats. These ecosystem services are important because man-grove carbon storage contributes to climate change mitigation while coastal protection relates to climate change adaptation. These services were quantified for each surf spot, normalized like all other indicators, and added together into the Climate Index, which has the same weight in the prioritization as all other indices.

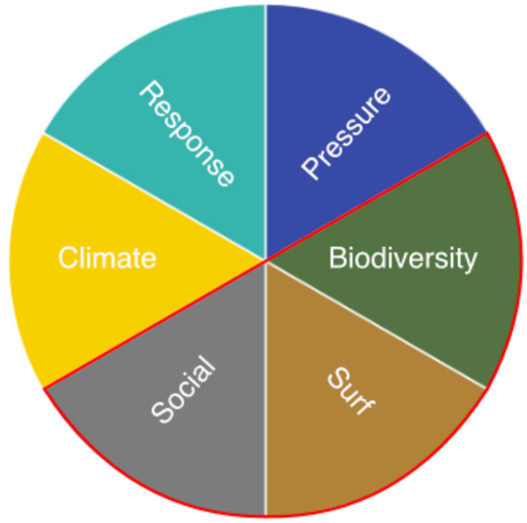

Figure 6. Climate Index incorporation into the Pressure-State-Response Index framework. All 6 indices and subindices are weighted equally.

Mangrove Carbon Assessment

To assess carbon storage in coastal ecosystems, we focused on mangrove forest due to a lack of data on the distribution and carbon storage capacity of other marine habitats such as seagrass and salt marsh in Brazil. To create the Brazilian mangrove carbon map, we modeled carbon storage and accumulation in three pools: aboveground biomass (AGB), belowground biomass (BGB), and soil organic carbon (SOC) (Figure 7). We obtained 900 square meter resolution data (30m x 30m) on mangrove AGB in units of Mg/ha from the Oak Ridge National Laboratory (Simard et al., 2019). This dataset was created using remotely sensed canopy height and region-specific allometric models. Following the methodology of the authors, we estimated BGB to be 49% of AGB. We used a stoichiometric factor of 0.451 to convert AGB to carbon (Simard et al., 2019), and 0.39 to convert BGB to carbon (Kauffman and Donato, 2012). To estimate the SOC pool, we used data produced by a global model of mangrove soil carbon based on coastal environmental settings such as deltas, estuaries, or lagoons (Rovai et al., 2018). To match the AGB data, we converted SOC from units of mg/cm^3 to Mg/ha for the top meter of soil (assuming soil carbon is relatively constant within the top meter of soil) and resampled from 0.0625 square degree (0.25° by 0.25°) to 900 square meter cells. Aboveground carbon, belowground carbon, and soil

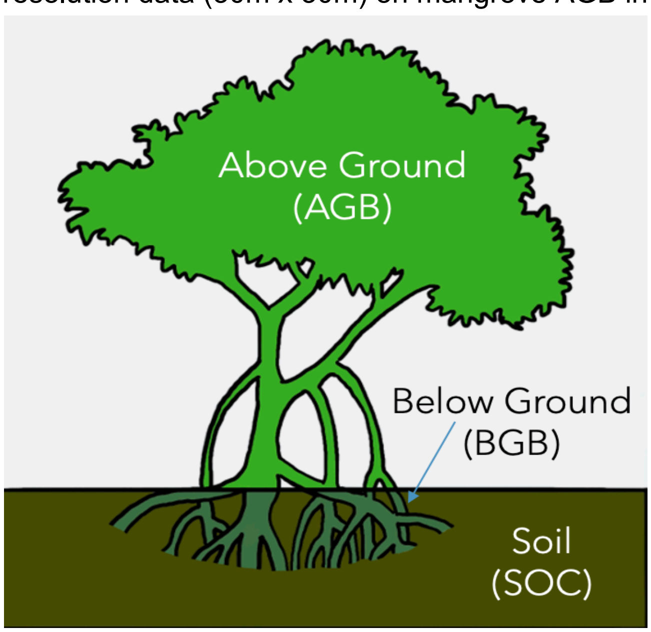

Figure 7. Mangrove carbon pools used in the mangrove carbon assessment.

organic carbon were summed to calculate total carbon storage for each 900 square meter cell of mangrove.

Using this storage map, we then estimated the carbon storage surrounding each surf break by multiplying values by the cell area and summing within a 10 km radius around each surf break. These total carbon storage values make up half of the Climate Index and were normalized by the same method as all other indicators in the SCI.

Coastal Protection Assessment

To map protection provided by coastal habitats we used the Coastal Vulnerability model that is included in the suite of ecosystem service valuation models in the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) software package (Natural Capital Project, n.d.). This model considers various natural habitats and geophysical features to compare coastal areas and their relative exposure to erosion and flooding during storm events. It is important to note that this model does not consider unique, region-specific coastal processes or predict changes in shoreline position or configuration.

The model required a set of inputs which were obtained from various global and regional datasets (*see Appendix A* for full table). The area of interest (AOI) was created using a 50 km buffer surrounding the coastline to include islands off the coast. The geomorphologic data we used divided the coastline into three categories: bedrock, beach, and wetland (Mao et al., 2022). Each category was assigned a numerical value between 1 and 5 based on exposure ranking (see *Appendix A*). Bedrock was assigned the lowest value of 1 (“very low exposure”) and beaches were assigned the highest value, 5 (“very high exposure”). Wetlands were assigned an average value of 4 (“high exposure”) as wetlands were defined as anything from deltas (exposure value 5) to marshes and estuaries (exposure value 3). Although this is a rough determination of coastal features, it is the best data available for Brazil.

To specify spatial habitat data and parameters, a habitat input table was constructed (*Appendix A*) following the format and ranking guidance provided in the InVEST user guide (Mao et al., 2022). We chose to include three habitat types: coral reefs, mangroves, and coastal forests. Other habitats like seagrass, dunes, and marshes were not included in this analysis due to limited availability of data on these types of habitats in Brazil. Each habitat was assigned a numerical value between 1 and 5 based on exposure ranking as well as a maximum protection distance beyond which the habitat does not protect the coastline (see *Appendix A*). The rank value assigned to habitat types follows the same logic as the value assigned to geomorphological features. A value of 1 (“low exposure”) can also be understood as providing the greatest amount of protection, while a value of 5 (“high exposure) corresponds to the least amount of protection.

Due to the complexity of this model and the large distance of coastline that needed to be evaluated (Brazil’s coastline is around 7,400 kilometers), we chose a model resolution (interval at which to space shore points along the coast) of 1 km to reduce processing time. The elevation averaging radius was set to 500 meters, half of the model resolution, as recommended in the InVEST user guide (Mao et al., 2022). The maximum fetch distance (the distance that wind blows across water which affects wave size) was set to 350 meters, which is the furthest distance from the Brazilian shoreline to the edge of the continental shelf. This is generally considered to be where meaningful wind-wave generation begins (Zhang et al., 2021).

Outputs from this analysis produced an overall “exposure” index value at each shorepoint (1 km interval) as well as a “no habitat” exposure index value that is calculated assuming no protective habitats are present within the radius of each shorepoint. Using the difference between index values for “exposure” and “no habitat” outputs, we can determine a unitless value of protection provided by natural habitats at each shorepoint. Values at each shorepoint were mapped in ArcGIS Pro and spatially joined to the 10 km buffered surf breaks. Within each buffer, shorepoint values were averaged to produce a coastal protection score for each surf break.

Sensitivity Analysis

To test the effect of changing size of the buffer surrounding each surf break on the results, the SCI (including the Climate Index) was run for surf breaks with a buffer size of 5 km and 1 km, in addition to the 10 km spots that were used before. Ten kilometers is thought to be the maximum practical size for surf break buffers, which is why the sensitivity analysis focused on the effects of using smaller size buffers for analysis.

Results

Because the assessment of mangrove carbon storage and coastal protection was newly developed for this analysis, we will first present the results of the ecosystem service assessments. The results of the Surf Conservation Index (SCI) will then be presented as a comparison between analyses with and without the Climate Index.

Mangrove Carbon Assessment

Our assessment found that Brazilian mangroves hold about 0.275 petagrams (Pg) of carbon in their biomass and underlying meter of soil. This value is slightly less than, but in line with, a recent estimate of 0.32 Pg of Brazilian mangrove carbon (Rovai et al., 2022). About 8.2 percent (22.6 Tg) of this carbon is stored by mangroves within 10 kilometers of a surf break. More mangrove carbon is stored in the northern, equatorial region of Brazil, due to more extensive and denser mangrove compared to southern Brazil. However, there are relatively fewer surf breaks in the north.

Of all 547 surf breaks, 338 (62%) contain mangroves within 10 kilometers, although most breaks contain very little. The surf break with the most mangrove carbon is Araruna, in the state of Pará, with 1.11 Tg. The top 27 of 547 surf breaks contain more than half of all surf-adjacent mangrove carbon in Brazil (Figure 8). See *Appendix B* for additional results.

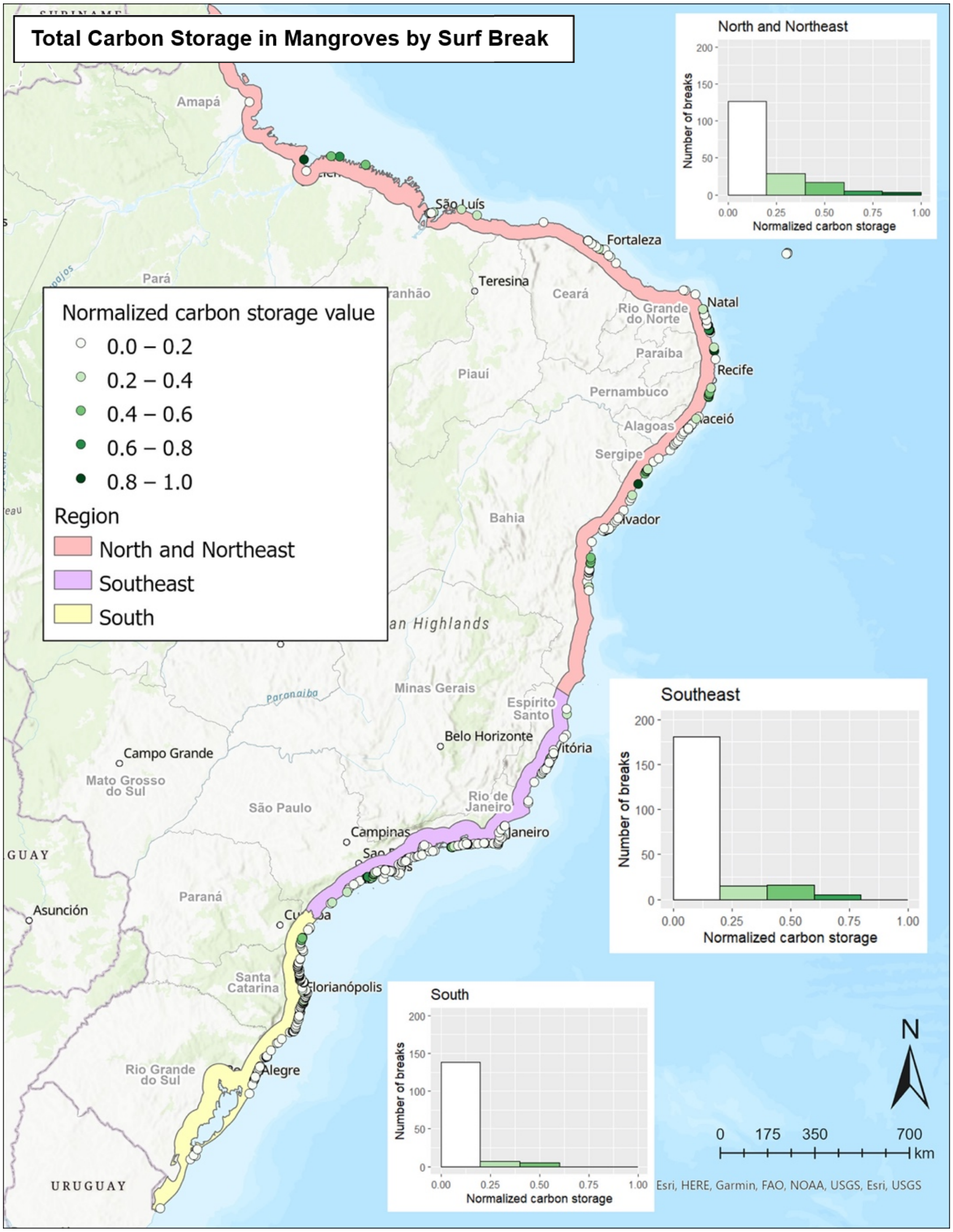

Figure 8. Total carbon storage in mangroves by surf break. Brazilian surf breaks are ranked by the amount of mangrove carbon stored within a 10 km radius of the surf break.

Coastal Protection Assessment

Natural habitats surrounding surf breaks play an important role in coastal protection. On average, habitat presence within the 10 km surf buffer reduced exposure index values by seven percent, or an index value of 0.303. The maximum decrease in exposure index value (0.704) was observed at Garça Torta in Alagoas (17.6%; Figure 9). The highest observed values of the role of habitats for coastal protection surrounding surf breaks were found in the north-northeastern region of Brazil. For detailed results, see *Appendix B*.

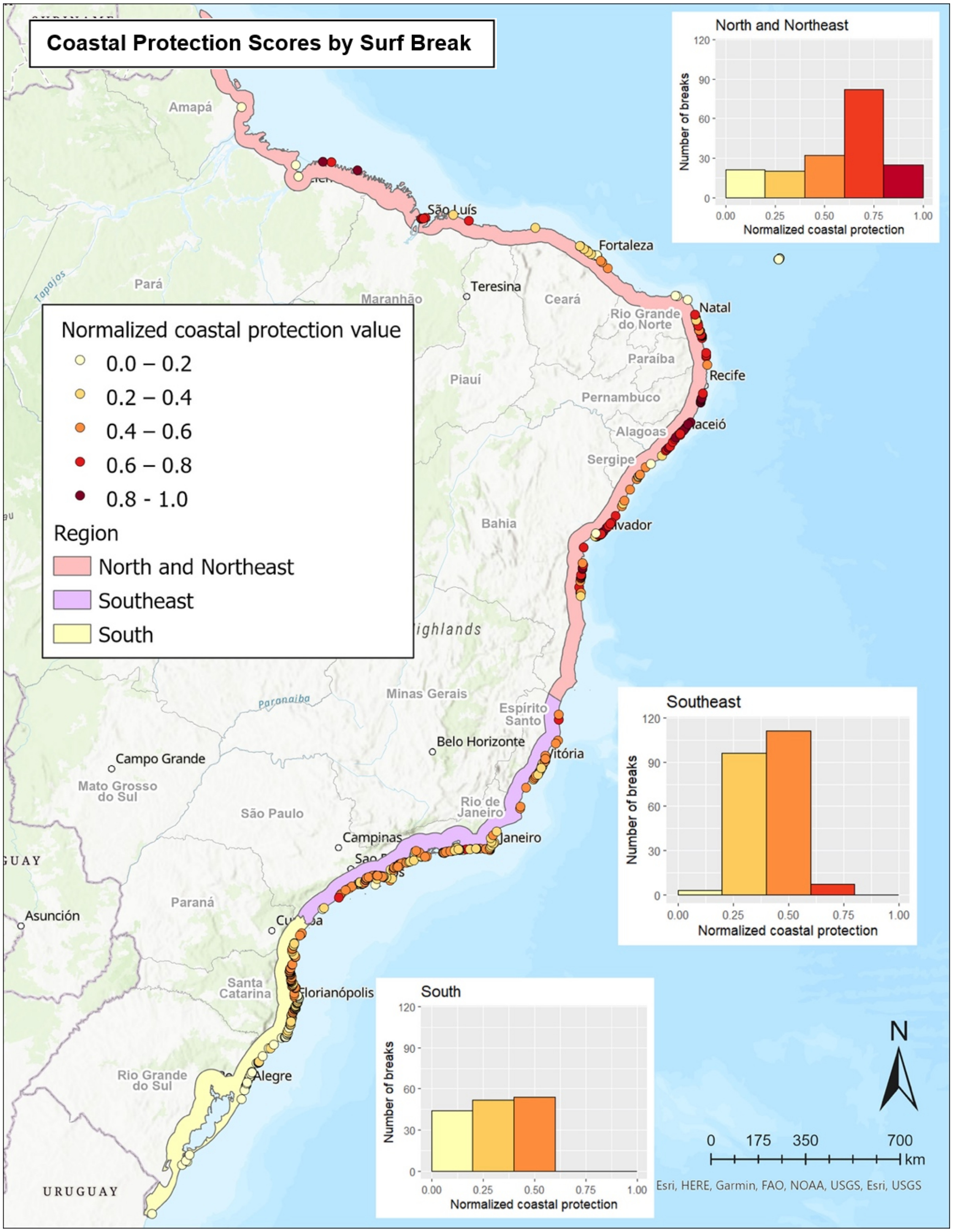

Figure 9. Coastal Protection scores by surf break. Brazilian surf breaks are ranked by the contribution of natural habitats (mangrove forest and/or coastal forest and/or coral reef) to coastal protection with 10 km of each surf break.

Surf Conservation Index

The SCI identified high priority surf breaks across all of Brazil. Before incorporating the Climate Index into the SCI, the top 10 highest priority breaks were in the states of São Paulo, Paraná, and Pernambuco (specifically the archipelago of Fernando de Noronha). After incorporating the Climate Index, the top 10 breaks were in the states of Bahia, São Paulo, Pernambuco, Paraíba, and Paraná. Five of the top 10 breaks were shared with the top 10 breaks in the SCI without Climate (Table 1).

Table 1. Comparison of the top 10 surf breaks. Results of the SCI with (right) and without (left) the Climate Index. Breaks highlighted in colored pairs appear in the top 10 ranking of both models.

	SCI without the Climate Index	**SCI with the Climate Index**
1	Itamambuca, São Paulo	Praia dos Algodões, Bahia
2	Vermelha do Norte, São Paulo	Desertinha, São Paulo
3	Desertinha, São Paulo	Saquaira, Bahia
4	Conceição, Pernambuco (Fernando de Noronha)	Borete, Pernambuco
5	Meio, Pernambuco (Fernando de Noronha)	Mar do Macaco, Paraíba
6	Praia Brava Guaratuba, Paraná	Praia Brava Guaratuba, Paraná
7	Vermelha do Centro, São Paulo	Maracaipe, Pernambuco
8	Guaratuba Praia Brava, Paraná	Itamambuca, São Paulo
9	Boldró, Pernambuco (Fernando de Noronha)	Vermelha do Norte, São Paulo
10	Praia Grande, São Paulo	Guaratuba Praia Brava, Paraná

Without Climate, 67 breaks were identified to be high priority (SCI > 0.75), 201 breaks as medium priority (0.5 < SCI < 0.75), 245 breaks as low priority (0.25 < SCI < 0.5), and 34 as very low priority (SCI < 0.25) (Figure 10). With Climate, 48 breaks were identified to be high priority, 238 spots as medium priority, 237 spots as low priority, and 24 as very low priority (Figure 11).

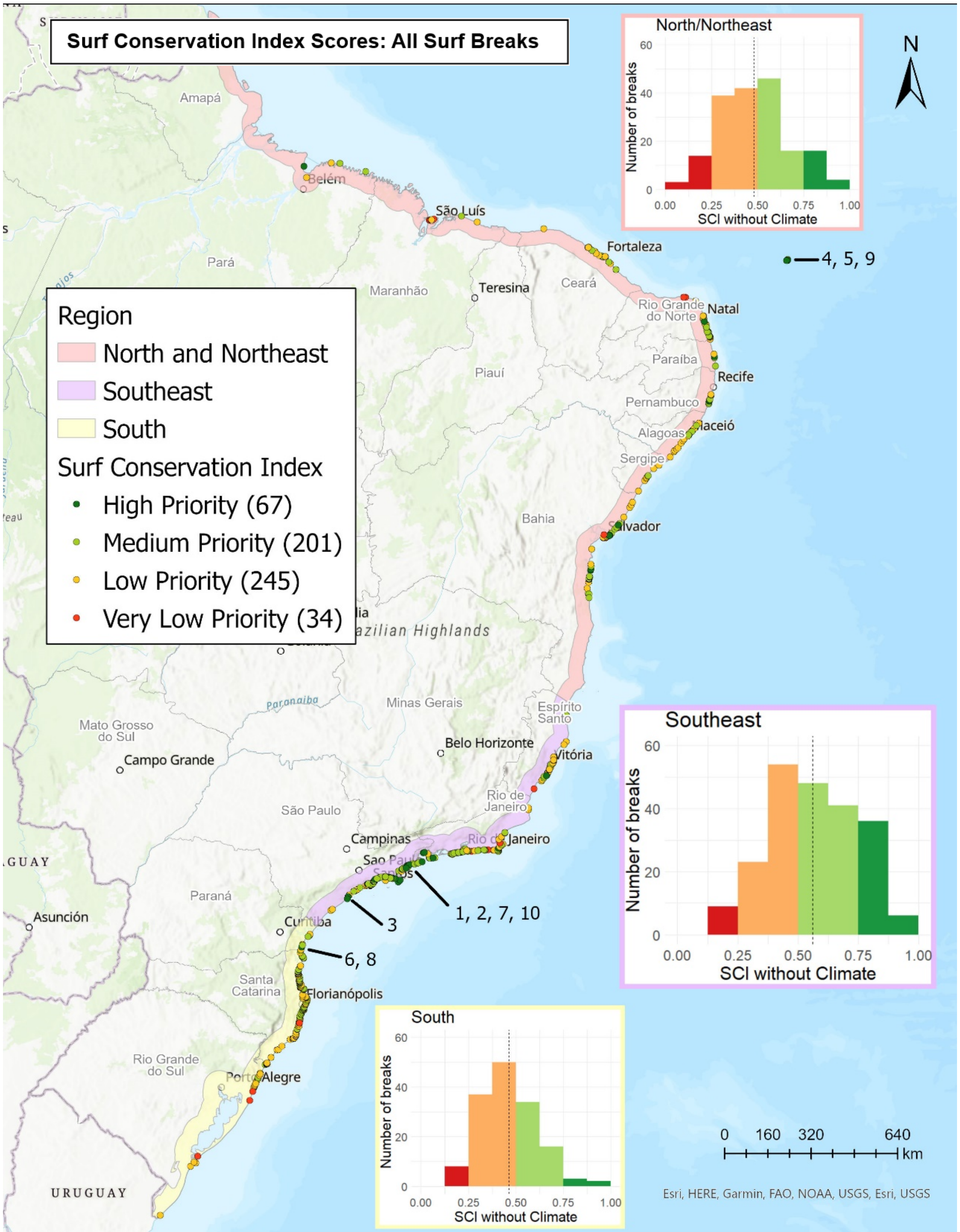

Figure 10. Surf Conservation Index scores *without* the Climate Index for all surf breaks. High Priority: SCI > 0.75. Medium priority: 0.5 < SCI ≤ 0.75. Low Priority: 0.25 < SCI ≤ 0.5. Very low priority: SCI ≤ 0.25. The top 10 breaks are labeled with their rank value. The distribution of prioritization values for each region is depicted by histograms corresponding to the region color. Mean prioritization value of all breaks in the region is indicated by the dashed line.

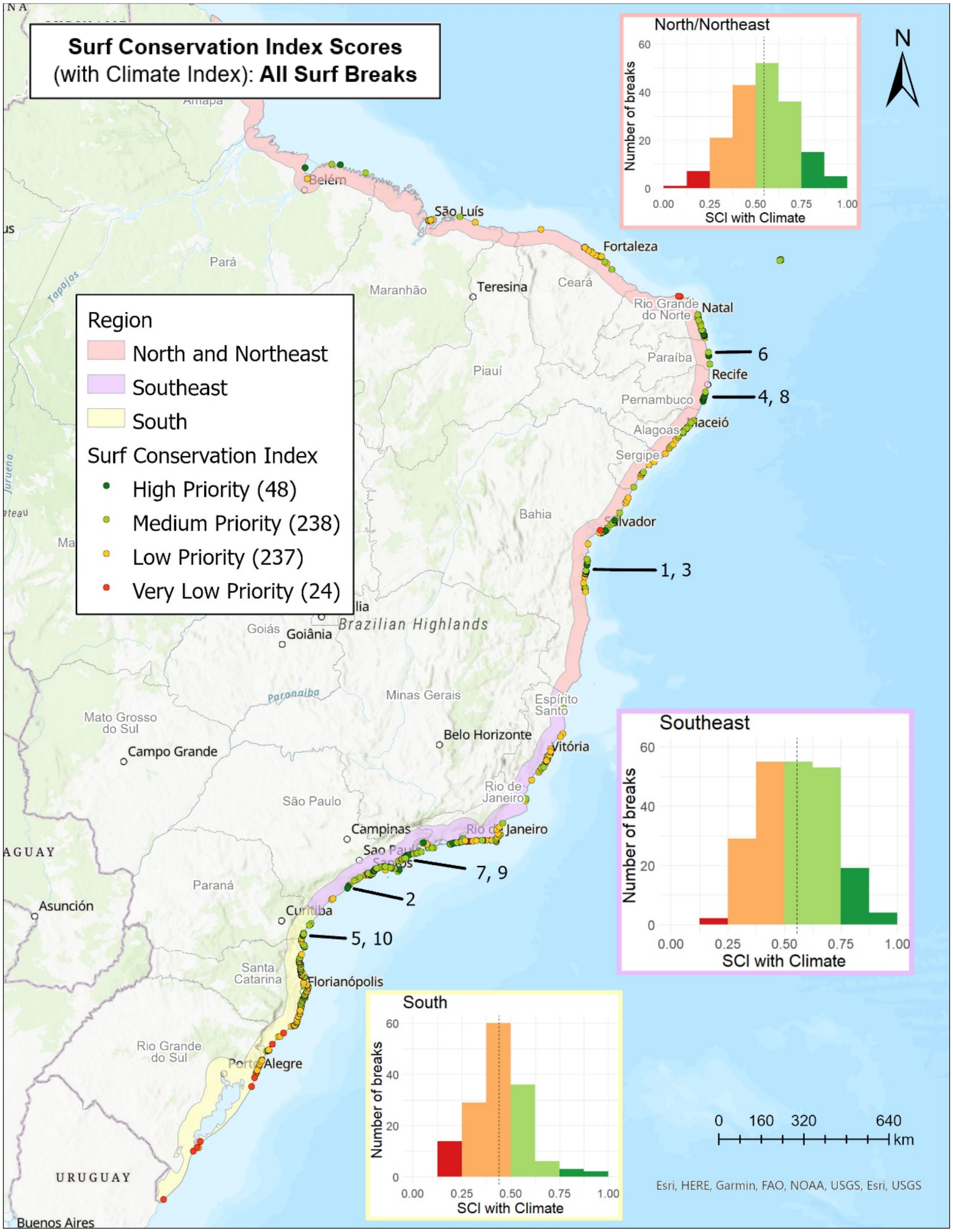

Figure 11. Surf Conservation Index *with* the Climate Index for all surf breaks. High priority: SCI > 0.75. Medium priority: 0.5 < SCI ≤ 0.75. Low priority: 0.25 < SCI ≤ 0.5. Very low priority: SCI ≤ 0.25. The top 10 breaks are labeled with their rank value. The distribution of prioritization values for each region is depicted by histograms corresponding to the region color. Mean prioritization value of all breaks in the region is indicated by the dashed line.

Before adding the Climate Index, the state with the highest priority breaks (SCI > 0.75) was São Paulo (22 surf breaks), followed by Rio de Janeiro (19 surf breaks) (Figure 12C). After adding the Climate Index, six breaks in São Paulo were no longer ranked as high priority. However, São Paulo remains the state with the most high priority breaks. Pernambuco replaced Rio de Janeiro as the state with the second most high priority surf breaks (Figure 12D).

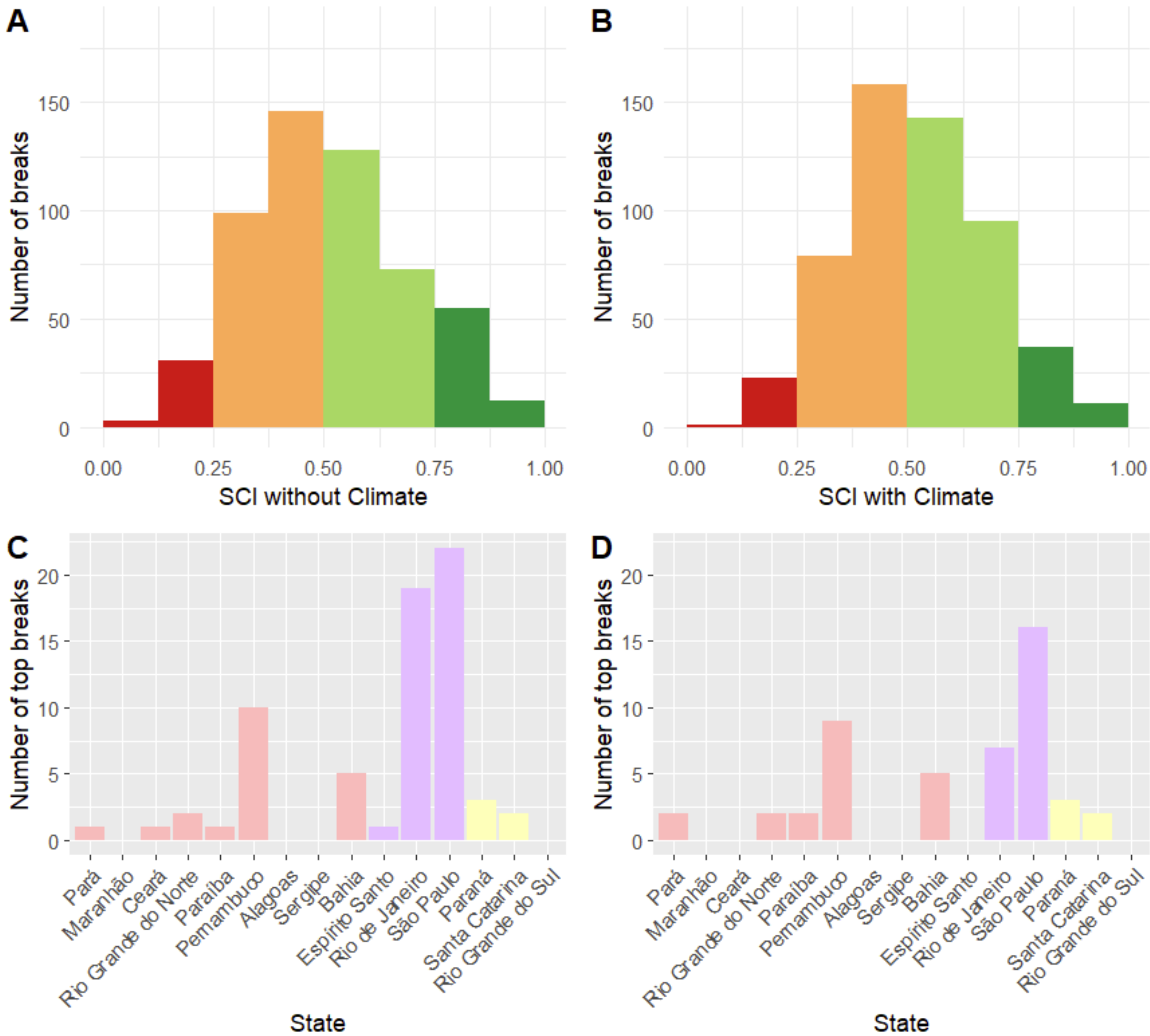

Figure 12. Results of the SCI *with* and *without* the Climate Index. *Panel A:* Distribution of SCI scores without the Climate Index. *Panel B:* Distribution of SCI scores with the Climate Index. Colors correspond to prioritization classification (red: very low, orange: low, light green: medium, dark green: high priority). *Panels C and D:* Number of high priority breaks (SCI > 0.75) with (*D*) and without (*C*) the Climate Index across all coastal states of Brazil (in order from north to south). Colored bars correspond to region (pink: northeast, purple: southeast, yellow: south) each state is found.

By visualizing only the high ranking breaks (SCI > 0.75) on the map, a hotspot with many high ranking breaks close together can be seen in northern São Paulo state and southern Rio de Janeiro state, with other high ranking breaks spread across the country (Figure 13). After adding the Climate Index, some high ranking breaks are removed from the São Paulo and Rio de Janeiro hotspot, but this area remains one of the highest priority areas for surf conservation in the country (Figure 14).

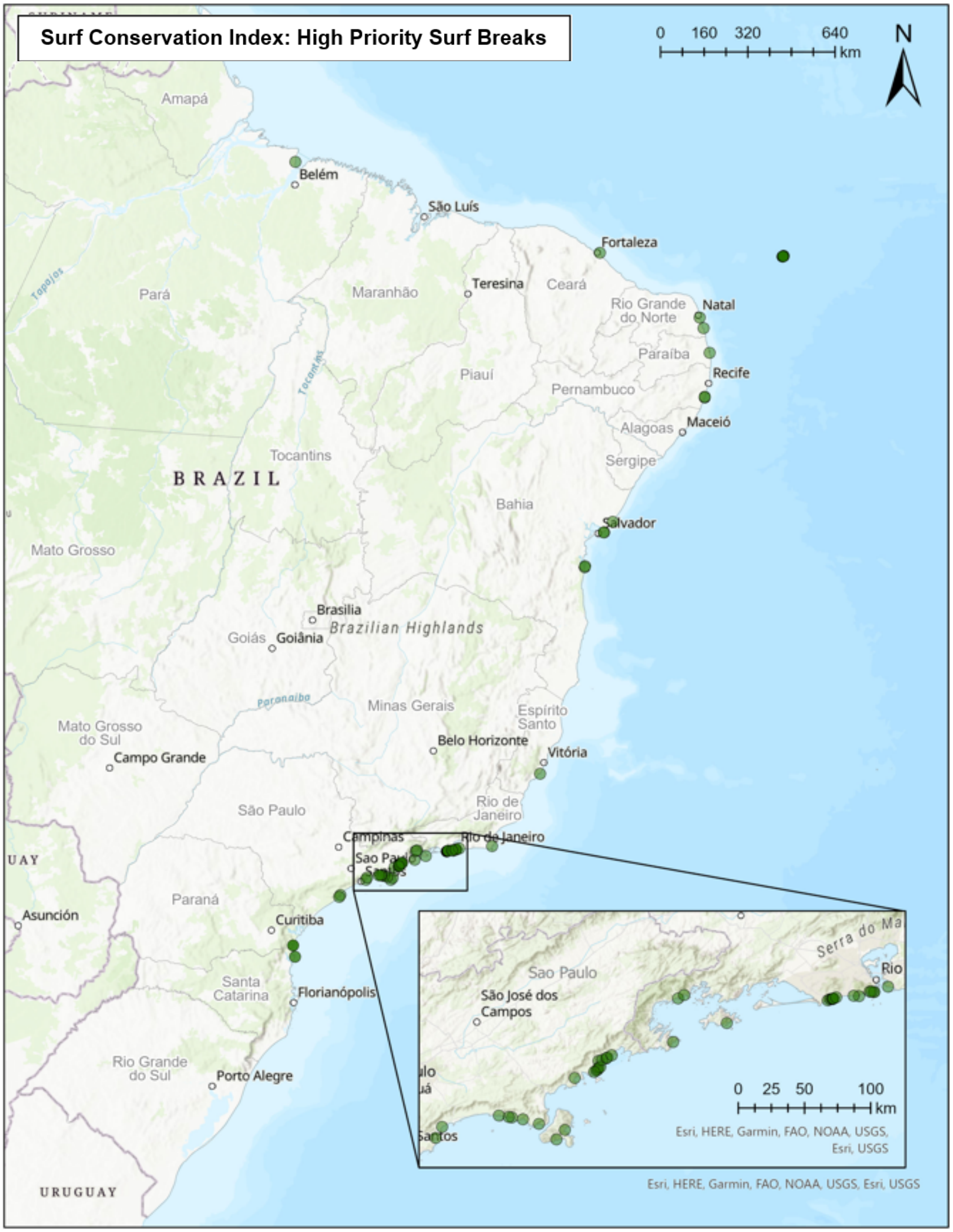

Figure 13. High priority surf breaks (SCI > 0.75) in the SCI *without* the Climate Index. Transparent green dots represent 10 km buffered surf breaks. Darker green dots are a result of multiple surf breaks overlapping each other.

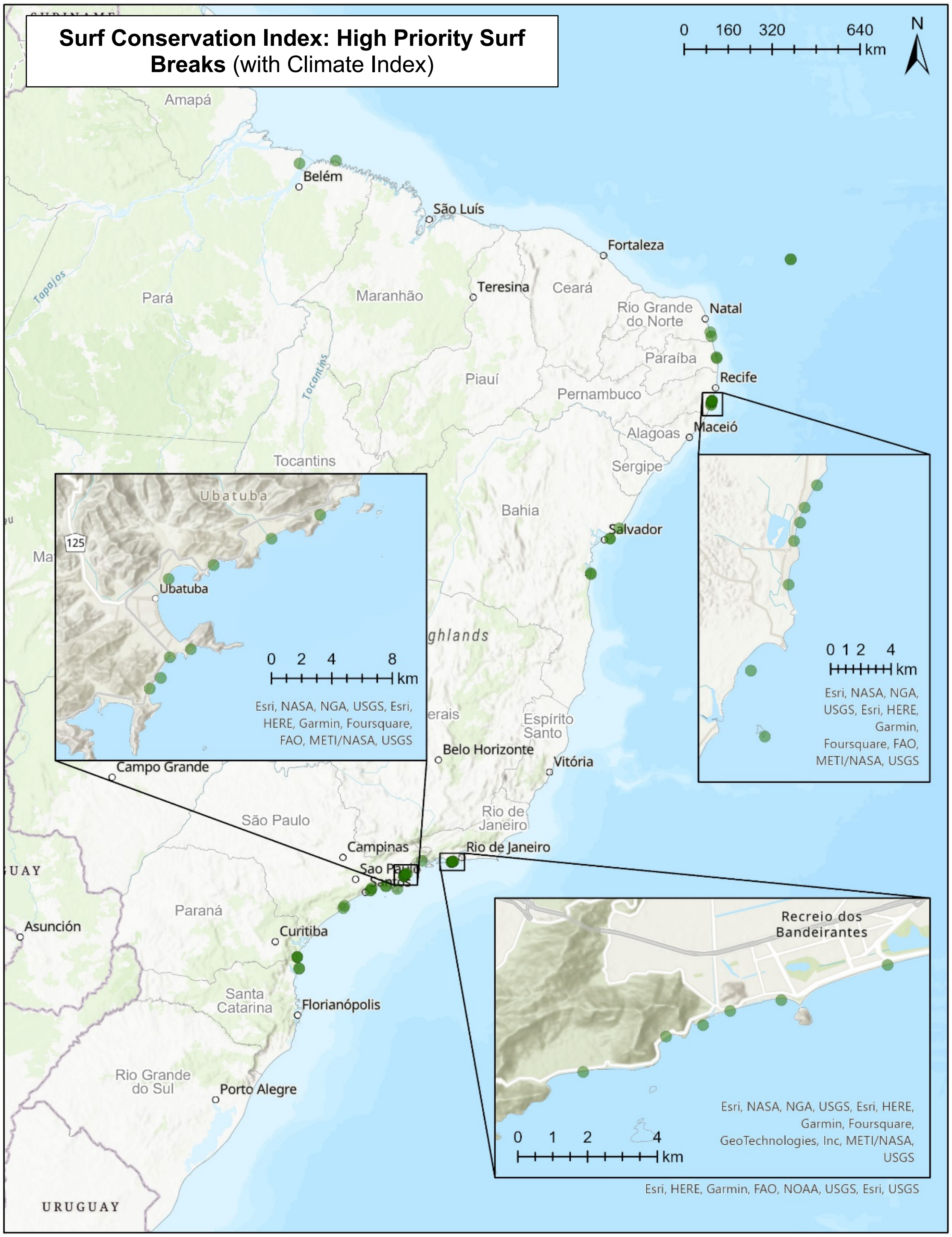

Figure 14. High priority surf break (SCI > 0.75) in the SCI *with* the Climate Index. Transparent green dots represent 10 km buffered surf breaks. Darker green dots are a result of multiple surf breaks overlapping each other.

A difference map was generated to compare the two SCIs above by subtracting the results of the SCI without climate from the results of the SCI with climate (Figure 15). Differences in SCI scores for a given surf break ranged from a decrease of 19.2% (Conceição on the island of Fernando de Noronha) to an increase of 22.9% (Atalaía in Pará, near Belém) (Figure 15).

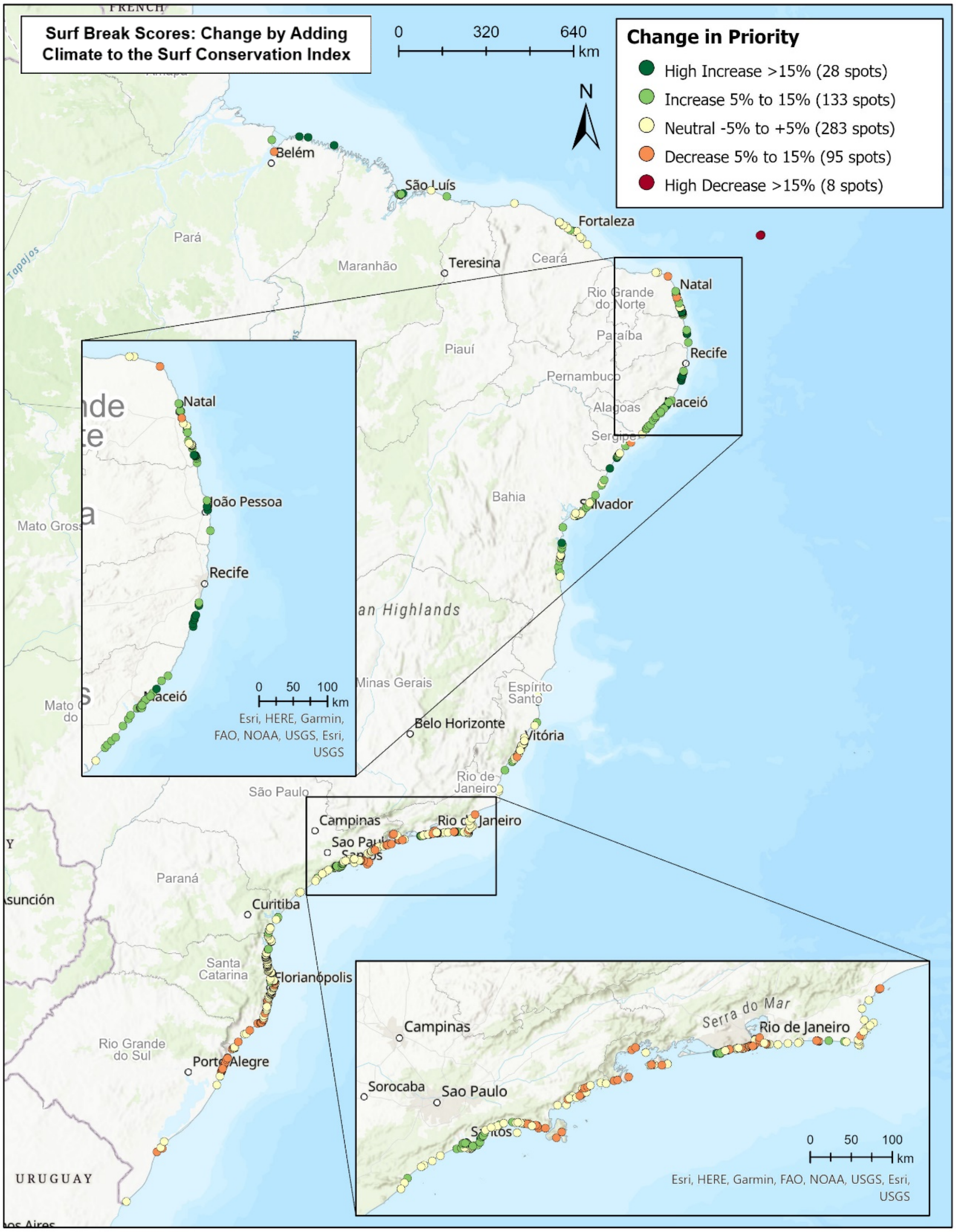

Figure 15. Surf break scores: change by adding the Climate Index to the Surf Conservation Index. *Equation:* SCI with the Climate Index minus the SCI without the Climate Index.

Sensitivity Analysis

Changing the buffer size of the surf breaks in the analysis affected the results considerably. Many of the top spots identified using 5 km and 1 km buffers were different than those identified using 10 km buffers. Decreasing the buffer size also decreased the mean priority value across all spots (Figure 16). Using a 5 km buffer size increased the number of surf breaks scoring above 0.75 in the north-northeast region while decreasing the number of breaks scoring above 0.75 in the southeast and south regions. Using a 1 km buffer size decreased the number of high priority surf breaks in all states except for Alagoas in the north-northeast region.

Table 2. Comparison of the top 10 surf breaks for SCI with Climate using different buffer sizes. Breaks highlighted in the same color appear in the top 10 for multiple buffer sizes.

	10 km	5 km	1 km
1	Praia dos Algodões, Bahia	Araruna, Pará	Camaraçu, Pará
2	Desertinha, São Paulo	Meio, Pernambuco	Maracaipe, Pernambuco
3	Saquaira, Bahia	Conceição, Pernambuco	Araruna, Pará
4	Borete, Pernambuco	Desertinha, São Paulo	Martim de Sa, Rio de Janeiro
5	Mar do Macaco, Paraíba	Serrambi, Pernambuco	Garca Torta, Alagoas
6	Praia Brava Guaratuba, Paraná	Guarau, São Paulo	Desertinha, São Paulo
7	Maracaipe, Pernambuco	Boldró, Pernambuco	Pipa, Rio Grande do Norte
8	Itamambuca, São Paulo	Cachorro, Pernambuco	New Orleans, Alagoas
9	Vermelha do Norte, São Paulo	Borete, Pernambuco	Prainha, Rio de Janeiro
10	Guaratuba Praia Brava, Paraná	Praia dos Algodões, Bahia	Mambucaba, Rio de Janeiro

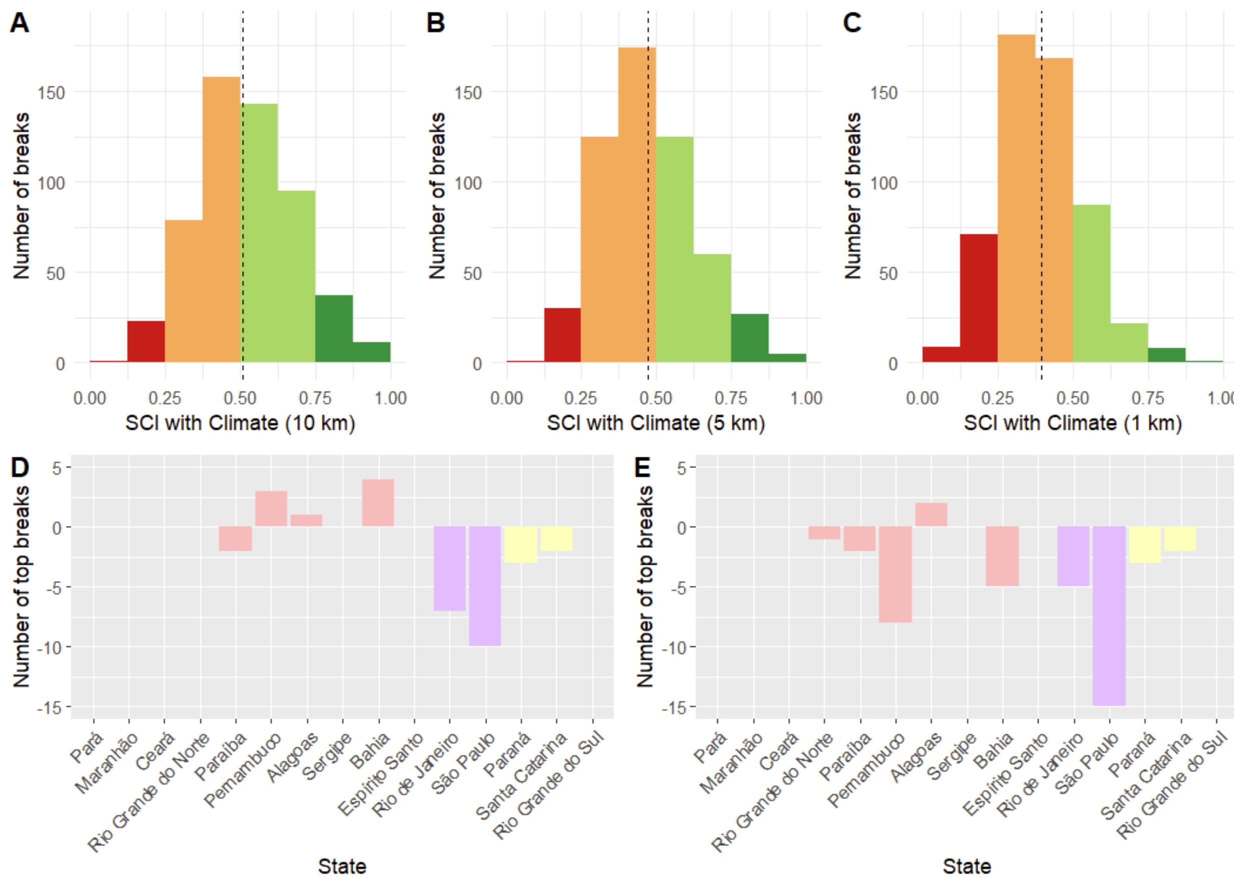

Figure 16. Surf buffer size effects on the SCI *with* the Climate Index. Mean SCI scores are indicated by the dashed lines on the histograms. *Panels A, B, and C:* Distribution of SCI scores using a 10 km buffer size (mean = 0.52; *A*), a 5 km buffer size (mean = 0.47; *B*), and a 1 km buffer size (mean = 0.40; *C*). Colors correspond to prioritization classification (red: very low, orange: low, light green: medium, dark green: high priority). *Panels D and E:* Change in the number of top breaks (SCI > 0.75) in each coastal state when the buffer was reduced from 10 km to 5 km (*D*) and from 10 km to 1 km (*E*). Colored bars correspond to the region (pink: north-northeast, purple: southeast, yellow: south) each state is found.

Discussion

The results across both the ecosystem services analysis and the Surf Conservation Index (SCI) indicate that there is value in using surfing as a motivation for coastal protection in Brazil. Even if surf resources do not contain the highest levels of biodiversity or density of critical habitat across the entire coast, there is still an ecological basis for protecting these spaces. Positive environmental outcomes are a bonus to the widely recognized economic and social benefits that surfing brings to coastal communities.

Ecosystem Services

The ecosystem services that exist within or near surf resources go far beyond what we were able to assess in this study given data limitations. Despite this, we found that areas surrounding surf breaks in Brazil provide significant ecosystem services in the form of carbon storage and coastal protection. These findings point towards the need for further research and evaluation of the immense natural value that may be protected through the designation of SPAs. For example, mangrove forests near surf breaks not only store carbon but can filter nutrients from runoff that could otherwise cause harmful algal blooms. They also serve as nursery habitat for many species that are important for local fisheries. Our findings present only a fraction of the total possible value provided by surf resources.

The high mangrove carbon storage in surf breaks of the north and northeast region indicates that protection of these areas could be a powerful tool in the fight against climate change. Our assessment shows that surf-adjacent Brazilian mangroves store over 22.6 million tons of carbon. Understanding which surf breaks have the highest carbon storage capacity will enable governments to prioritize conservation initiatives that could help prevent this carbon from entering the atmosphere. In fact, protecting only the top five percent of mangrove carbon storing surf ecosystems (27 breaks) could help save more than half of all surf-adjacent mangrove carbon in Brazil.

Our analysis also shows that habitats like mangroves, coastal forest, and coral reefs near surf breaks contribute significantly to coastal protection from storm surge, sea level rise, and erosion. Surf breaks providing the highest levels of coastal protection were also concentrated in the northern region of Brazil. This is due in large part to the presence of coral reefs and mangroves at these latitudes that are absent from the more subtropical and temperate southern parts of the country. These findings may aid decision makers who wish to focus conservation efforts on locations that will help to protect vulnerable communities from negative impacts resulting from climate change.

The Climate Index, which combines habitat contribution to carbon storage and coastal protection, is intended to augment the SCI process to better inform the allocation of limited resources for establishing protected areas. Our scores indicate that the surf breaks providing the most carbon storage and coastal protection are in the northern region, with the top 10 surf breaks in the Climate Index located there. The most extensive mangroves in Brazil lie near the mouth of the Amazon River, in the states of Amapá, Pará, and Maranhão. However, this area is not well-known for good surf and contains very few surf spots. In contrast, Brazil’s extreme northeastern coast, spanning the states of Pernambuco, Paraíba, and Rio Grande do Norte, includes more surf spots and is home to vibrant coral reefs and large mangrove forests. This area contains eight of the top 10 spots identified by our analysis. For this reason, we recommend that local and state governments and non-government partners pursue surf conservation in this area.

Surf Conservation Index

While significant on their own, we also wanted to understand how the results of the ecosystem services analysis would shift prioritization at the regional and national scale. To do this, we first had to develop a robust understanding of what prioritization looked like before making this addition. Results of the SCI without ecosystem services (excluding the Climate Index) locate the highest priority surf resources for protection near major cities such as Rio de Janeiro and Santos in the south, and Fortaleza in the north. Fernando de Noronha, a small archipelago off the northeastern coast, also hosts multiple high priority locations.

Since each of the Biodiversity, Surf, and Social Subindices (within the State index) are weighted equally to the Pressure and Response Indices, the concentration of priority locations near major coastal cities is strongly influenced by the Social Subindex. The Social Subindex includes factors like per-capita employment in tourism, availability of accommodations, and airport access which are generally higher near major cities and vacation destinations. Seventeen of the 18 breaks that scored higher than 0.75 (maximum value of 1) in the Social Subindex were located near Rio de Janeiro and Fortaleza. Additionally, many of the top scoring breaks in the Surf Subindex (>0.75) are located near the coastal cities of Rio de Janeiro and Santos. The coastline from Rio de Janeiro south to Santos is well known among the surfing community for its variety and abundance of consistent waves suitable for surfers of all skill levels (Lees, 2022; SurferToday.com, n.d.). The co-occurrence of both large tourism industries and high quality surf suggests that surfing may be a contributing factor to the area's popularity. Further research should be conducted to validate this observation in Brazil, but similar connections are backed by evidence from the surf tourism management field (see the section on Surf Tourism Management in Part 2 for more context).

Fernando de Noronha is another location with a large concentration of top priority surf breaks. The archipelago of islands is home to a wealth of biodiversity and contains several large existing reserves that are recognized as UNESCO World Heritage Sites. The islands are highly productive, providing important breeding grounds for tuna, shark, turtle, marine mammals, and the largest concentration of tropical seabirds in the Western Atlantic. As such, these islands are subject to legal protection under multiple federal and state regulations. However, the islands are considered by the IUCN World Heritage Outlook as an area of “significant concern” due to threats from tourism, urban development, lack of monitoring systems and limited resources to support new research in the area (UNESCO World Heritage Centre, n.d.). While unable to address every threat facing the islands, establishment of SPAs can help provide additional management tools and potential funding to protect these important areas.

The inclusion of the Climate Index shifts prioritization away from major cities and towards the north and northeastern regions where there are lower population densities and greater presence of natural habitats like mangroves, coastal forests, and coral reefs. It is important to note that we were unable to gather habitat data used in the Climate Index for Fernando de Noronha. The archipelago is known to include coastal forest and oceanic mangrove, but this habitat presence was not included in the datasets selected for our ecosystem services analysis (UNESCO World Heritage Centre n.d.). This resulted in Fernando de Noronha surf breaks receiving a score of zero for the Climate Index, meaning those breaks dropped in priority considerably after addition of the Climate Index. Given time and resource restraints of this project it was not possible to manually collect and fill gaps absent from larger data sets. Anyone wishing to use the results of this analysis should separately evaluate breaks surrounding Fernando de Noronha as it is clearly an important area for both surfing and conservation.

The highest priority sites in the SCI with Climate appear in areas with stronger Climate Index and Biodiversity Subindex scores. Many of these breaks are in the states of Bahia and Pernambuco in the northeast, although some surf breaks near São Paulo and Paraná states that ranked highly in the SCI without Climate remain among the top 10 priority breaks in the SCI with Climate. Figure 14 (difference map) shows that 28 breaks (mostly in the northeast) saw an increase of 15 percent or more in prioritization scores while scores of breaks in the southeast and south were more likely to decrease with the addition of the Climate Index. The shift in prioritization is likely due to lack of mangrove and coral reef habitat in the south and southeastern regions. This reduces scores in both the carbon storage and coastal protection indicators in the Climate Index, as well as the marine habitat cover indicator within the Biodiversity Subindex.

The shift in regional prioritization may be partially attributed to the fact that some habitats, like mangrove and coral reef, factor into both the Climate Index and Biodiversity Subindex. This project did not assess the effect of this increased weighting on the final prioritization, and it should be considered when interpreting the results. To better understand how each component influences surf break prioritization, we have included a full breakdown of the top-ranking surf breaks for each individual index and subindex (*Appendix D*).

Results of the sensitivity analysis comparing the effect of using 10-, 5-, and 1-kilometer buffers to define the extent of the surf resource surrounding surf breaks demonstrated that the spatial area included in the analysis has a large effect on which surf breaks are scored as highest priority (>0.75). Although there were some increases in surf break prioritization in the north-northeastern region using the five km buffer versus the 10 km buffer, we see a general trend of decreased number of high priority surf breaks as the size of the buffer decreases. This can be attributed to overall lower scores across all indices/subindices with the reduction of buffer size.

The prioritization conducted in this analysis is meant to serve as a guide. It does not mean surf conservation should not be implemented elsewhere in Brazil. Although the addition of the Climate Index highlights ecosystem services provided in the north and northeast regions, we also identified hotspots of ecosystem service provision located near surf spots in Rio de Janeiro and São Paulo states. Our regional Climate Index results will help inform conservation efforts in these areas and the southeast and south regions more broadly.

A potential future step to take for surf conservation in Brazil is to use the analytical hierarchy process (AHP) to assign weights to the indicators and subindices here according to stakeholder preferences. The changes seen after adding the Climate Index show that results can differ considerably based on the weighting of different priorities, so using AHP would ensure that conservation actions reflect the needs of the local communities where they are implemented. Additionally, because this analysis was limited to surf spots from the beginning, it may be valuable to take the opposite approach and identify areas of the coast of Brazil with the most biodiversity, habitat cover, and ecosystem services and then assess overlap of those areas with surf spots.

Although this study only assessed two of the many possible ecosystem services to be evaluated, our results indicate that surf resources harbor tremendous value for climate mitigation and adaptation initiatives. It is our hope that resource managers in Brazil will be able to use these results as a starting point for further surf conservation. Securing protection for some of the surf resources highlighted here presents an opportunity to protect biodiversity, prevent the destruction of carbon storing habitats, safeguard marine resources that coastal communities depend on for their livelihoods, and ensure that future generations will be able to connect with the ocean through surfing.

Part 2: Good Practices in Surf Conservation

Other sections of this report have highlighted the growing recognition of surfing as a driver of coastal conservation. Surfing is unique as a motivation for conservation since it directly connects environmental, economic, social, and cultural dimensions (Ball 2015; Scheske et al. 2019). Ranking potential surf protected area (SPA) sites is only one aspect of this process, which also encompasses a range of practical management decisions and coordination with a range of local and regional partners to implement SPAs. There is a small, but useful and growing body of research addressing these management questions. Here, we synthesize lessons from surf conservation programs around the globe and provide thoughtful analysis to help practitioners scale their surf management programs.

Chapter 1: Identifying Surf Resources + Conservation Targets	Defining the surf resource is a critical first step that precludes other management considerations.
	Surf Protected Areas, by nature, are not able to control every aspect that influences surf breaks. Definitions of the surf resource should focus on controllable elements.
	Threat identification and risk assessment should accompany initial resource identification. Threats should be mapped to clear indicators, or conservation targets, for monitoring.
Chapter 2: Protection Strategies	Surfing reserves are a political unit and may or may not include every aspect of the entire surfing resource.
	Protection can be understood along two axes: 1) the **breadth** of protection (i.e. individual sites or networks); and 2) the ***depth*** of protection (i.e. legal framework versus informal designation).
	Proactive management that includes a mix of protection strategies can maximize the effectiveness of surf conservation.
Chapter 3: Surf Tourism Management	Understanding the actors and resource ownership is a first step in developing a tourism plan.
	Proactive planning, especially at the regional scale, can alleviate some of the challenges associated with ad-hoc, reactive efforts to control overcrowding.
	Certification programs administered at the resort level are not a substitute for regional-scale tourism management.
Chapter 4: Valuing Surf Breaks	All valuation attempts are incomplete in nature, prioritizing some forms of value and ignoring others.
	Almost all surf valuation attempts have focused solely on direct spending by visiting surfers. These "Surfonomics" studies should be viewed as a lower bound for the total value of surfing resources.
	Contingent valuation is a challenging but feasible way to incorporate other forms of value associated with surfing.

This work draws on three key resources: 1) Interviews with practitioners; 2) Published surf management plans and studies; and 3) Academic research directly or tangentially assessing surf resources. Conversations with managers and advocates led to the selection of four primary chapters: 1) Identifying Surf Resources and Conservation Targets; 2) Protection Strategies; 3) Surf Tourism Management; and 4) Valuing Surf Breaks. Each of these chapters will highlight “good practices” derived from common threads identified across each key resource category.

Chapter 1: Surf Resource Identification and Conservation Targets

Chapter Highlights

- There is inconsistency in the way governments and NGOs define surf breaks with "surf ecosystem," "surf amenity," and "surf resource" appearing frequently.
- All definitions acknowledge that surf conservation should include some degree of surrounding ecosystems beyond the breaking wave.
- There are inland and offshore forces that lie outside the ability of a surf protected area to manage.
- Resource protection should begin with clear characterization of the surf resource and possible threats, complemented by measurable goals to assess protection efficacy.

Before devising a surf management plan, the elements that create a surfable wave and make up the greater surf experience– referred to as **surf resources**–should be clearly defined so that everyone involved (i.e., coastal managers, decision makers, practitioners) are unified on what exactly needs to be accounted for and managed in a surf management plan. With an established definition, foundational steps to understand and comprehensively evaluate the surf break's characteristics, spatial extent, surrounding ecosystems, and potential threats can begin.

Many surf breaks lack management plans altogether. Some of the plans that do exist fail to include all the necessary elements of a surf resource. To address a need for standard practices, practitioners based in New Zealand published the *Management Guidelines for Surfing Resources (2019)*, which provides a science-based adaptive process for sur resource management (Atkin et al., 2020). This document, described in **Figure 17**, can serve as a guide that other countries can use to model and adapt their existing legal and cultural framework. While originally developed within New Zealand's political and legal context, the document **contains fundamental guidance and tools that can be applied to surf resource management worldwide**. This process emphasizes the importance of gathering information and data on the waves and surrounding ecosystems, storing it in a publicly accessible database, acknowledging and responding to threats and risks, and incorporating local communities and knowledge throughout the process.

Figure 17. Foundational steps towards developing a surf management plan (Atkin et al., 2020; Reiblich, 2013).

1.1 Defining Elements of a "Surf Resource"

Several terms with varying definitions are used in reference to surf areas. Common examples include "surf ecosystem," "surf amenity," "surf break," and "surf resource." While they may refer to similar things, the exact meanings and usage are not the same. Recent literature and insight from practitioner interviews make the case for using *surf resource,* as a term that avoids confusion with the scientific understanding of what bounds an "ecosystem," and includes all elements that can be managed to sustain the wave as well as the experience of surfing. Therefore, getting coastal managers and practitioners on the same page with terminology and establishing a universally accepted definition of *surf resource* - the term this report will use - is key to cohesive and comprehensive surf management and conservation of surrounding coastal ecosystems.

What is included in a "surf resource"?

Surfing takes place at the land-sea interface; surf breaks are made up of a special interconnection between the ocean, waves, watersheds, coastal ecosystems, and people. Surf areas are the immediate area where the sport of surfing takes place and can include a single wave or a series of breaks. However, the formation of waves and other considerations, such as beach access, that also facilitate surfing cover a larger area that ranges far beyond the location where surfing occurs (Scarfe et al. 2009; Mead and Atkin 2019). Filling that gap, the term *surfing resources* includes all the elements that contribute to the creation of a rideable wave and the factors that enable the enjoyment of surfing in a given area, altogether including offshore processes and submerged land and habitat responsible for forming waves, as well as land-based recreational and experiential components. This definition is outlined in **Figure 18** and is a compilation of ideas from multiple researchers and organizations (Atkin et al., 2019; Reiblich 2013; Save the Waves Coalition, n.d.).

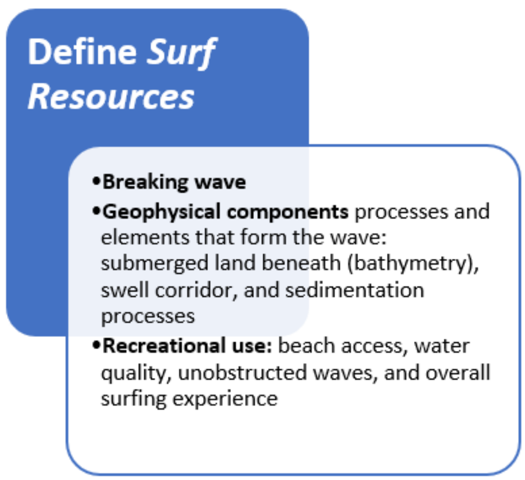

Figure 18. Elements of a surf resource defined (E. Atkin et al. 2020)

Holistic management should consider each of these elements because each contributes to sustaining the surfing experience in its entirety. Some literature, policy frameworks, and existing management schemes use a narrower definition including only the physical components of a wave and neglecting other aspects. These incomplete approaches lead to a higher risk that the surf break and surf experience will be negatively impacted by either harming or altering the wave itself, diminishing the surfing experience, or degrading the surf area's natural resources and processes.

1.2 Understanding the Surf Resource Area

Good practice in beginning a surf management plan starts by developing a thorough understanding of a location's surf resources. Atkin et. al (2019) details specific resources, tools, and technologies that can guide practitioners through additional steps to better understand surf areas (**Figure 19**):

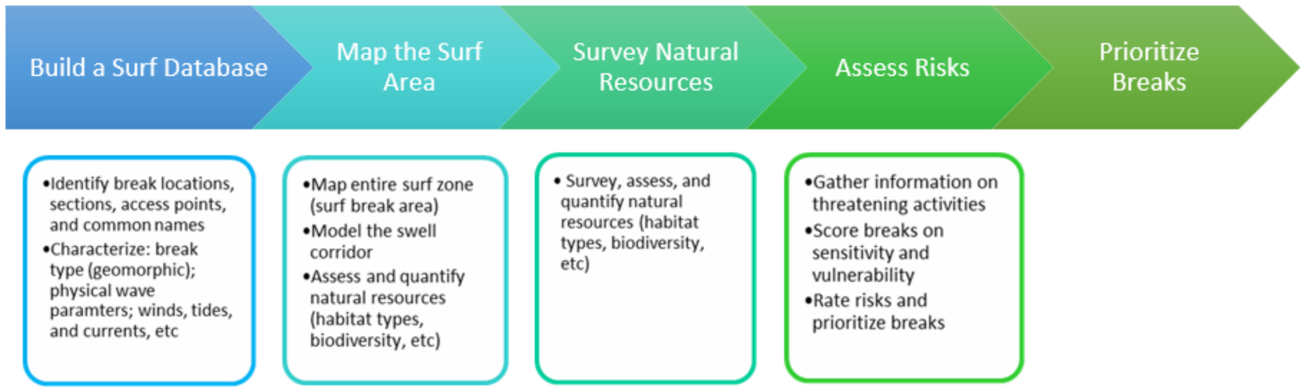

Figure 19. Steps to comprehensively evaluate and understand a surf area.

Creating a comprehensive surf database

This step develops a broad understanding of a location's surf resources (Atkin et al., 2019). Continually collecting quantitative data is critical for successful management. It facilitates the measurement of change, allowing practitioners to make informed decisions on how the surf resources are used and appropriately respond to and resolve management issues (Mead and Atkin, 2019).

Mapping and modeling the spatial extent

This step **creates a planning tool** that can aid decision making by identifying where activities could block or modify the waves traveling through the corridor area (Atkin et al., 2019). This step is especially important to inform the risk assessment.

Risk assessment

Completing a risk assessment can create a **"watch list" to prioritize and guide decision-making regarding activities that could threaten surf resources** and establish a monitoring plan can help managers establish actionable goals to protect surf resources (Atkin et al., 2019; E. Atkin, personal coomunication, Feb. 1, 2023). Threats to surfing are anything that can change the break's natural character or aesthetic, restrict access, raise health and safety concerns, or permanently harm the wave itself. Common threatening activities include: coastal construction (i.e., port, harbor, coastal protection, and infrastructure development), dredging and beach nourishment, offshore aquaculture of mining, overcrowding, and pollution events degrading water quality (Atkin et al., 2019; Ball, 2015; Reiblich, 2013; Touron-Gardic and Failler, 2022).

Surf breaks experience "cross-system threats" which include not only threats in the immediate vicinity, but also threats originating from *activities farther offshore outside the immediate wave break zone*. Some examples of these threats include offshore aquaculture, drilling and mining, and *terrestrial-based activities* such as construction actions cutting off sediment flow at the watershed level stopping form wave-creating sandbars from forming (Álvarez-Romero et al., 2011; Atkin et al., 2019; Reineman et al., 2021).

Important Considerations: Local & Native Knowledge and Engagement

☐ **Engaging with local communities is key** to gain accurate place-based knowledge of local surf characteristics, especially due to the variability of surf breaks and surrounding environments. Integrating this information with scientific approaches can contribute to more resilient protection of the surf resources (Arroyo et al., 2020; Skellern et al., 2013).

The ***Cultural Impact Assessment*** (Atkin et al., 2019) is a tool that was originally developed to facilitate Indigenous participation in New Zealand's planning process. This approach can be adapted to other locations to facilitate engagement with local communities and Native peoples and uplift their values and input on surf management planning.

The Surf Conservation Partnership (SCP) is addressing this in their World Surf Reserve system by working collaboratively with local partners at each WSR site to create a ***Local Stewardship Council*** and a ***Reserve Stewardship Plan*.**

1.3 Setting Conservation Targets

As stated in the *Significance, Global Context* section at the beginning of this report, the overlap between surf breaks and biodiversity areas presents a clear opportunity to use surf protection as a tool and motivator to conserve coastal marine environments both for their recreational value as well as their ecological value (Reineman et al. 2021; Touron-Gardic and Failler 2022).

Tying coastal marine ecosystem conservation into surf break management.

First, a clear understanding of what kind of natural resources and how many there are within a coastal marine surf area is needed. To achieve this, assess the habitats and species in a surf area by surveying the area, identify, and quantify the natural resources that are present**,** indicated in **Figure 19.** Gathering this information lays the foundation that enable practitioners to create conservation goals and a conservation strategy tailored to the location's resources. Importantly, once a conservation plan is created, monitoring strategies and enforcement schemes are necessary to make sure the ecosystems are protected (Atkin et al., 2019; Save the Waves Coalition, n.d.).

Surf reserves are moving toward protecting both the wave and the biodiversity in the area. For example, the wave reserve in Tres Palmas, Puerto Rico incentivized conservation management actions like debris removal and coral planning; reserves in Punta de Lobos, Mexico and Bells Beach, Australia spurred plant and animal restoration programs; and Santa Cruz World Surf Reserve triggered community discussion and eventually action was taken to address poor water quality issues (E. Atkin et al. 2020; Touron-Gardic and Failler 2022). Additional examples follow.

Example 1 Chile's Piedra del Viento coastal marine sanctuary

- Designation (2021) goals are to conserve the area's biodiversity (i.e traditional seaweed harvesting and fisheries) while simultaneously protecting the Topocalma and Puertecillo surf breaks.
- Aim: Create a participatory management plan with a bottom-up approach centering the local community as knowledgable stewards of the coastal environment
- Covers the coastal zone and marine areas and spearheaded by Marine Conservation Institute in partnership with Chile's Fundacion Rompientes

Example 2 World Surf Reserves

- Save the Wave's Coalition *World Surf Reserves* is a model example of an iniative that ties preserving waves together with conservation of the surrounding coastal marine ecosystems as a primary goal.

(Buttazzoni, 2021; "World Surfing Reserves", n.d.)

1.4 Chapter Summary and Findings

Protecting the overall surf experience, including the physical surf breaks in addition to the surrounding coastal marine environment is a relatively new concept with limited "successful" examples to reference. However, a few fundamental concepts should be considered when building a comprehensive management scheme.

1. Define "surf resources"

- Settling on a definition of surf resource is important to clarify what needs to be considered in surf management
- Surf resources include all the geophysical elements that create a surfable wave (e.g unobstructed swell corridor, submerged habitat) and recreational aspects (e.g beach access, water quality, crowding) that make up the greater surf experience
- Good practice for developing a holisitc, robust, and effective surf management plan accounts for all elements of a surf resource

2. Understand the surf break and surrounding area

- Compiling quantitative and qualitative information on surf breaks and the nearby ecosystems into a database helps practioners understand the area's characteristics
- Mapping the entire surf break and modeling the swell corridor creates useful planning tools
- Identifying potential threats and risks to surf break and creating a "watch list" can help prioritize breaks for conservation
- Altogether, these actions help measure change, guide decision making, & enable practitioners to resolve management issues
- Throughout this process, it is important to uplift local and native people's perspective and knowledge to achieve equitable decisions and improved resource protection

3. Tie in natural ecosystem conservation

- Surf breaks often overlap with biodiverse coastal marine ecosystems and can be a vehicle for environmental conservation
- Survey and quantify the habitats and create a conservation plan specific to the location's resources
- Incorporate ecosystem conservation plan into greater coastal surf management plan to achieve both goals simultaneously

Chapter 2: Protection Strategies

Chapter Highlights

- Surfing reserves are a political unit and may or may not include every aspect of the entire surfing resource.
- Proactive management is key and can avoid the need to rely on reactionary grassroots campaigns to respond to an actual or proposed harm to a surf spot.
- Protection options vary depending on the location's legal framework and protection is possible using coastal management policy even without surf-specific legislation.
- Currently, the best approach is to combine multiple protection strategies for full coverage of a surf break.

A one-size-fits-all approach to design and implementation of protected areas does not work (Halpern et al., 2013). This is especially true for SPAs. There are many ways surf breaks are protected around the world, including: a variety of legal avenues, informal designations, protective campaigns, and discussions on adapting existing conservation strategies to also protect surf breaks (Reiblich, 2013). The type of protection available to a surf break is heavily dependent on legal and political context for the particular site.

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Figure 20. The 5 elements of complete surf resource protection.

Comprehensive protection requires attention to each of the factors illustrated in **Figure 20**: formal recognition of the surf break; proactive measures preventing degradation; policies and regulatory language ensuring recreational use; inclusion of surrounding natural, social, and cultural systems; and adequate enforcement and compliance (Monteferri and Arroyo, 2022). These can be achieved through a variety of options: available legal avenues, strong informal social enforcement, and other management and policy levers. However, many ***current protection strategies and existing legal frameworks are generally thought to be***

insufficient in achieving effective protection across all the key elements of a surf resource (Reiblich, 2013).

2.1 Axes of Protection

Adequately protecting surf breaks is a difficult task due to a few main reasons: 1) there is considerable inconsistency when defining a surf resource (see Chapter 1); 2) existing coastal and marine management legislation does not necessarily include all components of a surf resource; 3) legislation at upper levels of government (i.e., federal, state) can hinder flexibility in local planning; and 4) jurisdictional boundaries are often blurry with overlapping public and private property rights.

For ease of comparison, protection strategies can be considered along two axes: 1) the ***breadth*** of protection (i.e., individual sites or networks); and 2) the ***depth*** of protection (i.e., legal framework versus informal designation). This is visualized in **Figure 21** below.

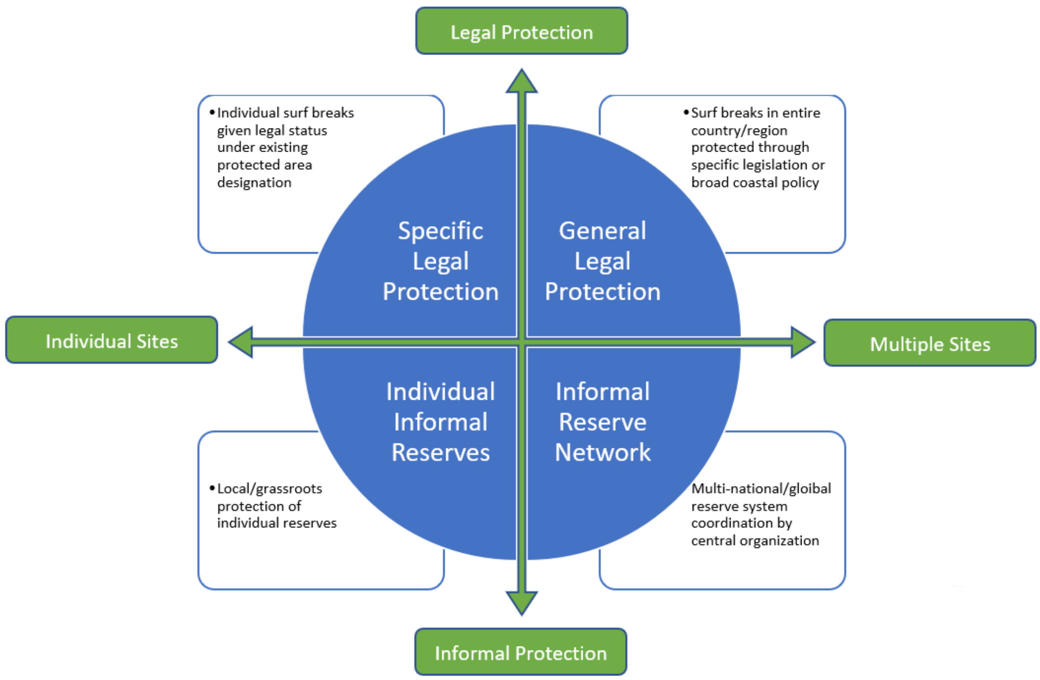


Figure 21. Protection strategies "breadth" and "depth" axes. The "breadth" axis defines the extent of protection strategies that can cover individual sites or a multitude of breaks. The "depth" axis includes the spectrum of weaker, informal protection to formalized legal protection.

Legal protection avenues can take place at multiple levels– local, regional, and national. Aside from Peru's Ley de Rompientes (or "Law of the Breakers"), it is not common for surf breaks to have specific legal protection (Kaminski, 2021). Therefore, surf breaks are often creatively incorporated to a variety of existing legal schemes. For example, surf break protection can be built into coastal management plans or policies, such as New Zealand's national policy framework, or Australia's local and regional surf management plans (i.e., City of Gold Coast incorporating a surf management plan into their official Ocean Beach Strategy). Alternatively, approaches that adapt existing conservation strategies (i.e., Marine Protected Areas, National Register of Historic Places, World Heritage Sites, International Union for Conservation of Nature (IUCN) protections) to include surf break protection have been explored (Blum and Orbach, 2021; Monteferri and Arroyo, n.d; Reiblich, 2013; Scheske et al., 2019).

Alternatively, **informal protection** strategies include reserve designations and campaign initiatives. Designating a reserve recognizes significant and high quality surf breaks, the important links between surfers and the wave, and can assist in conservation of the entire surf resource (Farmer and Short 2007). However, designations do not automatically extend any explicit legally binding protection without separate, supplemental action being taken to formally incorporate surf resources into broader planning and policy procedures. Examples include the 12 currently approved World Surf Reserves, such as those located in Santa Cruz, California and Punta de Lobos, Chile, and Hawaii's Governor's Executive Order in 2010 to establish surf reserves for breaks off Waikiki and the island's North Shore (Crabtree, 2010). **Campaign initiatives are usually retroactive attempts to save or protect a surf break once a threat has been identified**, such as those spearheaded by Surfrider Foundation and Surfers Against Sewage. They often entail galvanizing surfers and other coastal enthusiasts to pressure the government to officially and formally protect threatened surf breaks (Reiblich, 2013). Some examples include:

Example 1 Surfer's Against Sewage

- Launched in 2012, Protect Our Waves campaign mobilized over 50,000 surfers and other ocean-users to petition the United Kingdom government to consider legislation that would a) recognise surf breaks as important cultural, social, economic, and environmental assets, and b) protecting ocean water quality against pollution (e.g marine debris, sewage) and coastal development.

Example 2 World Surf Reserves

- Recently, Save the Waves Coalition joined forces with multiple local organizations in Oaxaca, Mexico (e.g including Reservas de Surf Mexico and Union de Surfistas y Salvavidas de Salina Cruz) to stop a coastal construction project for an industrial port that could harm the popular surf break Punta Conejo.

("Our Ocean Recovery Campaigns" n.d.; "Salvemos Punta Conejo" n.d.; "World Surfing Reserves" n.d.)

Many case studies of surf breaks being killed or degraded exist that serve as warnings for improper surf resource protection. Notably, the popular surf break Killer Dana at Dana Point, California was destroyed because the development of a coastal protection structure, a 1.5-mile-long jetty, at Dana Point Harbor cut off the swell responsible for forming the wave (Reiblich, 2013; Ball, 2015).

2.2 Comparing Protection Strategies

Not all protection strategies fit neatly into this classification, but it's useful to imagine different types of protection along these two axes. Peru, for example, is a good case of the "General Legal Protection" category where their "Law of the Breakers," which bestows legal protection on surf breaks, has successfully extended legal protection to 33 surf zones since 2000 and mobilized to limit the development of oil and gas, coastal infrastructure, and commercial fishing in prime surfing locations (Kaminski, 2021; Touron-Gardic and Failler, 2022). While Peru may fit into this category, many legal protections achieved for surf spots were born out of informal campaigns to protect specific sites including the World Surfing Reserve (WSR) at Huanchaco (Save the Waves Coalition, 2023; Touron-Gardic and Failler, 2022).

New Zealand is the first country to have a national policy framework explicitly requiring consideration of surf breaks in coastal development planning and decision making under the country's national Coastal Policy Statement (Mead and Atkin, 2019). While a statutory national policy is a great step forward for surf resource protection, so far protection has varied in effectiveness and there have been gaps in implementation (Orchard, 2017). Australia, on the other hand, has taken a more regional approach to surf protection and nominates select surf breaks for designation as Regional and/or National Surf Reserves (24 total); Australia can also claim the first ever wave recreation reserve designation with Bell's Beach in 1973 (Touron-Gardic and Failler, 2022). This designation, like the World Surf Reserve system, is non-statutory and mainly symbolic; therefore, it does not automatically afford the surf break any legal protections. It has proven to be effective nonetheless (Orchard, 2017). Designating surf breaks as reserves has been widely successful in building public support, catalyzing community conversation, and stimulating public policy for surf resource protection. For example, Malibu's surf breaks were added to the National Register of Historic Places after designation as a WSR. Australia's Gold Coast WSR, another example, adopted the Surf Management Plan into the City's greater coastal plan, the Ocean Beach Strategy ("Gold Coast Surf Management Plan", 2015; Touron-Gardic and Failler, 2022).

Unlike New Zealand, the United States does not have a clear legal pathway to protect surf breaks. Laws and policies that directly apply to surfing resources do not exist; however, several national and state-level statutes are relevant to different aspects of them (Atkin et al., 2020). California's governance framework, for example, is set up such that it could potentially adapt and expand New Zealand's legal and management structure and be used to strategically cover surf resources. One key difference is that California's opportunity to extend surf resources protection would be a bottom-up approach from the local level. California state legislation does not specifically protect surf breaks, but requires that local governments create Local Coastal Programs which grants the opportunity to explicitly recognize surfing resources and incorporate protections into local coastal plans and policies (Atkin et al., 2020). Another key difference is that New Zealand's Coastal Environment spans the entire watershed and extends 9 more nautical miles offshore than California; this larger jurisdictional area allows for surf resource policies to be created and applied more comprehensively and effectively (Atkin et al., 2020).

Other creative strategies that attempt to adapt existing conservation strategies (e.g., Marine Protected Areas, IUCN conservation protection, etc.) can be successful in partially protecting breaks. However, these are not ideal routes in that they are not created with surfing in mind and do not wholly cover all elements of a surf resource; further, it can be difficult for surf breaks to fit the criteria and achieve designations. The approach of fitting surf resources into established conservation strategies with legal backing, while not perfect, can serve as a useful temporary solution while more tailored approaches are crafted.

Most of the available literature and practitioners who were consulted for this report indicate that legal protection is the ultimate goal for most cases (A. McKinnon and S. Gillies, personal communication, Feb. 6, 2023). While achieving legal protection is ideal, it is not the only route available to successfully protecting surf breaks. This is especially true for countries with non-western systems of governance. In Papua New Guinea (PNG), the surf resources are "owned" by traditional resource custodians rather than following typical public or private property rights common of western systems. Here, there has been success in protecting surf breaks despite a lack of formal legal protections thanks to strong community engagement, local management through Surfing Association PNG, and social enforcement (A. Abel, personal communication, Feb. 1, 2023). More on this particular case is discussed in Chapter 3.

Further, more **complete and robust protection is possible by layering legal protections with other policy and management tools**. For example:

Example 1 Huanacho, Peru - legally protected surf break

- **Current protection:** Ley de Rompientes (Law of the Breakers) affords the surf break legal protection at the national level by listing it in the Peruvian Naval Archives. This ensures the government will take preventative measures against destructive infrastructure projects, as enforced by the Navy.
- **Gap**: Recreational use, like beach access, water quality, crowding, and other social and cultural systems are not covered in the law
- **Potential solution**: Supplementing this law with a World Surf Reserve designation fills the gaps by providing a pathway via the Local Stewardship Plan to build in missing considerations

Example 2 Guarda do Embau - designated World Surf Reserve

- **Current protection:** Acknowledges the prominent surf break within natural, social, and culturalsystems
- **Gap**: Does not outright enable recreational use, ensure preventative measures against threatening activities, or offer enforcement
- **Potential solution**: Couple explicit beach access protection and a wave corridor designation preventing activities that could harm or kill the wave

(Haro, 2014; "Federal Protection Granted for Huanchaco World Surfing Reserve," n.d.; "Brazil's Guarda Do Embaú Officially Dedicated as the 9th World Surfing Reserve", n.d.)

Table 3 below touches on some of the different types of protection currently being used or explored to protect surf breaks and provides examples, benefits, limitations of each, and potential solution as to how the protection strategy could be bolstered to provide more comprehensive protection.

Table 3. Current protection strategies for surf breaks.

Protection Strategy	*Example*	*Benefits*	*Shortcomings*	*Potential Solution*
Legal Avenues				
National Laws	**Peru's Ley de Rompientes** *Example: Huanchaco, Peru*	• Federal law recognizes significant surf breaks in Naval National Register; • Government has authority to prevent harmful coastal activities that could impact registered breaks	• Does not consider recreational use	• Combine national law with local management plans that protect land-based recreational elements
Coastal Management Policies & Plans	**National Policy Frameworks** *Example: New Zealand's Coastal Policy Statement*	• Explicitly requires consideration of surf breaks in national coastal development decisions • Could prevent coastal development that could harm surf breaks	• Requirements are mainly procedural and does not substantively protect all surf resource elements (i.e harmful offshore activities, recreational use)	• Compliment with robust local policies and surf management plans to protect recreational elements • Combine with legal protections specifically for the offshore swell corridor (e.g corridor designation)
	Regional and Local Management *Example: City of Gold Coast (Australia), adopting Surf Management Plan*	• Manages for recreational use, ensures monitoring, allows for locally-led adaptive management	• No formal regulations or legal protections that explicitly prevent potentially harmful infrastructure projects	• Supplement policies and plans with legal protections to specifically for the offshore swell corridor (e.g corridor designation)
Integrate Surfing into Other Conservation Strategies	**Marine Protected Areas** *Examples: Sanctuary Piedra del Viento in Chile; Santa Cruz in Monterey Bay National Marine Sanctuary*	• Provides various levels of use restrictions and protections • Can offer some legal protections depending on the marine protected area type	• Does not include preventative measures protecting swell corridor and beach access	• Compliment with a robust local policies and surf management plans to protect land-based recreational elements not covered in the MPA • Combine with legal protections to specifically protect the swell corridor (e.g swell corridor designation)
	National Register of Historic Places *Example: Malibu (California) Historic District*	• Raises awareness for precious surfing resources	• Procedural protections only apply to federal actions and activities and not state or local actions • Difficult for surf breaks to meet requirements; designation does not provide legal protections	• Supplement with legal or policy tools to protect against harmful development, implement active in-field surf management
Reserve Designations	**World Surf Reserves** (Save the Waves) *Examples: Bahia de Todos Santos (Mexico), Guarda Do Embau (Brazil), Ericeria (Portugal)*	• Enshrinement raises support for conserving outstanding surf breaks; • Designation leads to development of a Surf Management Plan (Local Stewardship Councils create management plans)	• Symbolic designation and does not outright provide formal, legal protections for the break, prevent harmful development, or enable recreational use	• Build recreational use elements into management plan • Explore locally available options for additional legal protections for the offshore swell corridor and against harmful development
	National & Regional Surf Reserves (Australia) *Example: Bell's Beach*	• Same as above	• Same as above	• Same as above
Campaigns	**Surfer's Against Sewage** *Example: Protect Our Waves campaign*	• Pressures the United Kingdom's government to enact legislation to specifically protect surf breaks	• Entirely reactive strategy (harm or threat must already be present) due to the UK's lack of legal protections for surf breaks	• Useful strategy for advocating for formal legal protections or creation of a policy framework • Implement as a backstop

(Atkin et al., 2020; Ball, 2015; "Federal Protection Granted for Huanchaco World Surfing Reserve", n.d.; Reiblich, 2013; Scheske et al., 2019; Orchard, 2017; "Our Ocean Recovery Campaigns", n.d.; "World Surfing Reserves", n.d.)

2.3 Chapter Summary and Findings

As previously mentioned, to adequately protect surf breaks, all four components need to be covered into the surf resource protection scheme: *the wave and submerged land beneath the wave, the swell corridor, beach access to the surf location, and the surf experience.* Since current protection schemes are inadequate, the best paths forward for surf protection are to either **1) developing entirely new legislation** that is specifically tailored to surfing and is inclusive of all the elements of a surf break (as outlined in Chapter 1), or **2) apply a patchwork approach to surf breaks and layer existing legal protection with other available policy and management tools**. For both options, it is good practice to make sure that all five aspects of "Complete Surf Resource Protection" as listed in **Figure 20** are appropriately incorporated. Below outlines the key findings from this chapter.

1. Current protection schemes are inadequate for complete surf break protection

- Surf break protection is a fairly new concept and is difficult to achieve for several reasons: existing coastal policy often does not include all parts of a surf resource; supportive legal frameworks are uncommon; and public and private jurisdicational boundaries are typically blurry in the coastal zone
- Currently, a variety of strategies are used to attempt to protect surf breaks, including both legal avenues through legislation and policy as well as informal reserves and campaigns
- The type of protection available to surf breaks heavily depends on the cultural and legal situation of the particlar site
- While it is possible to conserve surf breaks through a variety of pathways, achieving formal legal protection appears to be the ultimate goal
- Altogether, strategies used now fail to comprehensively protect all elements of a surf resource

2. Protection scheme should take a proactive, comprehensive approach

- Proactive protection is better practice to conserve a surf break versus a purely reactive approach that mobilizes after a threat is identified
- Involving the local communitiy and government at every level is critical for sustained protection
- Good practice is to apply the following 5 aspects to surf resource protection: 1) formal recognition of a surf break, 2) take proactive and preventative measures, 3) enable recreational use, 4) include natural, social, and cultural systems, and 5) provide enforcement and compliance

3. New legislation and innovate solutions are needed to adequately protect surf breaks

- The best path forward for surf protect is to create new legislation and policy mechanisms developed specifically for surf resources
- An alternative option in the meantime is to work within the current system and apply a patchwork approach of layering available legal protections with other policy and management tools, campaigns, and designations

Chapter 3: Surf Tourism Management

Chapter Highlights

- Understanding the actors and resource ownership is a first step in developing a tourism plan.
- Proactive planning, especially at the regional scale, can alleviate some of the challenges associated with ad-hoc, reactive efforts to control overcrowding.
- Surfers themselves are (theoretically) willing to pay for conservation activities.
- Certification programs administered at the resort level are not a substitute for regional-scale tourism management

3.1 Managing Local Impacts

Overuse and overcrowding significantly diminishes the enjoyment of surfing and is often a result of a lack of tourism management (Ponting and Mach, 2018; O'Brien and Ponting, 2013; Ponting and O'Brien, 2014). On the other hand, efforts to limit crowding using top-down approaches can also have adverse impacts. In Indonesia, for example, efforts to limit crowding led to a suppression in the development of a local surf culture (Mach and Ponting 2018).

Understanding resource ownership and use patterns is an essential first step in anticipating community impacts. There are many examples where surf tourism has developed in a way that exacerbated inequalities when foreign developers monopolize the property and infrastructure supporting surf tourism (Román et al. 2022). This is a form of "corporate" governance of surf resources, which is a foil of community-led models. Practitioners suggest that "inter-organizational cooperation" is critical for Sustainable Tourism Destination Governance (STDG) (Ponting and Mach, 2018; J. Ponting, personal communication, Jan. 25, 2023). Ponting and Mach (2018) pose the following model to help understand governance at different scales (**Figure 22)**.

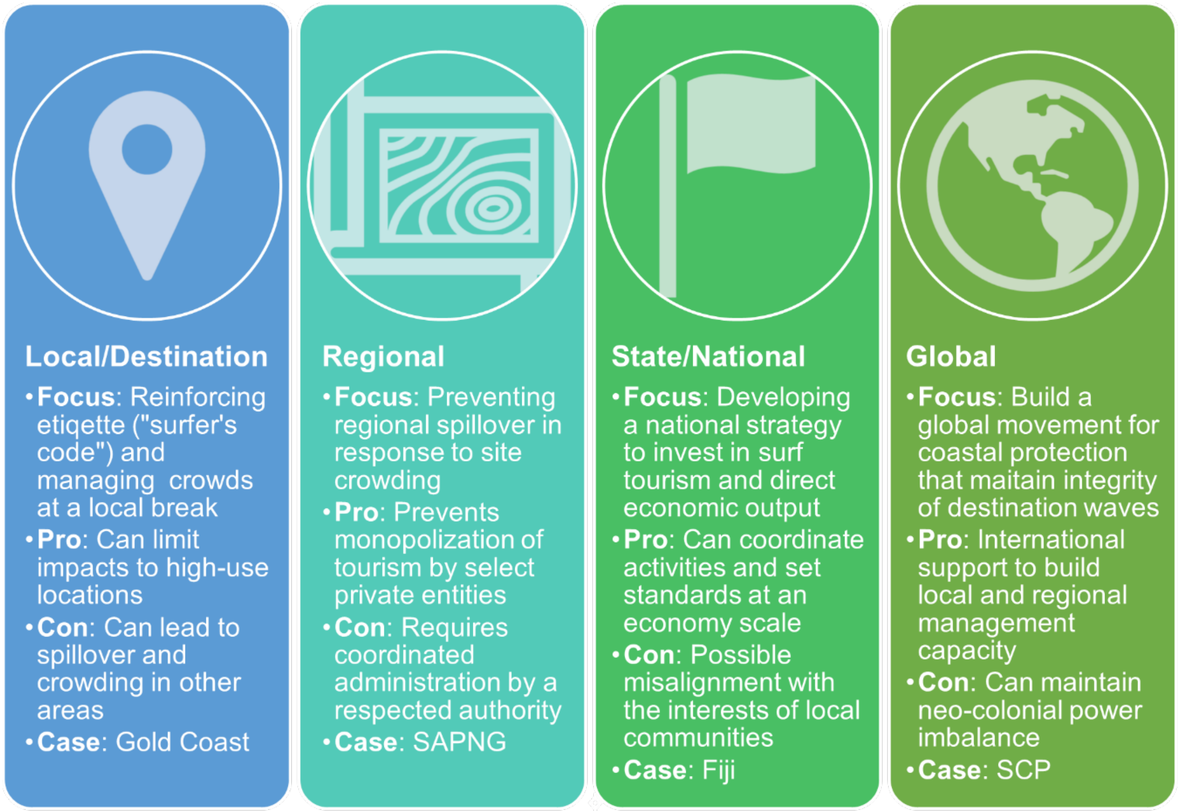


Figure 22. Tourism destination governance scales. This highlights the four primary scale of tourism destination governance outlined by Mach and Ponting (2018).

Tourism management is highly dependent on the political and social conditions of the country hosting visiting surfers. This overlaps directly with the protection strategies analysis from *Chapter 2*.

Proactive planning, especially at the regional scale, can alleviate some of the challenges associated with ad-hoc, reactive efforts to control overcrowding. The pathway for management differs significantly across two dimensions: 1) the scale of existing surf tourism, and 2) the wider socioeconomic context of the country (i.e., “developing” versus “developed”). The figure below provides examples of two different contexts.

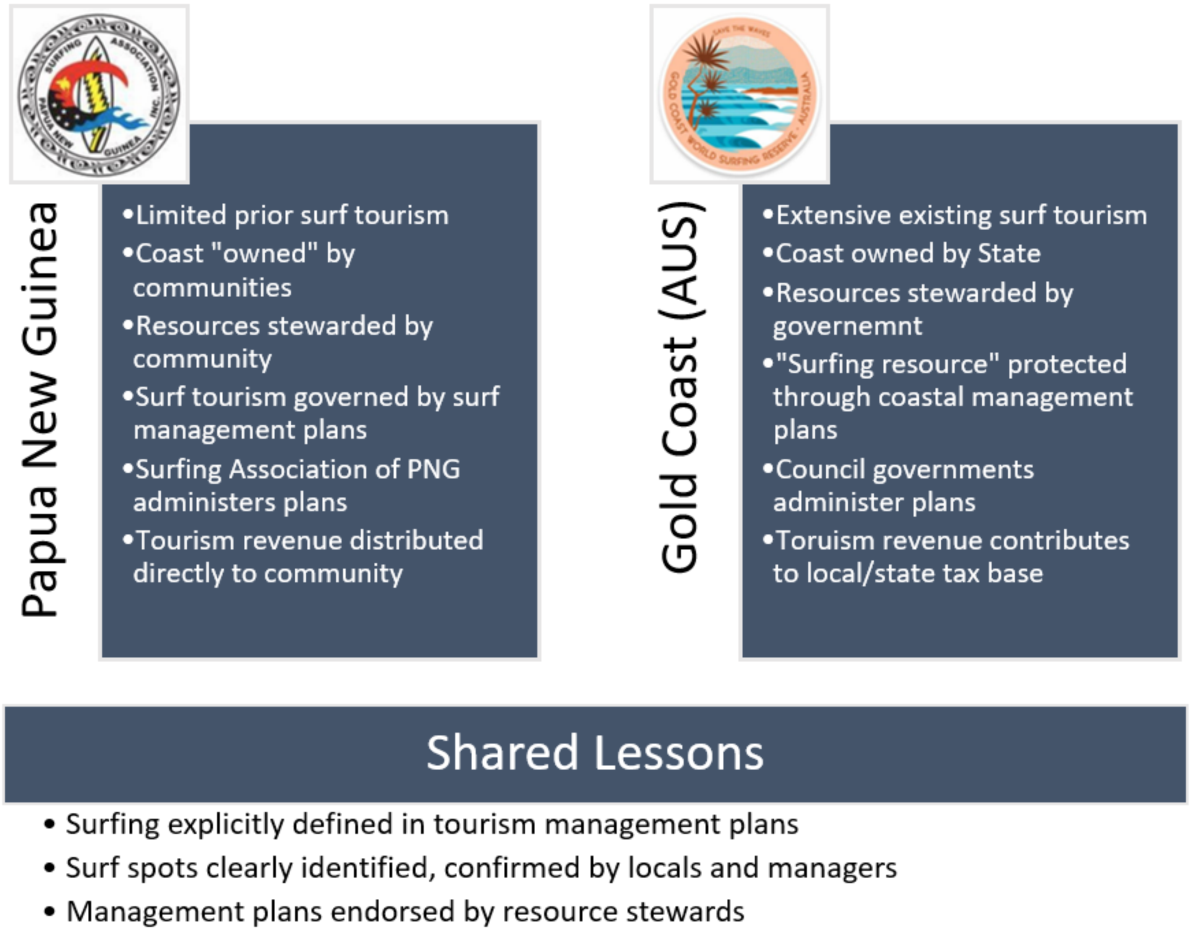


Figure 23. Surf tourism management in Papua New Guinea and Gold Coast (AUS). This figure highlights shared lessons and key differences in surf tourism management in two contexts (A. McKinnon and S. Gillies, personal communication, Feb. 6, 2023; A. Abel, personal communication, Feb. 6, 2023).

The distribution of surf tourism revenue and sector-level economic impacts is not well-understood. The rise of a global surf conservation movement is increasing focus on promoting equity and prioritizing sustainable development at the community-scale. **Establishing specific targets local (re)investment at early stages in the development of a surf tourism economy can minimize equity concerns**.

The Papua New Guinea case demonstrates how setting limits to surf tourism is not sufficient as a stand-alone policy if the objective of tourism is to empower local communities (Ponting and O'Brien, 2014). Island surf destinations, like the Mentawais and Bali, with a high level of foreign ownership of coastal property are even stronger cases for the need of management plans that include direct benefit to local communities (Román et al., 2022).

3.2 Sustainability Frameworks and Certifications

So far, this chapter has focused on the socioeconomic implications of surf tourism. It is also widely recognized that local engagement is necessary to maintain environmental goals (Bennett et al., 2021; Grorud-Colvert et al., 2021). The environmental dimension is an important and interrelated aspect when assessing the sustainability of different surf tourism programs.

There are several existing frameworks for assessing the impact of surf tourism and recognizing establishments with sustainable practices. The following graphic visualizes the core principles of the sustainable tourism certification non-profit, STOKE Certified, which adapts the Framework Analysis for Sustainable Surf Tourism (FASST) in their approach (**Figure 24**).

Figure 24. FASST Model and STOKE certified platform. The left figure shows an abbreviated version of the five core tenets of the FASST model that has been applied to assess surf tourism in destinations like Fiji and Portugal. These principles are used to assess the sustainability of individual surf tourism accommodations through the STOKE Certified platform. These principles are codified into a scoring system summarized in the right figure.

Beyond what surfers already contribute to the global economy, there is also indication that some in the surfing community would be willing to pay more to surf tourism providers committed to sustainability (Mach and Ponting, 2021). There is also indication that the surfers themselves would be willing to subsidize this protection to a certain point. Leveraging tourism as a funding source for coastal conservation can maximize the benefits to local economies and environments (Touron-Gardic and Failler, 2022). This is the key justification from programs like STOKE that assume surfers will respond positively and patronize establishments with a reputation for good practices.

Certification programs are not a substitute for regional-scale tourism management seen in Papua New Guinea. However, they can be an important tool when surfing resources are deregulated, as has been seen in Fiji (Ponting and O'Brien, 2014). Box 1 explores the management history nationally, and the specific approach of Tavarua Island Resort encapsulated in their STOKE profile.

Box 1: Case Study - FASST in Fiji

Ponting and O'Brien (2014) present a timeline of major events in the management of surf tourism in Fiji. These developments can be summarized into a **"initial" period** and a "**current" period**.

In the initial period, management followed *qoliqoli*, a system of traditional fishing rights. Resort owners, including those on Tavarua, were granted licenses under the condition that they protect the reefs by capping visitation and remitting money directly to the resource owners (Ponting and O'Brien, 2014). This models the case of Papua New Guinea explored above.

The current period includes everything following the implementation of the "surfing decree" in 2010. The decree effectively removed all licenses and capacity limits on surf breaks in the country and reduced the role of indigenous communities in surf tourism management. The implications of this are highlighted in the figure below.

1. Top-down, liberalized development increased
   - **Initial**: Resorts worked with indigenous stewards to manage surf resource
   - **Current**: 2010 "surfing decree" revoked special licenses and did not formalize traditional rights

2. Limits to growth were removed
   - **Initial**: Site-based capacity limits set by resort and community
   - **Current**: Tourism encouraged to expand without limits

3. Cross-cultural coordination deprioritized
   - **Initial**: Traditional land and fishing rights prioritized
   - **Current**: Indigenous communities shut out of tourism economy

4. Local Sport Development Increased
   - **Initial**: Limited surfing partcipation from Fijians
   - **Current**: Increase in local surfing population with Fiji Surfing Association

5. Poverty Alleviation Mixed
   - **Initial**: $ millions remitted directly to traditional resource managers
   - **Current**: Income distributed more widely across industry

This issue is still being debated and there is a renewed effort in 2023 to repeal the surf decree (Fox 2023). On one side, the decree is credited for creating an overcrowding issue at prime breaks and disadvantaging indigenous communities. On the other hand, tourism officials say it helped develop a national sport culture around surfing.

As this conversation plays out, resort managers continue to pursue their own management plans. Tavarua Island Resort, one of the longest-standing surf resorts in the world, has been given a "Sustainable" certification level through the STOKE process. Some aspects of this are highlighted below ("STOKE - Sustainability Certification", n.d.).

STOKE Scoring

There are a host of other questions that tie into the surf tourism management conversation. The Fiji case, before the implementation of the surf doctrine, is an example of how partnerships between resorts and local communities can ensure compensation is given to traditional resource managers. Direct funding support is especially important if the development of surf tourism involves any economic losses associated with shifting use of resources. Sustainable tourism models recognize that the most cost-effective solutions may not produce the lasting results that equity-focused solutions can provide (Halpern et al. 2013).

3.3 Chapter Summary and Findings

1. Understand Who "Owns" the Surf Resource

- Government, private, or community ownership will determine first steps in tourism plan
- Resource owner must eventually sign off on management plan
- Ownership also will dictate goals around equity and economic distribution

2. Measure Who is Using the Surf Resource

- Presence/absence of local surfing contingency will affect management decisions
- Capping access for locals is unlikely to result in long-term sustainable management
- Visitation from high-income foreigners could present opportunity to leverage funds for community development and conservation

3. Adapt Existing Surf Tourism Models

- Ample cases of what to avoid when setting tourism strategy
- Range of coverage in cases from small island to large, developed country context
- Adapt goals (i.e., FASST) to suit local/regional conditions

4. Outline Tourism Growth Goals

- Quota-based capacity limits may not be appropriate in all cases
- Stage of development of surf tourism (i.e., early, late) will determine what can be implemented
- Tourism levies could fill gaps and remove conservation funding burden from locals

5. Assess Equity Components of Existing Plans

- Management plans that prioritize foreign investors are unlikely to benefit local communities
- Equity will be overlooked without a specific funding component for locals
- Plans that limit traditional resource access/use will exacerbte inequality and lead to conflict

Chapter 4: Valuing Surf Breaks

Chapter Highlights

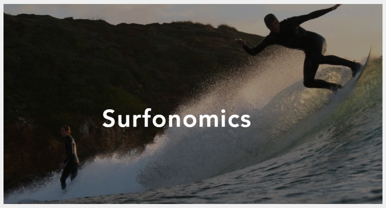
- Almost all surf valuation attempts have focused solely on direct spending by visiting surfers.
- ‘Surfonomics’ literature should be viewed as a lower bound for the total value of surfing resources.
- Non-market methods estimating travel cost and real estate effects each have limitations in the surfing context.
- Contingent valuation is a challenging but feasible way to incorporate other forms of value associated with surfing.
- A relevant valuation study requires input from the community on what they value and an understanding of how different spots are used.

4.1: Surfonomics and Direct Expenditure

There is a growing body of literature estimating the economic value surfing brings to coastal communities around the world. At a global level, surf tourism could contribute up to $64.9 billion in direct spending from surf-related travel (Mach and Ponting 2021).

There have been eight studies (known as ‘Surfonomics’) commissioned by the SCP that have estimated the direct spending tied to surf tourism specific sites. Collectively, these studies estimate more than $250 million per year in direct spending by visiting, and sometimes local, surfers (Bosquetti and de Souza, 2019). These figures typically employ surveys to aggregate reported spending on market goods like lodging and food to estimate a combined total “direct expenditure” for surf tourism. The cost of traveling to the location is excluded in most cases.

Box 2: Case Study - Comparing Playa Hermosa, Costa Rica to Guarda do Embaú, Brazil

		
People Surveyed	274	368
Annual Visitation (Tourists)	11,568	11,745*
Percent of Domestic Tourists	17%	85%
Average Trip Length	13 days	6 days
Average Daily Spending	$113	$61
Annual Economic Contribution	$11 million	$4.2 million

** Includes travel partners*

This table shows overlap in some areas between the two sites, and considerable differences in other aspects. Both studies used the same, non-random convenience sampling method and were careful to exclude both the travel cost and expenditure by locals in their analyses. Survey administrators in both cases were trained and surveys were piloted with smaller groups before administration (Bosquetti and de Souza, 2019; Bosquetti and Hodges, 2021).

While comparisons between sites is difficult for several reasons, this clearly shows the significance that trip length and daily spending play in total annual economic contributions. The total contribution of surf tourism to the economy in Playa Hermosa is more than double that of Guarda do Embaú. While the total contribution in Guarda do Embaú was less, surfing contributed a much larger share of the region's tourism economy as a whole (Bosquetti and de Souza, 2019).

Direct Expenditure Method Summary

Advantages	● Addresses the value of the surfing resource directly ● Avoids need to extrapolate from housing values or travel spending
Limitations	● Only captures actual use of surfing resource ● Surveys are subject to bias (non-random) ● Spending is typically reported and not validated
Takeaways	● Surfonomics could be marketed as a conservative baseline value of a surf break ● Studies could explore distribution of surf tourism dollars in the local economy like in Mundaka study (Murphy and Bernal 2008)

	● Contingent valuation questions could be integrated into ongoing survey work (discussed below)

4.2 Travel Cost and Real Estate Markets

Using proxies like travel costs and housing prices is a common approach to inferring the value associated with a resource that is not captured in the market. In the context of surfing, Travel Cost Method (TCM) studies collect data on the distance people travel to surf. Consumer surplus is aggregated based on this information and the cost (in both fuel and time) that people incur getting to surf areas (Scorse and Hodges, 2017). The consumer surplus is measured as the difference between the price (in time and fuel) people are currently paying and the (hypothetical) price at which no one would surf any longer.

Box 3: Research Spotlight - TCM in Trestles (Nelsen 2012)

(Nelsen 2012) provides a helpful outline and historical context around the use of different valuation techniques pertaining to surfing and coastal recreation with a California focus. The crux of the study, a single-site TCM conducted specifically for the world-famous surf break at Trestles, is one of the most comprehensive surf-specific studies to date.

Direct Economic Value	$13 million
Survey Responses	973
Surplus (per visit)	$29* - $138 ($2006)
Annual Visitors	330,000
Total Surplus	$21 - $45 million*

**Analysis included the more conservative lower bound from* (Chapman and Henemann 2001).

The study notes that surfers account for as much as 15 percent of all beach visits in California. It also implies that the **non-market consumer surplus value of surfing could outweigh direct economic value for some surf areas**.

Another way to approach non-market values is by identifying the impacts a resource like surfing has on home prices. This is referred to as the Hedonic Pricing Method (HPM) in the literature and usually requires the development of a regression model to isolate the influence of one factor on real estate value (Scorse and Hodges 2017). The theory here is that the shadow value of the non-market, environmental amenity is capitalized in the price of the real estate.

Box 4: Research Spotlight - HPM in Santa Cruz (Scorse, Reynolds, and Sackett 2015)

(Scorse, Reynolds, and Sackett 2015) is one of few studies that attempt to isolate the impact of proximity to surfing on home prices. To do this, researchers identified confounding factors that influence housing prices (i.e., number of rooms) and controlled for these to estimate the surf-specific contribution to the local real estate market in Santa Cruz. provides a helpful outline and historical context around the use of different valuation techniques pertaining to surfing and coastal recreation with a California focus. The crux of the study, a single-site TCM conducted specifically for the world-famous surf break at Trestles, is one of the most comprehensive surf-specific studies to date.

Homes in Sample	357
Average Home Price (Pleasure Point)	$1.1 million
Surf Contribution to Price	$106,000 ($2011)
County-wide Property Tax Contribution	$10 million per year*

**Scorse (2017) reduced surf contribution to conservative $10,000 across all 94,000 households in Santa Cruz County with a tax rate of 1.1%*

The study notes that the results could be biased by the fact that all residents in Santa Cruz experience relatively convenient access to surf. This could dampen the effects measured in the study. **Of particular note is the potential for an increase in property tax revenue for local governments as surfing becomes more popular and drives up coastal home prices**. Increasing property taxes near surf breaks is one way governments could redistribute money to the benefit of local communities.

TCM and HPM Summary

Advantages	● Revealed preference less subject to bias than stated preference ● Both methods capture value of surf break to local/regional visitors that is missed by Surfonomics
Limitations	● Value is aggregated indirectly and can be hard to isolate ● Validity of both methods highly dependent on the type of surf area being assessed and usage demographics ● Difficult to scale to regional level
Takeaways	● TCM and HPM are options to get at missing piece of Surfonomics - value to local communities ● Increasing the number of studies, especially outside of the California context, could help expand understanding of surfing value ● Both methods, but especially HPM, require more data than is currently being leveraged in Surfonomic

4.3 Contingent Valuation and Non-Use Methods

Contingent valuation is the most common method of “stated preference” valuation. Soliciting someone’s preference, usually with surveys, is the only way to value non-use aspects of a resource (i.e., philanthropic, existence value). Contingent valuation typically presents respondents with a hypothetical scenario to determine how much they would be willing to pay to preserve the integrity of a resource or ecosystem.

There have been few contingent valuation or non-use studies focused on surfing to date and likely none conducted before 2017 (Scorse and Hodges 2017)**.** However, there is a proven connection between coastal recreation and a willingness to protect natural spaces both in a general sense and for surfers specifically (Usher and Kerstetter 2015; Mach and Ponting 2021).

Research Spotlight: CV for Surf Conservation in Portugal (2019)

In their study titled "Surf as a Driver for Sustainable Coastal Preservation – Application of the Contingent Valuation Method in Portugal," researchers in Portugal applied CV methods to assess willingness to pay for coastal protection (Ramos et al. 2019).

The survey solicited information on several points including demographic information and general preferences around different spots and conditions. Respondents were given a mix of scenarios. The first asked if they are willing to pay an access fee to fund conservation, and if so, how much. The second focused willingness to pay a one-time fee to remediate damages resulting from an oil spill, differentiating between urban and non-urban beaches. The results are summarized below.

People in Sample	141
WTP for beach access fee (per trip)	€1.58
WTP for One-time Restoration (Non-Urban)	€22.28
WTP for One-time Restoration (Urban)	€15.56
Difference	43%

Key findings include that surfers in the study were resistant to the idea of paying for access to the beach itself. They were also more willing to pay to restore non-urban beaches that retained some level of their original natural environment.

Contingent Valuation Summary

Advantages	• One of few tested ways to measure non use values • Survey-based method that could be harmonized with ongoing Surfonomics and tourism work
Limitations	• Survey design even more subject to bias than other methods • Hypothetical scenarios do not necessarily reflect surfer (or beachgoer) ability to pay for protection
Takeaways	• Contingent valuation studies in SPAs could supplement Surfonomics work • More studies are required before a benefits transfer could be implemented

	• Existing studies can provide a basis for designing scenarios or setting thresholds to use in surveys

4.4 Chapter Summary and Findings

1. Determine What People Value

- **Good**: Talk to local surfers, businesses, and organizations to establish general sense of community values
- **Better**: Conduct coordinated interviews with local partners to establish a list of well-defined indicators that can be used measure important values
- **Best**: Conduct a formal survey of local respondents to develop ranked prioritization for value categories

2. Understand the Usage Patterns of the Site

- **Good**: Talk to local experts to determine general use paterns at a given site
- **Better**: Consult agencies and businesses to identify general metrics on surfer use patterns and demographics
- **Best**: Conduct a formal survey to determine accurate information on lenght of stay, domestic vs. foreign,

3. Review Existing Studies

- **Good**: See what has been done in the region (or similar geographies) and adapt methods
- **Better**: Use specific usage patterns to identify what types of valuation are appropriate
- **Best**: "Better"approach while also taking preperatory steps to conduct wider survey efforts

4. Conduct a Preliminary Analysis

- **Good**: Conduct a Sufronimics but expand survey questions to begin bulding raw data for wider valuation study
- **Better**: Run an expanded Surfonomics that captures both direct expenditure and travel cost
- **Best**: Revamp Surfonomics to include direct expenditure, travel cost, and contingent valuation methods

5. Compare Results and Solicit Feeback

- **Good**: Check results with other studies and authors of previod Surfonomics
- **Better**: Set up meeting with resource managers to discuss findings and share insight
- **Best**: Share findings with wider community to identify gaps

6. Identify Next Steps

- **Good**: Communicate study results publicly and highlight potential wider application
- **Better**: Make a plan to fill data gaps to assess other forms of value
- **Best**: Buikd a roadmap to integrate site-specific studies at a regional scale

Chapter 5: Discussion and Further Research

Chapter Highlights

- There are several key findings that span the subjects covered throughout this report and provide clear management guidance in a variety of contexts.
- Additional research on the performance of SPAs relative to unprotected coastal areas and other forms of coastal reserves could inform future management guidelines.
- There is a gap in understanding of the distributional implications of the surf economy and its ability to drive equitable economic growth.
- There are few studies exploring the value of non-recreational ecosystem services (like carbon storage) associated or co-located with surf resources.

5.1 Discussion

Finding: Proactive measures can mitigate threats to surf resources

This finding should be relatively intuitive for managers. Across all case studies and projects assessed in this report, identifying threats and outlining response plans early in the management process can head off major problems. Relying on reactionary responses like grassroots campaigns or emergency protocols to halt projects with adverse impacts on surf resources is an unreliable way to achieve long term protection.

Early identification of key participants and goal setting is a low-cost way to begin building coalitions around surf protection. Local or regional buy-in to surf conservation initiatives is required in all cases and establishing working relationships early on can avoid future conflict. When done thoroughly, this process will also identify potential challenges, both legal and social, associated with moving towards more intentional surf management.

1. Establish consensus around what the "surf resource" includes and key threats
2. Determine who "owns" or manages the resource
3. Document the use patterns of the resource
4. Identify a management structure that reconciles use patterns with threats/sustainability goals
5. Outline the legal and social requirements to formalize this management plan

Figure 25. Steps for designing a surf management plan.

Finding: Focusing on individual breaks is inefficient if the goal is to achieve broader protection of surf resources.

Consensus from both practitioners and published studies agrees that multi-site management is more efficient at preventing degradation of surf resources. Focusing on individual breaks, even if they are particularly prone to overuse and overcrowding, leaves other surf resources and coastal areas vulnerable to development tourism, and other pressure. Concerns over possible spillover effects, where protection in one area leads to overuse in another, are widely cited in the conservation literature.

Regional or national surf management is not possible in every context. In fact, it is the exception for most existing surf conservation practices. However, implementing baseline practices and following some of the steps outlined in the figure above can help form management strategies that are general enough to be adapted to new breaks when the opportunity for protection arises. Regional models, like that developed by the Surfing Association of Papua New Guinea discussed in Chapter 3, can accelerate the rate at which surf protection is scaled while guaranteeing recurring benefits to local communities.

Finding: The best surf resource management plans acknowledge each of the four major aspects outlined in this report

In some ways, the delineation of the different chapters of this report are somewhat arbitrary. Each of the major categories explored are interconnected and should be considered as *aspects* of holistic surf conservation. Surf resource identification can be seen as a prerequisite for other components of the management process. Surf resources cannot be valued if they are not clearly defined. Nor can tourism plans or effective protection strategies be implemented if managers do not understand how surf resources are being used.

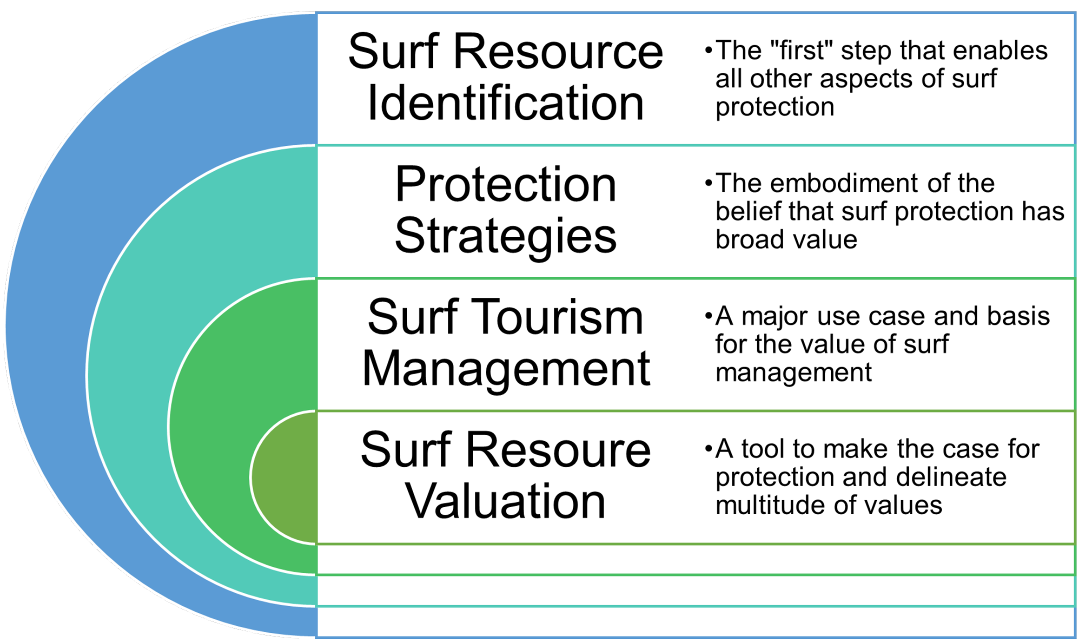


Figure 26. Four aspects of surf resource management plans.

5.2 Further Research

There are many unanswered research questions in the surf conservation space. This section seeks to highlight some of the gaps in the published literature and suggest some topics for further exploration as the practice of surf conservation expands globally. These questions are broken up into three categories: management, effectiveness, and valuation. Below are a few examples of these (**Figure 27**).

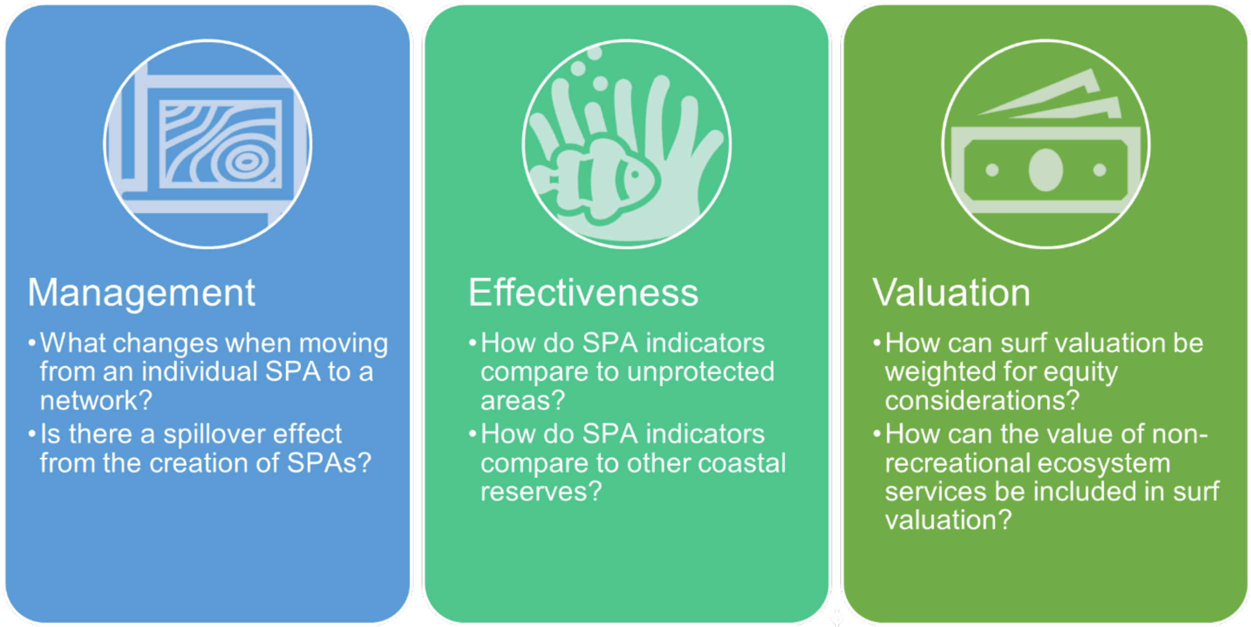


Figure 27. Further research questions and considerations.

Some of these questions begin to address the possible scaling effects of moving from single site or reserve-based surf protection to SPA networks (as envisioned by the Surf Conservation Partnership). Practitioners acknowledge the fact that surf resources may not always contain the highest level of desirable conservation targets like biodiversity. Future surf conservation efforts should look to these existing examples of networked coastal protection to determine whether achieving a similar level of connectivity is feasible.

Additionally, there have been limited attempts to determine how effectively SPAs are meeting their objectives. The logical next step in making the case for surf conservation is to demonstrate that protection is yielding measurable, positive results compared to unregulated areas with similar characteristics. This can be particularly helpful in understanding the role that protected status has in determining SPA effectiveness.

There is also room to expand surf valuation efforts. While investment in local communities is often discussed in the context of surf valuation studies, there has only been one study that explicitly explored the ways in which surf tourism revenue is distributed within a local economy (Murphy and Bernal 2008). Other research has shown that an absence of surf management can limit the economic benefits flowing to local communities (O’Brien and Ponting 2013). Understanding who in the community is benefitting from the economy surrounding a surf break is critical for understanding the equity implications of conservation programs. Other research could help expand wider understanding of the value of coastal ecosystems from a climate perspective. One line of research that surf valuation has not pursued is accounting for the value of non-recreational ecosystem services, and specifically carbon storage, included within a SPA. If a SPA is afforded legal protection, *and* one assumes the surrounding coastal ecosystems could have been lost or degraded without protection, it follows that there is additional ecosystem value that exists within a SPA beyond recreational benefits. Understanding the carbon sequestration potential across their projects is an organizational priority for our client, Conservation International (CI), and could be an impactful direction for research to take (Zamanian, Zhou, and Kuzyakov 2021).

However, establishing a "price" for coastal carbon is a challenging endeavor and requires many assumptions. A global database maintained by the World Bank indicates that Brazil has not yet, but may be, considering implementing an emissions trading system under its National Climate Change Policy (World Bank 2022). As such, we did not suggest a particular carbon price or recommend applying a value to coastal carbon storage in Brazil at this time. Future analyses could look to other examples of studies where coastal carbon storage has been valued to determine the appropriate price points and methods for translating these to geographies with no established trading system or national guidance on the social cost of carbon (Wedding et al. 2021). At worst, global estimates can be used (Nordhaus 2017).

5.3 Conclusions

This chapter is meant to elucidate two things: 1) shared lessons across the four primary chapter categories of this report, and 2) examples of future research questions that could enhance the field of surf conservation. This is by no means comprehensive and there are a multitude of other ways that practitioners could enhance programs. Surf conservation is likely to continue being used as a vehicle for coastal protection and understanding the interconnected aspects of surf resource management are essential for developing plans that simultaneously enhance the human enjoyment of these spaces and defend vulnerable ecosystems against threats.

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Appendix A: SCI and Ecosystem Service Methodology Addendums

Table *4*. Data needs and structure for the Surf Conservation Index. Indicators that are included in this analysis but have not been used in previous SCIs are highlighted in green.

INDEX	SUBINDEX	INDICATOR	SOURCE
Pressure		Population change	(IBGE 2000; 2010)
		Land use change	(Kennedy et al. 2020; Center For International Earth Science Information Network-CIESIN-Columbia University 2018)
		Built area	(Geofabrick GmbH and OpenStreetMap Contributors 2022)
		Roads	(Geofabrick GmbH and OpenStreetMap Contributors 2022)
		Ports	(Ministério da Infraestrutura 2021b)
State	Biodiversity	Terrestrial species richness (birds, amphibians, mammals)	(Jenkins et al. 2015)
		Tree cover	(MapBiomas Project 2020)
		Marine habitat cover (mangrove, seagrass, and coral reef)	(Bunting et al. 2022; UNEP-WCMC et al. 2021; UNEP-WCMC and Short 2021)
		Marine species richness	(O'Hara 2023)
		Terrestrial Priority Areas for Conservation	(MMA 2021)
		Coastal Priority Areas for Conservation	(MMA 2021)
	Surf	Wave quality	("Brazil - WannaSurf, Surf Spots Atlas, Surfing Photos, Maps, GPS Location" n.d.)
		Wave frequency	
		Wave direction	
		Experience level	
		Surf spot clustering	("Brazil - WannaSurf, Surf Spots Atlas, Surfing

			Photos, Maps, GPS Location” n.d.; “Surfline.Com” n.d.)
	Social	Per-capita employment in sports, recreation, and leisure	(IBGE 2010)
		Accommodations	(Geofabrick GmbH and OpenStreetMap Contributors 2022)
		Airports	(Ministério da Infraestrutura 2021a)
Response		Protected areas	(Departamento de Áreas Protegidas 2022)
		World Surfing Reserves	(Save the Waves Coaltion n.d.)
		Ramsar sites (internationally important wetlands)	(Wetlands International n.d.)
		UNESCO World Heritage Sites	(UNEP-WCMC and IUCN 2022)
		UNESCO Biosphere Reserves	(UNESCO 2019)
		Bandeira Azul beaches	(Foundation for Environmental Education n.d.)
Climate		Mangrove carbon storage	Custom-built model
		Coastal protection by mangrove, coastal forest, and coral reef	InVEST Coastal Vulnerability model

Table 5. InVEST Coastal Vulnerability model data needs and descriptions.

Inputs	Description	Source(s)
Area of interest (AOI)	50 km; buffer surrounding coastline over which to run the model. Shorepoints are plotted on all landmass coastline within this AOI	(IBGE 2017a)
Model resolution	1 km; interval at which shorepoints are plotted along the coastline	N/A
Landmasses	Map of all Brazil landmasses in and around AOI polygon	(IBGE 2017b)
WaveWatchIII	Map of gridded wind and wave data that represent storm conditions	(National Centers for Environmental Prediction 2019)
Maximum fetch distance	350 m; the maximum distance to extend rays from shorepoints. Determined as the farthest distance from the continental shelf to shore	(Zhang et al. 2021)
Bathymetry	Used to find average water depths for wave height and period calculations	(GEBCO Compilation Group 2022)
DEM	Map of elevation above sea level (meters)	(Verdin 2017)
Elevation averaging radius	500 m; radius around each shore point within which to average elevation values in the DEM raster	InVEST
Continental shelf contour	Map of the edges of the continental shelf extracted from bathymetry data; determined using isobath of 200 m	(GEBCO Compilation Group 2022)
Habitats Table	Specifies spatial habitat data and parameters (rank and protection distance); see Appendix I for ranking table	(MapBiomas Project 2020; UNEP-WCMC et al. 2021)
Geomorphology (optional)	Map of relative exposure of each segment of coastline; see Appendix II for ranking table	(Mao et al. 2022b)
Geomorphology fill value	3, moderate exposure; rank assigned to any shore point that is not near to any segment in the geomorphology vector.	N/A

* Human population and sea level rise were optional input variables that were omitted due to lack of data.

Appendix B: Additional Climate Index Results

Table 6. Top 5% of Brazilian surf spots by amount of mangrove carbon stored. Values were calculated using a 10 km buffer around each break. Carbon index was calculated by dividing the carbon value for each break by the range of observed carbon storage values to receive a normalized value between 0 and 1.

Surf spot	Latitude	Longitude	Carbon stored (tons)	Carbon index
Araruna	-0.688517	-48.48327	1113842	1.000
Mangue Seco	-11.483614	-37.36445	939791	0.844
Mar do Macaco	-7.045016	-34.84142	892637	0.801
Atalaia (salinas)	-0.596981	-47.29362	881248	0.791
Bessa	-7.091138	-34.83277	877956	0.788
Baia Formosa	-6.366994	-35.01480	844799	0.758
Itarare	-23.972333	-46.36200	837500	0.752
Pereque	-23.927583	-46.17883	793426	0.712
Sao Pedro	-23.908522	-46.16658	789008	0.708
porta do sol	-23.981332	-46.37376	749159	0.673
Mar da Frente	-6.365217	-35.00621	735303	0.660
Santos	-23.971744	-46.34721	709124	0.637
Impossivel	-8.615505	-35.02038	684254	0.614
Restinga a Marambaia	-23.061833	-43.59167	668109	0.600
Direitas de Guaratuba	-25.890046	-48.56029	657029	0.590
Mosqueiro	-11.138116	-37.14549	652467	0.586
Praia Brava Guaratuba	-25.892817	-48.56146	647596	0.581
Praia de Iporanga	-23.902192	-46.15272	641690	0.576
Saquaira	-14.041089	-38.94808	641337	0.576
Taguaíba	-23.896726	-46.15135	640735	0.575
Guaratuba Praia Brava	-25.897758	-48.56429	635011	0.570
Barra de Guaratiba	-23.064018	-43.56937	634999	0.570
Serrambi	-8.576358	-35.02871	627244	0.563
Praia de Camburi	-20.275804	-40.27099	621290	0.558
Sol do Muta	-13.881859	-38.94834	617845	0.555
Pontal	-6.368680	-34.99342	611773	0.549
Praia de Pernambuco (Pernambuco Beach, in Guaruja)	-23.963431	-46.18403	606549	0.545

Table 7. Top 5% of Brazilian surf breaks by Coastal Protection Index value. Values were calculated using a 10 km buffer around each surf break. CP habitat role is the difference between exposure index with and without natural habitats.

Surf spot	Latitude	Longitude	CP habitat role	CP index
Garca Torta	-9.487114	-35.55748	0.704	1.000
Mirante da Sirena	-9.430906	-35.50368	0.697	0.991
New Orleans	-9.526290	-35.58302	0.697	0.991
Praia de Jatiuca	-9.531449	-35.59093	0.695	0.988
Porto de Galinhas	-8.488678	-34.99950	0.687	0.977
Cupe	-8.479708	-34.99658	0.687	0.977
Borete	-8.499622	-35.00313	0.687	0.976
Japaratinga	-9.261582	-35.35337	0.672	0.955
Riacho Doce	-9.568050	-35.64679	0.651	0.925
cupe	-8.466621	-34.98944	0.646	0.918
Maracaipe	-8.525427	-35.00626	0.645	0.916
Praia Do Francês	-9.772375	-35.84517	0.633	0.900
Serrambi	-8.576358	-35.02871	0.620	0.881
Impossivel	-8.615505	-35.02038	0.618	0.878
Praia do Morro	-9.327169	-35.43853	0.613	0.872
Itacimirim	-12.639232	-38.04819	0.610	0.867
Pedra Virada	-9.585522	-35.66004	0.604	0.859
Saquaira	-14.041089	-38.94808	0.603	0.857
Busca Vida	-12.863464	-38.25596	0.599	0.851
Forjos	-10.107662	-36.09767	0.593	0.843
Praia dos Algodoes	-14.077500	-38.95444	0.588	0.836
Vilas	-12.894546	-38.29079	0.578	0.822
Praia do forte	-12.734415	-38.14444	0.573	0.815
Algodoal	-0.577838	-47.57990	0.570	0.811
Camaraçu	-0.868831	-46.43080	0.568	0.807
Guriri	-18.910750	-39.73856	0.561	0.797
Praia do Pontal	-9.682590	-35.75854	0.561	0.798

Appendix C: Regional Prioritizations

To provide a more comprehensive analysis of the surf breaks in Brazil, we split the coast into regions and conducted the SCI with the Climate Index for each region.

North and Northeast

The North and Northeast region has 16 surf breaks identified as high priority (figure 27). The top 10 breaks are:

1. Praia dos Algodões, Bahia
2. Saquaíra, Bahia
3. Borete, Pernambuco
4. Maracaípe, Pernambuco
5. Mar do Macaco, Paraíba
6. Praia das Ondas, Bahia
7. Bessa, Paraíba
8. Impossível, Pernambuco
9. Baía Formosa, Rio Grande Do Norte
10. Scar Reef, Bahia

Table 8. High priority surf break distribution by state in the North-Northeast region of Brazil.

State	Number of Breaks
Pará	1
Rio Grande Do Norte	1
Paraíba	2
Pernambuco	6
Bahia	6

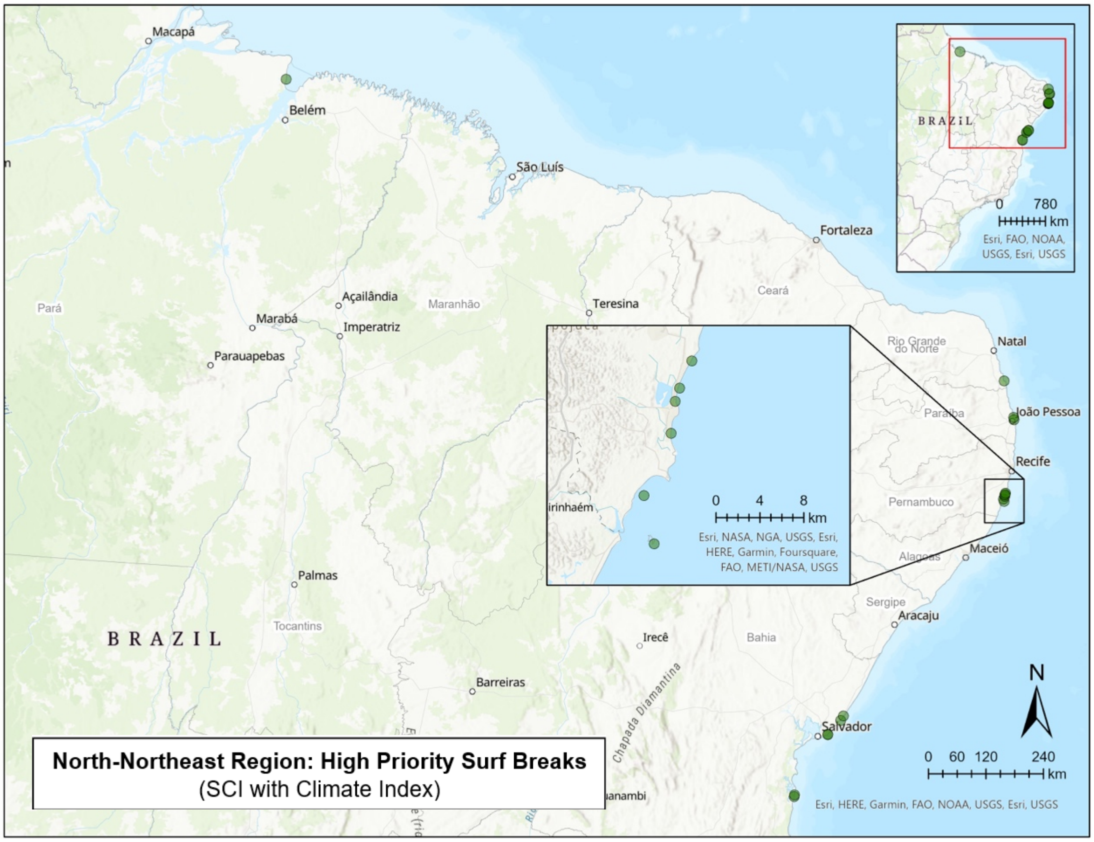

Figure 28. North-Northeast Region: High priority surf breaks. Top breaks were identified using the SCI with the Climate Index; 16 breaks were identified.

Southeast

The southeast region consists of 14 high priority breaks (figure 28). The top 10 surf breaks are:

1. Desertinha, São Paulo
2. São Pedro, São Paulo
3. Guaraú, São Paulo
4. Taguaíba, São Paulo
5. Prainha, Rio de Janeiro
6. Itamambuca, São Paulo
7. Vermelha do Norte, São Paulo
8. CcB, Rio de Janeiro
9. Vermelha do Centro, São Paulo
10. Grumari, Rio de Janeiro

Table 9. High priority surf break distribution by state in the Southeast region of Brazil.

State	Number of Breaks
Espírito Santo	1
Rio de Janeiro	5
São Paulo	8

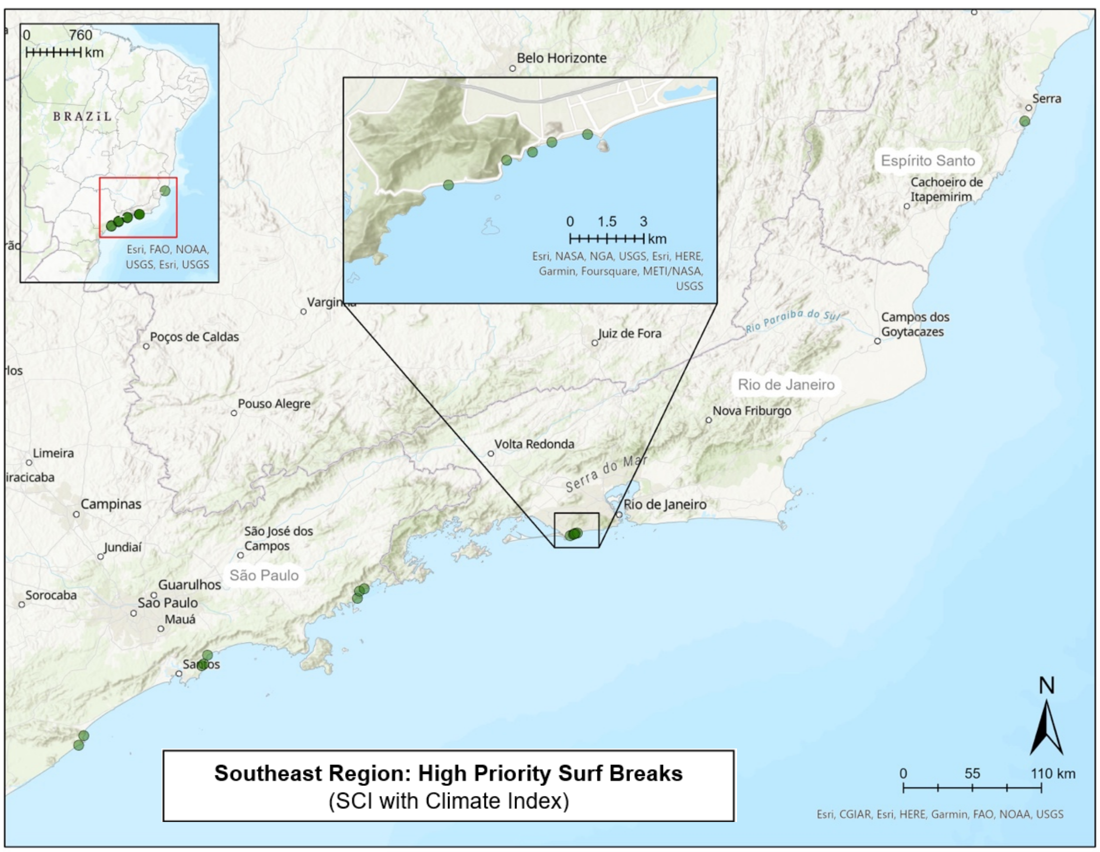

Figure 29. Southeast Region: High priority surf breaks. Top breaks were identified using the SCI with the Climate Index; 14 breaks were identified.

South

The South region contains 3 high priority surf breaks, which are:

1. Guaratuba Praia Brava, Paraná
2. Praia Brava Guaratuba, Paraná
3. Direitas de Guaratuba, Paraná

Due to the surf breaks being so close together, in the same region within 1100 meters of each other, we chose not to create a map.

Appendix D: Index Prioritizations

Pressure Index

Due to the inverse nature of the pressure index, 350 breaks were identified to have an SCI score greater than 0.75. These breaks face less pressure, as they are often away from cities and in hard to access areas. The top 10 surf breaks that face the least pressure are:

1. Travosa, Maranhão
2. Camaraçu, Pará
3. Montão do Trigo, São Paulo
4. Bonete, São Paulo
5. Desertinha, São Paulo
6. Martim de Sá, Rio de Janeiro
7. Praia da Fazenda, São Paulo
8. Castelhanos, São Paulo
9. Brava do Camburi, São Paulo
10. Atins, Maranhão

Due to the much higher number of high priority breaks in this index, we chose not to create a map.

Biodiversity Subindex

In the biodiversity subindex, 25 breaks received a normalized subindex score greater than 0.75 (figure 29). Higher normalized values were given to surf breaks that contained more species richness, priority areas, and greater ecosystem variety within its buffer. The 10 breaks with the highest normalized values in this subindex are:

1. Mar do Macaco, Paraíba
2. Borete, Pernambuco
3. Porto de Galinhas, Pernambuco
4. Bessa, Paraíba
5. Cupê, Pernambuco
6. Maracaipe, Pernambuco
7. Cupê, Pernambuco
8. Serrambi, Pernambuco
9. Impossível, Pernambuco
10. Barra Sol, Espírito Santo

Table 10. High priority surf break distribution by state in the Biodiversity Subindex.

State	Number of Breaks
Paraíba	3
Pernambuco	8
Alagoas	5
Bahia	2
Espírito Santo	7

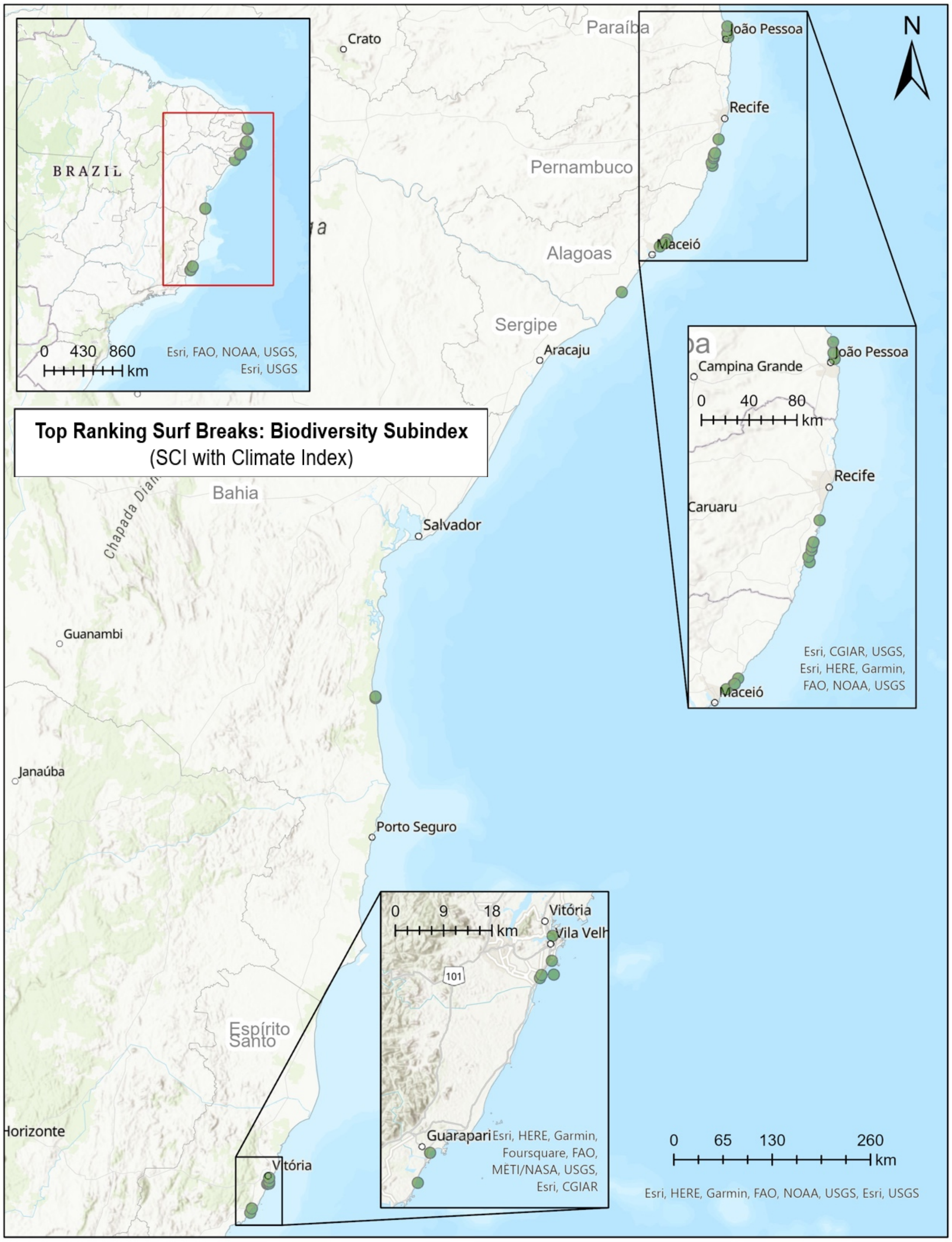

Figure 30. Top ranking surf breaks: Biodiversity Subindex. Twenty-five breaks were ranked high in this subindex.

Surf Subindex

Forty-eight breaks were identified to have a normalized surf score over 0.75 (figure 30). These breaks were ranked highly due to their frequency and quality rankings, as well as, to a lesser extent, the accessibility to all surfers and the number of wave directions the surf break has. The 10 breaks with the highest normalized surf scores are:

1. Praia da Macumba, Rio de Janeiro
2. Prainha, Rio de Janeiro
3. Jaguaripe, Bahia
4. CcB, Rio de Janeiro
5. Arpoador, Rio de Janeiro
6. Praia do Diabo, Rio de Janeiro
7. Rock Quentel, Bahia
8. Leblon, Rio de Janeiro
9. Prainha de Adão e Eva, Rio de Janeiro
10. Stella Maris, Bahia

Table 11. High priority surf break distribution by state in the Surf Subindex.

State	Number of Breaks
Rio Grande Do Norte	3
Alagoas	2
Bahia	6
Espírito Santo	2
Rio de Janeiro	19
São Paulo	9
Santa Catarina	7

These ranked surf breaks tend to cluster around large cities due to the clustering effect, however Guarda do Embaú, the world surfing reserve in Southern Brazil, has a cluster of surf breaks with highly rated surf values.

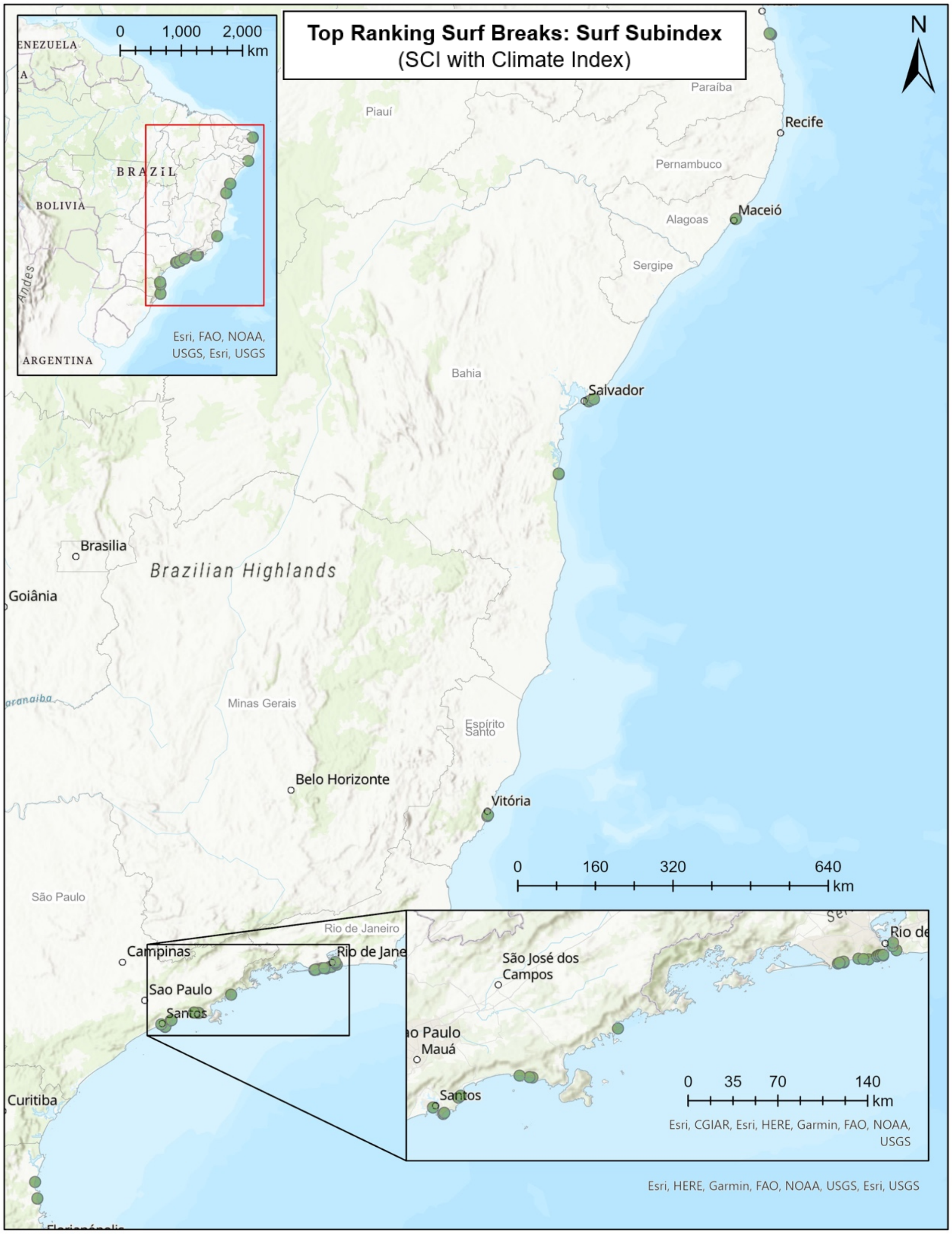

Figure 31. Top ranking surf breaks: Surf Subindex. Forty-eight breaks were ranked high in this subindex.

Social Subindex

There are 18 breaks in the social subindex that received a normalized score greater than 0.75 (figure 31). The top breaks in this index are the inverse of the top breaks in the pressure index as the score is determined by the number of airports, hotels, and employees working in the sports, recreation, and leisure sector in each buffer. The more of these indicators a buffer contains, the higher it is ranked. The 10 breaks with the highest normalized social index scores are:

1. Volta da Jurema, Ceará
2. Futuro, Ceará
3. Portão, Ceará
4. Iracema, Ceará
5. Leste Oeste, Ceará
6. Praia do Fora, Rio de Janeiro
7. Laje do Pão de Açúcar, Rio de Janeiro
8. Leme, Rio de Janeiro
9. Flamengo, Rio de Janeiro
10. Arpoador, Rio de Janeiro

Table 12. High priority surf break distribution by state in the Social Subindex.

State	Number of Breaks
Ceará	5
Rio Grande Do Norte	1
Rio de Janeiro	12

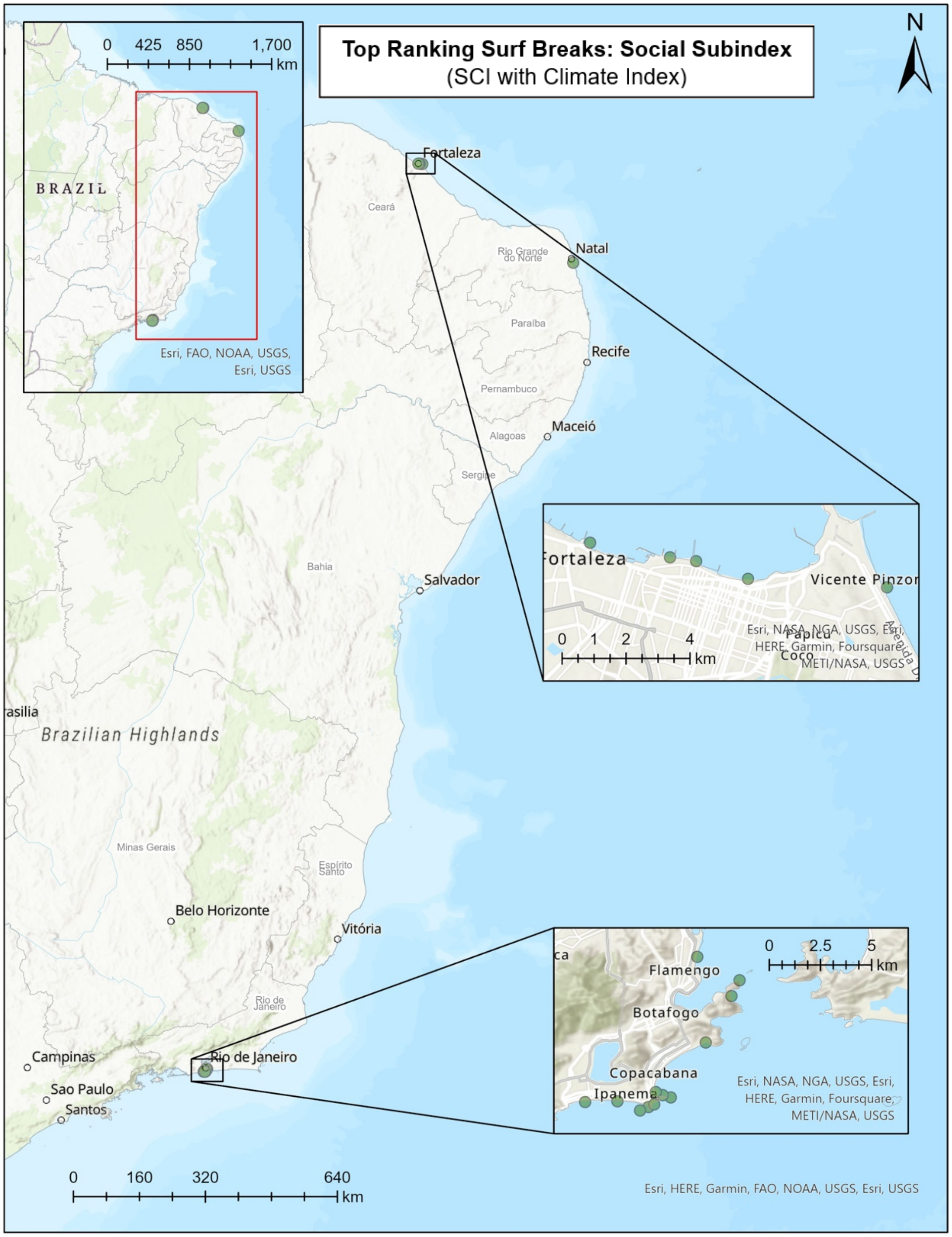

Figure 32. Top ranking surf breaks: Social Subindex. Eighteen surf breaks were ranked high in this subindex.

Climate Index

Twenty-one breaks in this Climate Index received scores greater than 0.75 (figure 32). Higher normalized scores indicate that there are more natural climatic change adaptation and mitigation, which include higher presence of natural ecosystems (mangroves, coral reefs, and coastal forest) that both protect the coastline and store carbon. The 10 breaks that scored highest for the climate index are:

1. Atalaia, Pará
2. Bessa, Paraíba
3. Mar do Macaco, Paraíba
4. Cupê, Pernambuco
5. Porto de Galinhas, Pernambuco
6. Impossível, Pernambuco
7. Borete, Pernambuco
8. Baía Formosa, Rio Grande do Norte
9. Serrambi, Pernambuco
10. Saquaíra, Bahia

Table 13. High priority surf break distribution by state in the Climate Index.

State	Number of Breaks
Pará	3
Rio Grande Do Norte	4
Paraíba	2
Pernambuco	7
Bahia	3
São Paulo	2

Given the lack of data for the climate index on the island of Fernando de Noronha, breaks located there were given a 0 in terms of scoring.

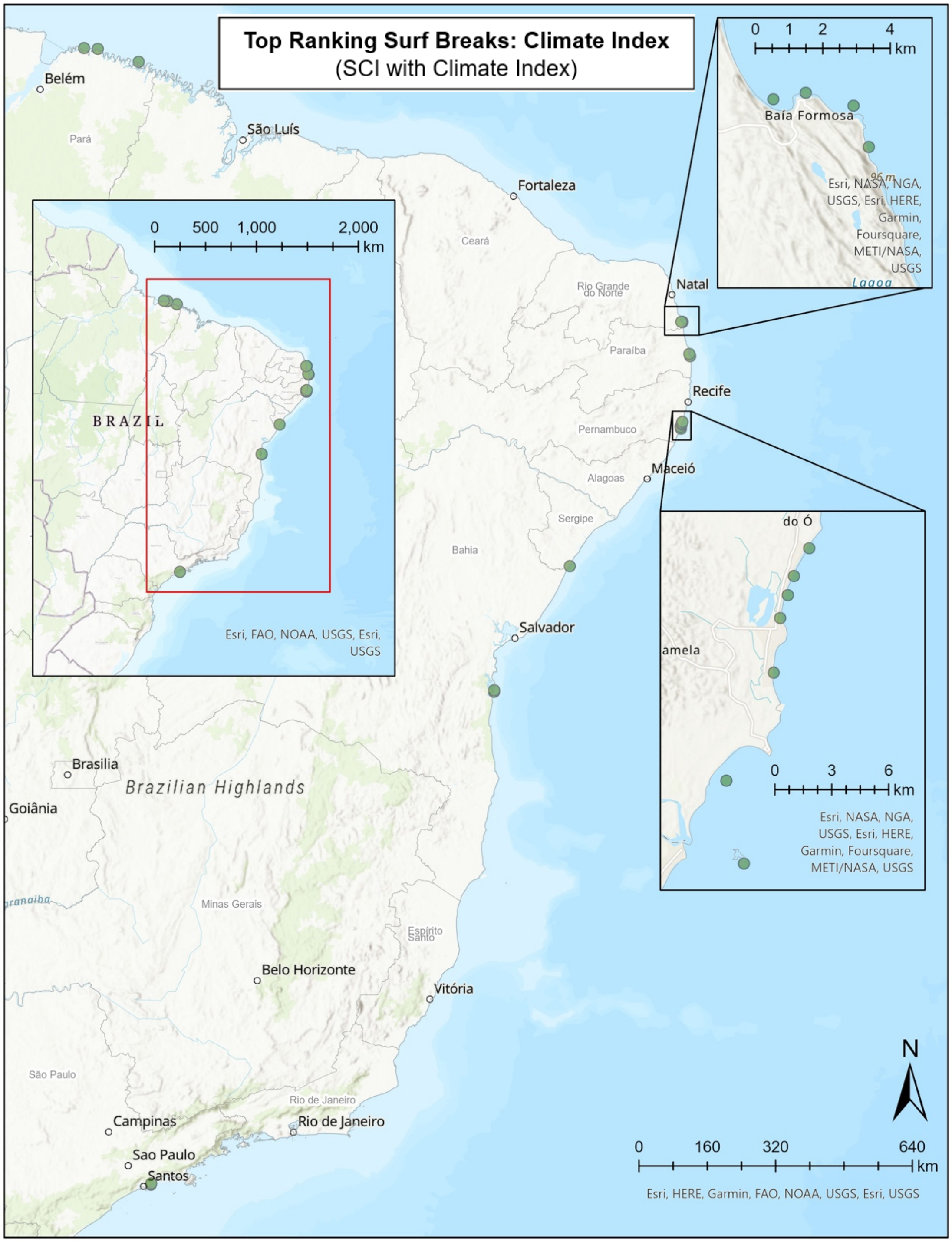

Figure 33. Top ranking surf breaks: Climate Index. Twenty-one surf breaks were ranked highly in this index. This index is only used in the SCI adapted with the Climate Index.

Response Index

For the response index, 16 breaks received a score greater than 0.75 for the index (figure xx). Highest priority was given to breaks that contained more areas dedicated to conservation within their buffers, such as protected areas. The 10 breaks that scored the highest under this index are:

1. Desertinha, São Paulo
2. Conceição, Fernando de Noronha, Pernambuco
3. Meio, Fernando de Noronha, Pernambuco
4. Cachorro, Fernando de Noronha, Pernambuco
5. Boldró, Fernando de Noronha, Pernambuco
6. Laje do Bode, Fernando de Noronha, Pernambuco
7. Cacimba do Padre, Fernando de Noronha, Pernambuco
8. Biboca, Fernando de Noronha, Pernambuco
9. Abras, Fernando de Noronha, Pernambuco
10. Guaraú, São Paulo

Table 14. High priority surf break distribution by state in the Response Index.

State	Number of Breaks
Pernambuco – Fernando de Noronha	9
Bahia	2
São Paulo	2
Santa Catarina	3

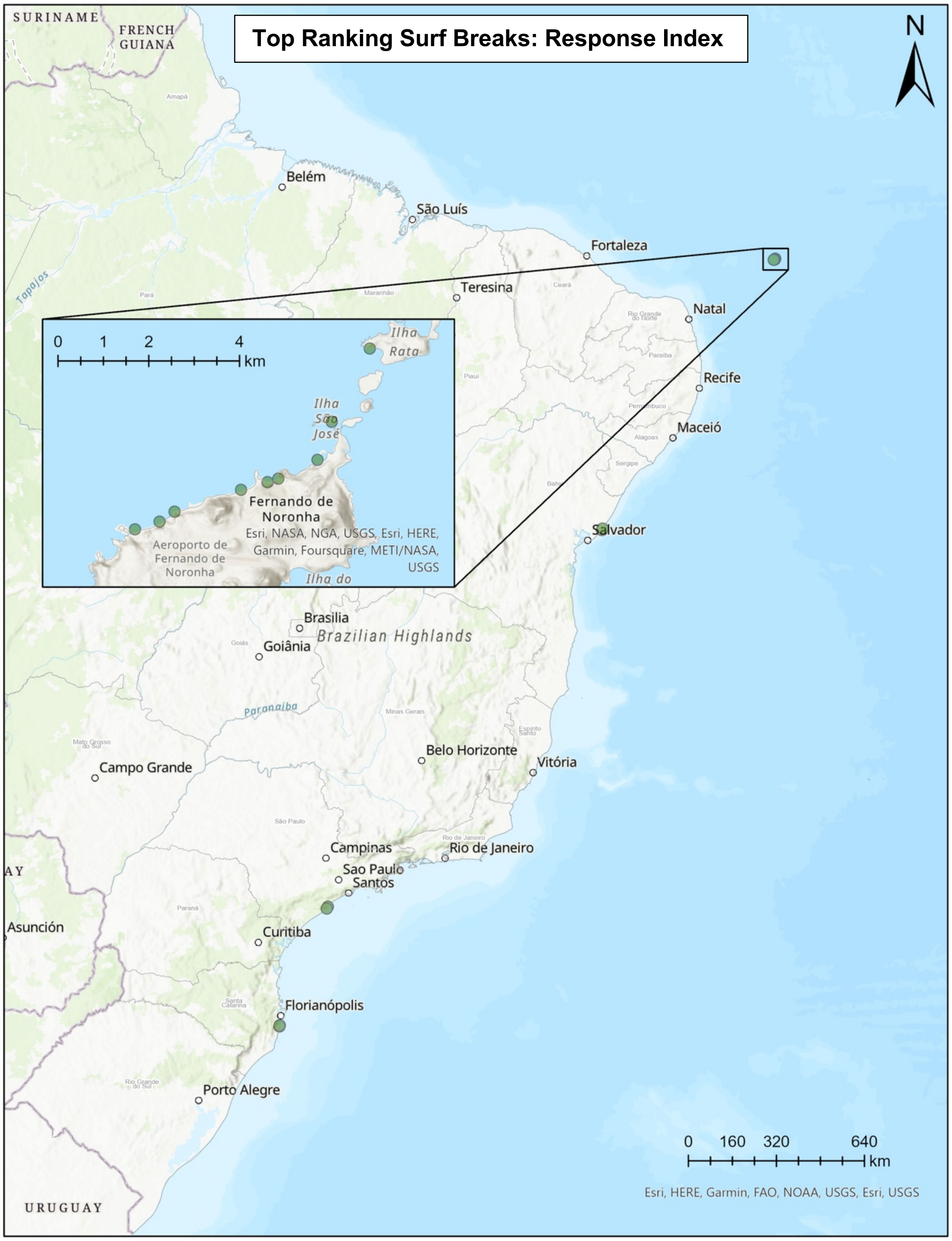

Figure 34. Top ranking surf breaks: Response Index. Sixteen surf breaks were identified as high priority in this index.