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Conservation prioritization to conservation action in the Gulf of California, Mexico

Leah R. Gerber; José D. Anadón; Caterina D'Agrosa; Anne Gondor

***Leah R. Gerber**
Professor
Ecology, Evolution and Environmental Sciences,
School of Life Sciences
Arizona State University, College & University
Tempe, AZ 85287
Phone: (480) 727-3109
Email: leah.gerber@asu.edu

José D. Anadón
Postdoctoral Fellow
Ecology, Evolution and Environmental Sciences,
School of Life Sciences
Arizona State University, College & University
Tempe, AZ 85287
Department of Conservation Biology
Estación Biológica de Doñana EBD-CSIC
Avda. Américo Vespucio s/n
Isla Cartuja, 46092, Seville, Spain
Email: jdanadon@asu.edu

Caterina D'Agrosa
Postdoctoral Fellow
Ecology, Evolution and Environmental Sciences,
School of Life Sciences
Arizona State University, College & University
Tempe, AZ 85287
Email: caterina.dagrosa@gmail.com

Anne Gondor
Conservation Scientist
The Nature Conservancy
1510 E. Fort Lowell Road
Tucson, AZ 85719
Email: agondor@TNC.ORG

**corresponding author*

ABSTRACT: Identifying priority areas for conservation is a widely-used approach to allocate limited resources to achieve desired conservation outcomes. While selection algorithms have become popular methods for designing networks of conservation areas, support is often insufficient to protect all proposed sites. A recent ecoregional assessment in the Gulf of California identified critical conservation sites to protect biodiversity in this region. Here we build on this foundation of conservation planning work to identify a path forward from conservation prioritization to conservation action, bringing conservation priorities to a management scale. We prioritize areas for conservation action at two scales (within and among sites) using a combination of conservation planning tools, including: 1) a transparent approach that relies on the comparison of irreplaceability and vulnerability scores among the 54 conservation sites, and 2) expert opinion in distilling biodiversity goals into eight habitat targets that represent biodiversity. Irreplaceability of each conservation target was given a distinct score based on the conservation status, endemism, and critical life stages of each species. A threat score was estimated from expert surveys for each target to assess vulnerability. Our analyses can be used to identify priority sites, depending on level of risk-aversion and preferences for vulnerable or irreplaceable conservation targets, and to prioritize small-scale areas within sites. We discuss key lessons learned that could be easily applied to other conservation planning problems.

Keywords: Biodiversity, conservation planning, Gulf of California, irreplaceability, marine conservation, prioritization, spatial scale, viability, vulnerability

INTRODUCTION

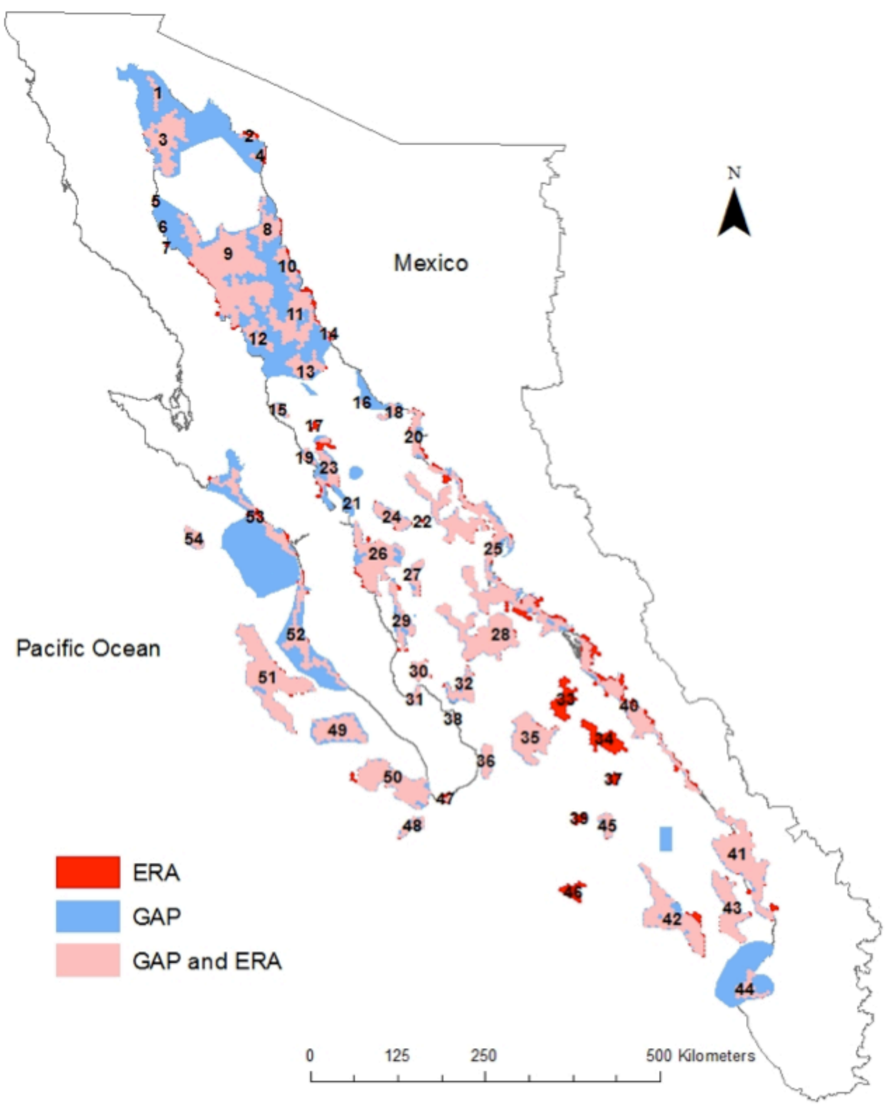
Recognition that marine ecosystems are inextricably linked to human well-being has led to a shift from marine protected areas to marine spatial planning where emphasis is on how multiple uses can be accommodated in an area of conservation concern (Pressey et al. 2007, White et al. 2012, Kukkala and Moilanen 2013). Most actual or proposed networks of conservation areas comprise prioritization of more than 20% of the target study area, but available funds are insufficient to protect all proposed sites (McCrea-Strub 2011). Funding is typically spread over time, and conservation actors (e.g. governments, NGOs, etc.) must prioritize sites for implementing effective conservation management while also satisfying multiple resource uses and different conservation goals. This is particularly relevant for coastal areas that contain exceptionally high biodiversity and where networks of marine protected areas may have been proposed but where real implementation and enforcement are challenges due to social conflicts and pressures for resource extraction. Biodiversity and threat information is usually available at coarse resolutions and over large extents, and spatial planning exercises are usually carried out at large spatial scales. As a result, there is a notable mismatch in scale between the vast size of spatial planning proposals and on-the-ground, small-scale conservation efforts. Thus, there is a need for finer-scale prioritization analyses to decide where within a network of conservation sites to focus immediate conservation action. In this paper we analyze vulnerability and irreplaceability of sites in a conservation prioritization effort in the Gulf of California (Mexico) in order to identify a path toward conservation action; bringing conservation priorities to a management scale. Due to its high productivity and diversity, the Gulf is considered an important area both in Mexico as well as internationally (Carvajal et al. 2004).

The identification of priority areas for conservation occurs in various ways (e.g. Margules and Pressey 2000, Groves 2003), including algorithms to optimize the selection of priority sites based on stated objectives. The reserve-selection software Marxan (Ball and Possingham 2000) allows the practitioner to iteratively achieve an efficient spatial configuration of sites by minimizing a cost subject to the constraint that quantitative conservation targets (i.e., protect 30% of each feature) are achieved. Although Marxan provides for selection of an optimized set of conservation areas, it does so through satisfying representation of all conservation targets, and may not be selecting the optimal areas for individual conservation targets, such as those with special habitat requirements. This process has the potential to omit areas that represent the best sites to conserve highly irreplaceable and vulnerable species (Schill and Raber 2006). Priority sites are generally extensive, and finer-scale prioritization analyses are necessary to decide which sites are most critical for conservation action (Pressey and Taffs 2001). Finally, because achieving true conservation must involve different stakeholders (e.g. scientists, policy makers and managers, NGOs) that may vary over time, the conservation goals employed for the identification of protected areas and their prioritization may also differ.

In 2006, a marine ecoregional assessment for the Gulf and near-shore Pacific coast of southern Baja California was conducted (Ulloa et al. 2006, Figure 1). This analysis relied on The Nature Conservancy (TNC) ecoregional assessment methodology defined in Groves et al. (2000) and used 3500-hectare hexagonal planning units along with the Marxan site selection algorithm to identify 54 conservation areas covering 26% of the ecoregion. Subsequently, this conservation proposal has been integrated into a national prioritization effort for Mexico (GAP; CONABIO-CONANP-TNC-PRONATURA 2007). In general, the sites identified by the Ecoregional Assessment (ERA) are included in the national prioritization effort for the Gulf ecoregion (Figure 1). The primary modification made by the subsequent national prioritization (CONABIO-CONANP-TNC-PRONATURA 2007) was to combine the 14 ecoregional assessment sites located in the northern Gulf into two large conservation areas (Figure 1). For our analysis, we rely on the ecoregional assessment, which includes a more fine-scale resolution of sites within the ecoregion.

The ecoregional assessment did not attempt to specify priority areas for on-the-ground conservation. In order to implement conservation in the network of conservation areas identified in the ecoregional assessment, two primary issues with the network design should be addressed. First, there is a notable mismatch in scale between the vast size of the proposal (47500 km^2) and on-the-ground, small-scale conservation efforts (e.g. Fujitani et al. 2012). Small-scale conservation efforts allow conservation practitioners to work directly with stakeholders. Given the size of the

Figure 1: Overlapping of the two main marine spatial planning proposals in the GoC. ERA= Gulf of California and west coast of Southern Baja California Ecoregional Assessment (Ulloa et al. 2006). GAP= Gap analysis for the conservation of marine biodiversity in Mexico (CONABIO-CONANP-TNC-PRONATURA. 2007). The numbers identify the 54 sites identified in the ERA: 1=Delta del Rio Colorado, 2=Laguna Salada, 3=Rocas Consag, 4=Bahía San Jorge, 5=Puertecitos, 6=Isla San Luis, 7=Bahía San Luis Consag, 8=Puerto Libertad, 9=Isla Ángel de la Guarda, 10=El desemboque, 11=Isla Tiburón, 12=Archipielago San Lorenzo, 13=Isla San Pedro Mártir, 14=Bahía Kino, 15=Bahía San Carlos, 16=Isla San Pedro Nolasco, 17=Isla Tortuga, 18=Bahía de Guaymas, 19=Isla San Marcos, 20=Estero de Lobos, 21=Isla San Ildefonso, 22=Sinaloa-Sonora, 23=Bahía Concepcion, 24=Depresión del Carmen, 25=Corredor Bahía de Tobari-Bahía Sta. Maria, 26=Isla del Carmen, 27=Bajo Catalina y talúd entre depresión El Carmen, 28=Depresion Farallón, 29=Áreas con decretos, 30=Isla Espíritu Santo, 31=Bahía de la Paz, 32=Isla Cerralvo, 33=Talud Continental depresión El Pescador, 34=Talud Continental Sinaloa, 35=Montana Alarcón depresion El Pescador, 36=Cabo Pulmo, 37=Bajo costa Sinaloa, 38=Bahía de los Muertos, 39=Fosa Riff norte, 40=Corredor Bahía Sta. María-Laguna el Caimanero, 41=Corredor Laguna el Caimanero-Nayarit, 42=Islas Marías, 43=Isla Isabel, 44=Bahía Banderas e Islas Marietas, 45=Talud continental fosa Riff, 46=Margen oriental fosa Riff, 47=Cabo San Lucas, 48=Bordeland bajo San Jaime, 49=Bancos Morgan, 50=Bordeland banco Golden Gate, 51=Bordeland banco Petrel, 52=Bahía Magdalena, 53=Corredor Punta Abreojos-Laguna San Ignacio, 54=Bordeland bajo Rosa (Ulloa et al. 2006).



ecoregional assessment proposal, a finer inter- and intra-site prioritization process is needed to inform in which areas small-scale conservation efforts are more urgent to engage stakeholders. Second, previous work suggests that efforts incorporating stakeholder interests – without compromising conservation goals – are more likely to be successful in protecting marine ecosystems (Klein et al. 2008). Recent studies demonstrate that including socioeconomic information within optimization methods designed to identify locations for marine conservation areas is successful in identifying areas that are consistent with conservation goals while minimizing impacts to fishermen (Klein et al. 2008a, b). By engaging practitioners in a transparent, fine-scale prioritization process, our goal is to rank conservation areas according to value and threat status. By taking a different approach than previous Marxan work, we aim to identify where conservation action should be implemented by expanding cooperation with conservation practitioners. Several approaches to finer-scale prioritization have been described (e.g. Margules and Pressey 2000, Noss et al. 2002, Groves 2003, Strager and Rosenberger 2006, van Wilgen et al. 2007, Wilhere et al. 2008). This paper builds on that body of work to identify areas in need of immediate conservation action in the Gulf. This study is intended to facilitate the selection of a subset of these areas in order to inform implementation of small-scale conservation strategies compatible with stakeholder buy-in. Our case study also illustrates the challenge of identifying a path toward conservation action in light of continuous changes in both conservation planning efforts and ecological conditions.

METHODS

General Approach and Conservation Targets

Our prioritization approach was based on the comparison of irreplaceability and vulnerability scores among the 54 conservation sites identified in the ecoregional assessment (Margules and Pressey 2000). We used the eight ecosystem-scale conservation targets identified by TNC and the World Wildlife Fund (WWF): seamounts, estuaries, rocky reefs and rocky bottom (reefs), coastal shallow soft bottom, coastline, migratory species, elasmobranchs (e.g. rays and sharks), and insular species. These targets represent the most impacted areas in the region for which current conservation strategies could prove most effective. For irreplaceability, each conservation target was given a differential score based on the conservation status, endemism, and critical life stages of species associated to it. Vulnerability of each was assessed starting from a threat score determined for each target that was estimated from expert surveys.

The Irreplaceability and Threat indices per site were not summarized in a single metric since the direct comparison of both metrics requires an arbitrary weighting of both indices. The decision to rank certain sites as higher priorities than others will depend on the rationale, goals and strategies of each conservation action (e.g. Groves 2003). Accordingly, we provide a menu of options that a manager can select based on priorities (Margules and Pressey 2000) by means of plotting Irreplaceability vs Threat. Our results do not suggest an optimal solution, but rather suggests which sites should be selected based on different conservation targets.

Biologically-weighted Irreplaceability (IRR)

In this work, irreplaceability refers to "the potential contribution of a site to a preservation goal," following the more broad, original definition by Pressey et al (1993). Irreplaceability is intimately linked to biodiversity, since conservation goals of spatial marine planning processes are to protect as many elements of biodiversity as possible (Pressey et al. 1993). In our prioritization proposal, we measure biodiversity as species richness weighted by species attributes such as conservation status, endemism, and life-history traits. In this work, irreplaceability is not the result of an iterative quantitative goal-driven approach, as in C-Plan (Pressey et al. 2008) or Marxan (Ball and Possingham 2000), but is an index resulting from a weighted overlay.

In order to estimate irreplaceability and spatial location of the conservation targets, we used a fine-filter subset of 317 species from the databases generated for the ERA, that contains priority species from a diverse groups (algae, grasses, corals, fishes, turtles, birds, mammals) (Ulloa et al. 2006). We assigned irreplaceability scores to each species, which were then aggregated into a composite target index (per TNC's eight targets, see definition

below). This target index was aggregated across targets per hexagon (the smallest spatial unit within a site), and then by site (one of the 54 ecoregional assessment sites, comprised of varying numbers of hexagons).

In order to rank the relative conservation importance of species, we assigned a species score to each of the 317 species in the ecoregional assessment (Appendix 2 in Ulloa et al. 2006). For each species, we used the listing category defined for each species used in the IUCN Red List 2004, the NORMA Oficial Mexicana (NOM-059-ECOL-2001), NatureServe Global Ranks, and the 2007 CITES Appendices (NOM-029, Table 1). We also summarized relevant biological details for each species describing level of endemism and life-stage parameters (Table 1). We then ranked the status of each species according to each classification scheme (Table 1). To obtain one score for each species, we considered three general alternatives

Table 1: Within-criteria ranking for scoring of species threat. This approach was adopted because information on each of these 6 parameters is not available for all species, and as a way to "normalize" putative species (e.g. a species with IUCN criteria of CR and another with a localized endemism).

Rank	IUCN	NOM-059 [a]	CITES	NatureServe [b]	Endemism	Critical Life-stage
5	Critically endangered (CR)	Endangered (P)	Appendix 1	Critically Imperiled (G1)	Local (*e.g.* Upper Gulf)	Any aggregation; breeding (restricted, island, beaches), colonies/rookeries, feeding/spawning aggregations, insular species
4	Endangered (EN)			Imperiled (G2)		
3	Vulnerable (VU)	Threatened (A)	Appendix 2	Vulnerable (G3)	Regional	Confirmed breeding, irregular/disjunct breeding, permanent resident, breeding resident
2	Lower Risk (LR) Conservation-Dependent (CD) Near-threatened (NT) Least concern (LC)	Subject to Special Protection (Pr)	Appendix 3	Apparently Secure (G4) and Secure (G5)	National (Mexico)	Non-breeding, migrant, vagrant
1	Data Deficient (DD)			Unranked (GNR) Global rank not yet assessed		
0	Not in Redlist	Not in NOM	Not in CITES	Not in NatureServe	Not endemic	Not applicable

[a] *If elasmobranch NOT listed in NOM-059, NOM-029 was applied.*
[b] *In case of a range rank (i.e., G1G2), the smaller rank was used.*

yielding five different scoring scenarios (A to E, Table 2): 1) all factors weight equally, 2) threat and management opportunity outweighs biology and 3) endemism is more important than management or threat. The third alternative was explored by means of three different specific weightings to examine the potential importance of endemism on the prioritized sites (Mace et al. 2008). Because different species' attributes regarding conservation status, endemism, and life-history traits can be correlated (i.e., part of IUCN Red Listing ranking explicitly takes into account with endemism; Butchart 2007), our species scoring approach likely emphasizes the differences among species. We categorized habitat requirements for each species into eight targets (i.e., estuaries, seamounts, reefs, coastal shallow soft bottom, coastline, migratory, elasmobranchs, insular species). Species that occur in more than one target (e.g. a shark species that requires estuaries) were assigned to each target (double counted). We calculated the average score of each target based on the component species of a given target. For example, for estuaries, we compiled all the species that rely on estuaries (n = 115) and calculated the mean estuary score (Table 3). Considering the average value, rather than the sum, smoothes the conservation value of areas that contain a large amount of species of low conservation value. We also combined coral and rocky reefs into a single category, and estuaries and mangroves into a single category. Migratory species include large whales (sperm whales and balaenopterids), turtles, and migratory birds. Data were compiled from a number of sources (Ulloa et al. 2006, J. Rupnow and E. Sala, unpublished data, Brusca et al. 2006), and each target was then mapped and combined. Targets that are best represented as point locations (reefs, seamounts, elasmobranchs, migratory species) were mapped as such. In the case of elasmobranchs, migratory species, and reefs, the species' locations served as proxies for the actual target. In the case of estuaries, insular species, coastal shallow soft bottoms, and seamounts, we derived the target maps independently of the species information, based on the location of the given target. Once the targets were scored, we calculated the sum across all target occurrences for each hexagon within the ecoregional assessment. This allowed us to identify where the areas with more targets and more occurrences of targets are located within each of the 54 ecoregional assessment areas. In order to prioritize among the 54 areas, we averaged the values for the hexagons within each site. As hexagons are the same size, we can compare across sites because averaging the values of each hexagon accounts for the discrepancies in the area of each site. The main assumptions in this process are: 1) all components of a target (e.g. all mangroves) are equally vulnerable, and 2) all targets are represented with an adequate sample size, both in terms of species occurrences, threat surveys, and spatial representation.

THREATS

To gain understanding of which threats impact each target, and due to the lack of spatial data on threats in the Gulf, we employed a modified version of the expert-based approach developed by Halpern et al. (2007). In particular, we carried out a survey that included a list of threats per target or ecosystem, and respondents answered about different levels of spatial scale, severity, frequency, and time to recovery (Table 4). Our threat assessment does not reflect the level of threat to any one species, but the eight targets within which species live.

We distributed an electronic survey to 461 researchers in the Gulf who were identified through a Web of Science search. For targets with no respondents, we either used available literature (e.g. seamounts) and/or knowledge from TNC and WWF personnel (e.g. migratory species, insular species, elasmobranchs). Due to the relatively low response rate (31%, see Results), in some cases we extrapolated to the entire ecoregion threats that experts reported for a specific area (e.g. Upper Gulf). We then aggregated the individual scores per survey per threat per target into one overall threat score per target. Meaning, for example, that each estuary received the same threat score regardless of its individual level of threat**.** Each target was then assigned its respective summed and average threat scores. For example, every estuary has a summed threat score of 39.26 and an average threat score of 1.03 (Table 3). These scores were then aggregated by summing and averaging the threats for each hexagon.

Table 2: Alternative scenarios for ranking of species threats, based on a ranking of 1 (least) to 6 (most) important.

<table>
<tr><th>Scenario</th><th>Description</th><th>Expression</th></tr>
<tr><td>A</td><td>All factors weights equally</td><td>score = NOM + IUCN + Endemism + Critical life stage + CITES + NatureServe</td></tr>
<tr><td>B*</td><td>Threat and management opportunity outweighs biology</td><td>score = NOM * 6 + IUCN * 5 + Endemism * 4 + Critical life stage * 3 + NatureServe * 2 + CITES * 1</td></tr>
<tr><td>C</td><td rowspan="3">Endemism is more important than management or threat</td><td>score = NOM * 6 + IUCN * 4 + Endemism* 5 + Critical life stage * 3 + NatureServe * 2 + CITES * 1</td></tr>
<tr><td>D</td><td>score = NOM * 5 + IUCN * 4 + Endemism* 6 + Critical life stage * 3 + NatureServe * 2 + CITES * 1</td></tr>
<tr><td>E</td><td>score = NOM * 1 + IUCN * 1 + Endemism* 6 + Critical life stage * 1 + NatureServe * 1 + CITES * 1</td></tr>
</table>

** This scenario allots the highest weight to Mexican legislation, which is important since these waters are exclusively Mexican, and is followed by international conventions. Biology in this case is ranked lower than political criteria to facilitate buy-in from the Mexican government in the long term.*

Table 3: Mean scores for aggregated targets (using scores where endemism is weighted higher than NOM).

Target	Mean IRR Score	Min IRR Score	Max IRR Score	Mean Threat Score	No. Species	No. Species Occurrences
Rocky/coral reefs	21.25	9	67	2.58	60	746
Coastal shallow soft bottom	39.00	9	97	1.48	17	2136
Seamount	32.00	18	38	0.53	8	271
Estuaries	29.03	6	72	1.03	115	5508
Coastline	30.00	12	105	1.88	120	7127
Insular Species	32.96	12	88	0.93	38	3872

Table 4: Gulf of California Marine Ecosystem Threats Survey: Explanations and Examples of Threat Types (*adapted from Halpern et al. 2007*)

Threat Type		Factors Involved
Freshwater input:		**Note:** Freshwater input is likely to have different effects on marine ecosystems depending on whether natural input levels are increased or decreased. Please consider these cases separately.
	Increase	Watershed size, flow rate, channelization
	Decrease	Watershed size, flow rate, dam size/ distribution, agricultural diversion
Sediment input:		**Note:** Sediment input is likely to have different effects on marine ecosystems depending on whether natural input levels are increased or decreased. Please consider these cases separately.
	Increase	Logging (of mangroves), agriculture, urban development, dust input, dam size/distribution, flow rate, channelization, mining, fire/suppression
	Decrease	Watershed size, flow rate, dam size/ distribution, agricultural diversion
Nutrient input:		
	Into oligotrophic systems	Agriculture, aquaculture, sewage
	Into eutrophic systems	
Pollution:		
	Atmospheric fallout	Dust, jet fuel, heavy metals
	Point source (organic)	Point sources of industry, agriculture, hormones, endocrine-disruptors, urban run-off, sewage, pathogens, mining activities, oil spills
	Point source (nonorganic)	
	Nonpoint source (organic)	Non-point sources of industry, agriculture, hormones, endocrine-disruptors, urban run-off, sewage, pathogens, mining activities
	Nonpoint source (nonorganic)	
Coastal engineering		Seawalls, piers, jetties, beach nourishment, sand mining
Coastal development		Development (buildings, houses, hotels, etc), land fill, reclamation, dredging
Direct human impact		Trampling, noise & light pollution, thermal pollution, trash input, human activity, coral harvest
Aquaculture		Habitat destruction, nutrient input, livestock escapes, infrastructure effects, etc. from shrimp and other farms, etc.
Fishing:		
	Industrial Demersal (habitat destructive)	E.g. trawling. Includes bycatch
	Industrial Demersal (non-habitat destructive)	E.g. traps. Includes bycatch
	Industrial Pelagic (high bycatch)	Nets (big drift and gill nets), longlines (palangres), etc.
	Industrial Pelagic (low bycatch)	Purse-seine, etc.
	Aquarium	Live catch for aquarium trade
	IUU	Illegal, Unregulated and Unreported fishing
	Artisanal (destructive)	Blast, cyanide, etc. Includes bycatch
	Artisanal (non-destructive)	Collecting, pangas (gillnets, longlines), line fishing, hookah diving, etc. Includes bycatch
	Sport	Legal sportfishing
Climate change:		
	Sea level	Rising sea level
	Sea temperature	Increasing sea temperature
	Acidification	Increasing acidification of seawater
	Ozone/UV	Increasing ultraviolet exposure
Species invasion		Shipping, aquaculture, aquarium trade, coastal development
Disease		Sewage, urban run-off, aquaculture
Algal blooms		Harmful algal blooms
Hypoxia		Abnormally low oxygen from whatever source
Ocean-based pollution		Ship-based (bilge water, antifouling, waste), toxic/trash waste disposal, sound, light, vehicle wrecks, marine debris
Commercial activity		Shipping lanes, ferry lanes, groundings/scrapings, related anchoring
Ocean mining		Hydrothermal vents, nodule fields, gas/oil development, diamonds, sand/gravel, large-scale coral mining
Offshore development		Oil & gas platforms, windmills
Benthic structures		Pipelines, communications structures
Ecotourism		Diving, whale watching, nature viewing, related anchorings/ moorings

RESULTS

Biologically-weighted Irreplaceability and Threats

Although the exact score that any given hexagon received varied with each biologically-weighted scenario, the overall patterns were similar. Larger clusters of hexagons and/or the 54 areas themselves changed little in terms of their "relative" priority across scenarios. The only difference was in the scenario where endemism was scored the highest and all else was scored a 1 (scenario E). We employed scenario D for all subsequent analyses because endemism and national/international policy are particularly relevant factors to conservation action in Mexico. Resulting scores for the eight habitat targets are shown in Table 3. The number of species assigned to the conservation targets ranged between 8 (seamounts) and 145 (migratory species). Irreplaceability scores ranged between 21.25 (rocky/coral reefs) and 39 (coastal shallow soft bottom). For threats, we received 144 responses, although only 23 of them resulted in completed surveys. Reasons given for partial survey responses included survey was too long and/or too detailed, difficulties saving the data when entered, and lack of time. Rocky and coral reefs are the most threatened target, with an average threat score of 2.58, followed by the migratory species (score = 1.91), and shoreline (score = 1.88) targets (Table 2).

Prioritization Within Sites

Examination of the data at the hexagon level within each of the 54 conservation areas may be used to guide management action, particularly because the distribution of targets and threats is frequently not uniform within each area (Figures 2 and 3). For example, there is a gradient in the biological scores of the Isla Angel de la Guarda and Isla del Carmen sites that ranges from higher scores in the southwestern corner to lower scores as one moves farther east (offshore). Threat levels in this area are relatively consistent, ranging from moderate levels along the coastal areas to low levels offshore. Biological scores are highest in the area along the coasts of Sonora and Sinaloa, particularly along the shore, but threat levels here are generally lower (with some exceptions). Areas such as Bahía Magdalena and Punta Abreojos have high biological scores, but low threat levels. There are also gradients across sites, with most of the targets occurring in the coastal and nearshore sites. Large expanses within several conservation areas lack any of the eight conservation targets. This is because these areas were selected by the Marxan analysis during the ecoregional assessment based on modeled habitat and species distributions, such as benthic complexity, polygons representing density areas of cetaceans, birds and turtles, or oceanographic processes. Three pelagic conservation areas of the 54 areas have none of the conservation targets. Because our analysis included all the Gulf and additional data not included in the original ecoregional assessment dataset, we were able to identify those areas (or cells) that are important for the eight conservation targets but that were not included in any of the 54 ecoregional assessment conservation areas. A large number of cells with high values of irreplaceability and vulnerability indices are present in the Alto Golfo region, Bahía de La Paz, between conservation areas of Isla Tiburón and Isla San Pedro Mártir, or in Los Cabos. In addition, we included data into this prioritization that were not included into the original ecoregional assessment analysis (described below). The prioritization within sites and the protection of those areas with higher irreplaceability value results in more efficient conservation of the defined targets. As shown in Figure 3, protecting the 50% of the hexagons with the highest irreplaceability values ensures the protection of the totality of the conservation targets. This 1:2 relationship holds for different levels of protection. For example, if we protect the top 20% of the hexagons, according to their irreplaceability index, we protect around 40% of the hexagons where the conservation targets occur. The highest spatial correlation with the irreplaceability index is shown by estuaries, insular species, and coast line targets with a 1:3 relationship (e.g. the top 20% of the hexagons, according to the irreplaceability index, includes 60% of these habitats in the Gulf). On the contrary, elasmobranch species is the target with the lowest ratio (2:3, i.e., the 20% of the hexagons with highest irreplaceability values includes 30% of the target, according to our spatial data). In any case, because all targets present a ratio <1, our results indicate that the prioritization is thus efficient for all targets, according to the conservation value of the hexagons. The prioritization according to the threat index also shows ratios <1, thus indicating that protecting the most threatened hexagons also ensures protecting the largest proportions of the conservation targets.

Figure 2: Per hexagon irreplaceability and threat scores for the 54 Gulf of California and western coast of Baja California Sur ecoregion sites. Those areas inside the ecoregion sites with irreplaceability=0 or threat =0 are on white.

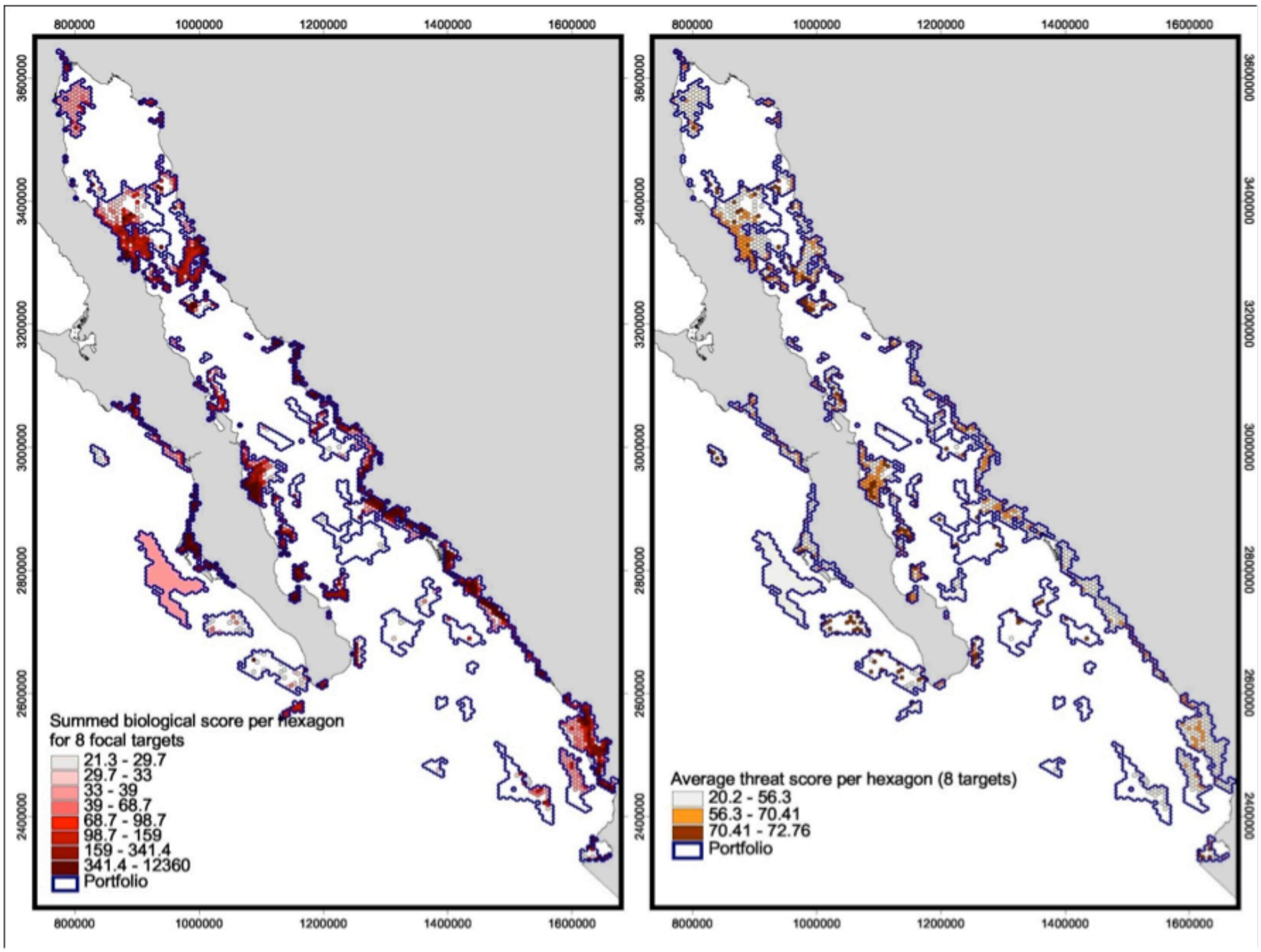
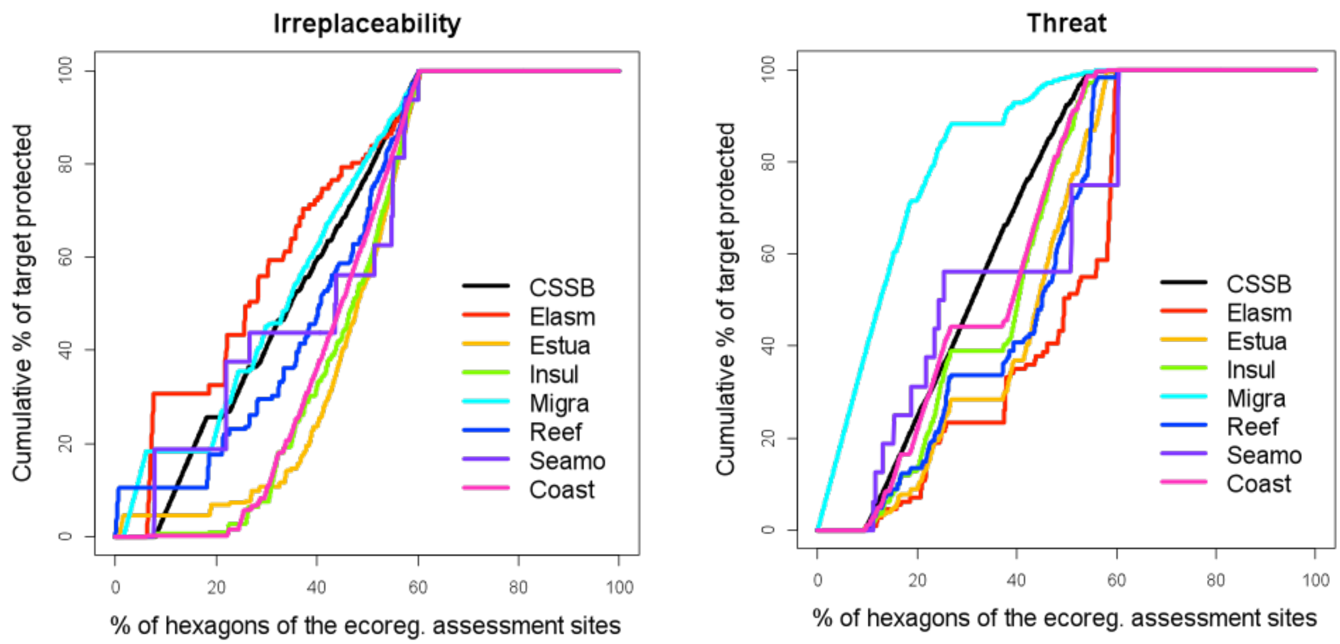


Figure 3. Cumulative amount of habitat of the eight conservation targets included in the hexagons of the ecoregional assessment sites ordered by the irreplaceability index (i.e., from high to low values of irreplaceability) (left) and the threat index (i.e., from high to low values of threat) (right). Targets: Rocky/coral reefs, Coastal shallow soft bottom, Elasmobranchs, Estuaries, Insular Species, Migratory Species, Rocky and coral reefs, Seamount, Coastline.



Prioritization Among Sites

After averaging the hexagons within each of the 54 sites, the sites with the highest biological scores are sites 18 (Bahía de Guaymas), 31 (Bahía La Paz), 20 (Estero Lobos) and 52 (Bahía Magdalena), and the top threatened sites are 31 (Bahía La Paz), 14 (Bahía Kino), 30 (Isla Espiritu Santo), 1 (Delta del Rio Colorado), 4 (Bahía San Jorge) and 19 (Isla San Marcos) (Figure 4). Interestingly, once the interaction of these two metrics is considered, the sites in the upper right-hand quadrant (Q1) of the graph (i.e., those that would be considered as the areas most likely to be lost and with higher biodiversity) are sites 18, 20, 31, 52, and 14 (Figure 5). The 17 sites that ranked in the lower left quadrant (Q4) are all pelagic. Three of these sites, including Bajo Costa Sinaloa (37), Fosa Riff Norte (39), and Talud Continental Fosa Riff (45), have threat and biological scores of 0. The remaining 13 sites had low biological scores and slightly higher threat scores.

Figure 4: Aggregated, portfolio-level irreplaceability and threat scores per conservation site for the Gulf of California and west coast of Baja California Sur ecoregion.

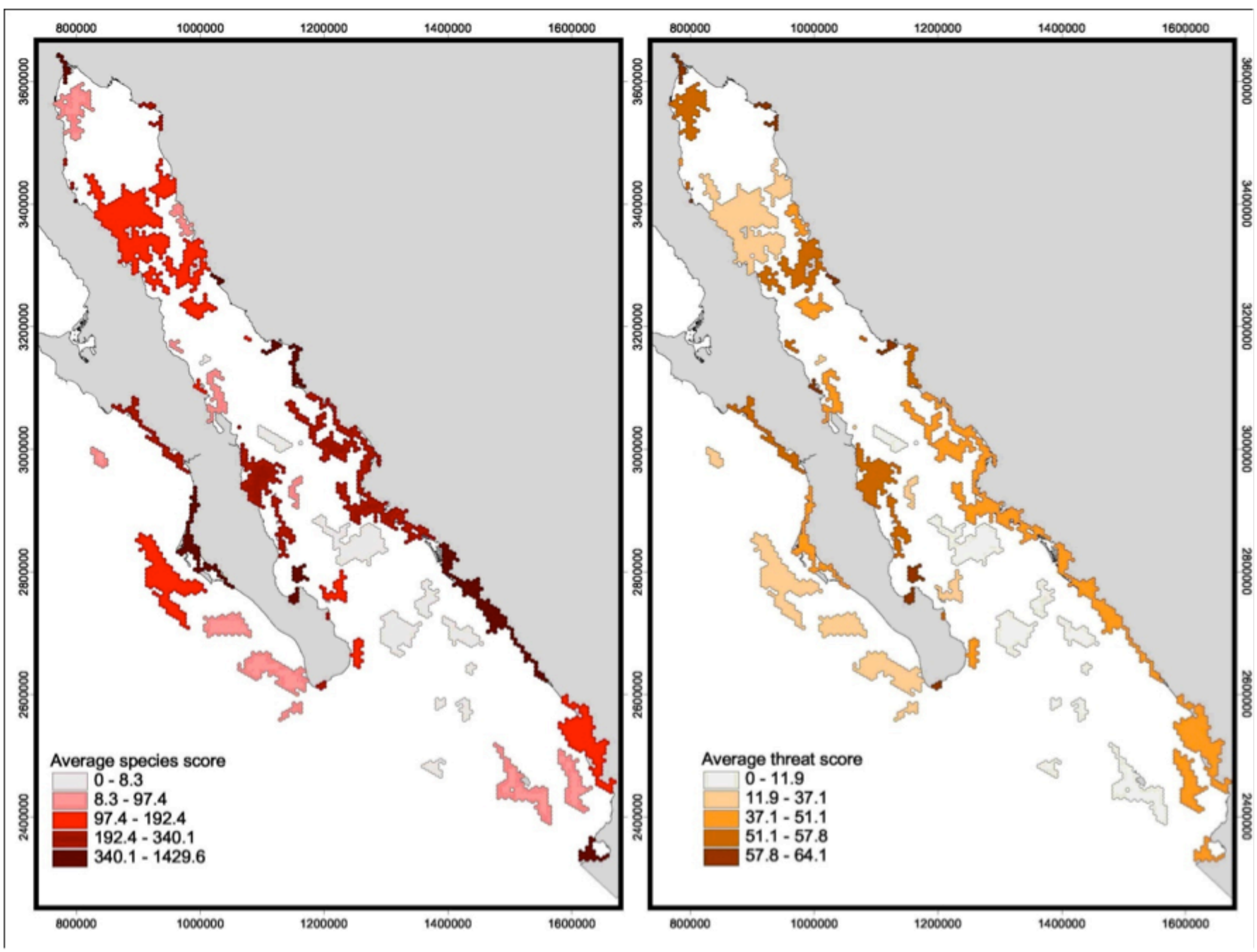
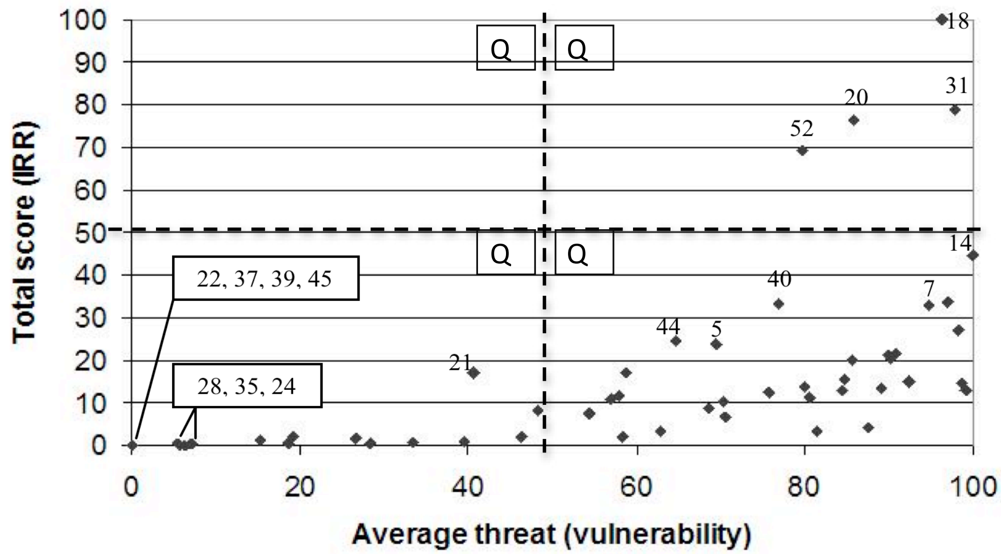


Figure 5: Interaction between threat (a measure of vulnerability) and biological score (a measure of irreplaceability) for the 54 conservation areas of the Gulf of California and western coast of Baja California Sur ecoregion.



DISCUSSION

In order to be truly effective in the persistence of biodiversity, there is a strong push for conservation practitioners to incorporate new aspects of both threats and biodiversity in a spatially explicit way into their planning (Margules and Pressey 2000, Pressey et al. 2007). Biodiversity and threat information is usually available at coarse resolutions and over large extents, and spatial planning exercises are usually conducted at large spatial scales. As a result, a notable mismatch in scale exists between the vast size of spatial planning proposals and on-the-ground, small-scale conservation efforts. To facilitate the prioritization of a network of conservation areas in the Gulf, we developed a "biologically weighted" irreplaceability versus vulnerability analysis using novel data. Our analysis allows us to make recommendations for a smaller suite of sites to initiate conservation action, as well as which areas inside each site should be prioritized. The analyses of our prioritization within sites (Figure 3; see Results for a detailed description) shows that our approach leads to a more efficient conservation of the defined targets according to both irreplaceability and threat indexes.

The decision to assign some sites higher priority than others will depend on the rationale, goals, and strategies of each conservation action (e.g. Groves 2003). Accordingly, we provide a menu of options that a manager can choose from based on priorities (Margules and Pressey 2000). Our results do not identify an optimal solution, but rather what sites should be selected based on different conservation targets. Here, the interaction of threat levels and biology value can be used to help establish priorities for conservation (Figure 5). Margules and Pressey (2000) suggest that sites with the highest priority should be vulnerable to loss but highly irreplaceable (Q1), and those with the lowest should have low irreplaceability and low vulnerability (Q4). The quadrant with the second-highest priority is in the lower right-hand side (Q3), because these areas are theoretically vulnerable to loss, but more replaceable. However, Noss et al. (2002) ranked Q2 as higher priority because they wanted to conserve areas with high irreplaceability while such areas were still intact. For our study, if the goal of the 54 areas is to select sites that are highly threatened and irreplaceable, sites in Q1 would be selected. If the goal is to work in areas that are unthreatened, then one would work on sites in the left side of the graph (Q2 and Q4). If the goal is to conserve areas with highest levels

of targets, then perhaps the sites that have IRR scores above 20 (N=15) should be considered priority. Once the priority sites have been selected, our analysis at the small scale (i.e., intra-site or hexagon level) provides a way to select the local areas for which conservation action should be taken. Brooks et al. (2006) refer to high threat and high endemism places as opportunities for "reactive conservation" and those with low threat places as places for "proactive conservation" (Brooks et al. 2006).

Our results should be interpreted with caution given our scoring system and the nature of the data. First, the use of scoring to prioritize places for conservation may not always maximize the number of species represented in a conservation plan (Moilanen 2009, Game et al. 2011). In particular, our approach is based on two single summary metrics describing biodiversity and threats for each space unit (i.e., hexagon). It has been noted that summary scores from different conservation targets are particularly suited when targets are positively correlated in space. On the contrary, when targets are negatively correlated in space, the summary statistic is largely dependent on the relative weights of each target (Newburn et al. 2005). Second, our approach includes benefit (i.e., biodiversity) and threat components of spatial planning but cost component is lacking. The three components have been described to interact; each is necessary in spatial planning (Newburn et al. 2005). Specifically, for example, because threat and cost are usually correlated, selecting the highest threatened sites could come at a very high economic or social cost (Newburn et al. 2005). Therefore, future efforts in the Gulf should include these three components simultaneously. Third, regarding our classification of sites into four classes (Q1 to Q4), the sites in Q1 are those nearest to academic institutions/research stations where there is a high degree of sampling effort and scientific knowledge relative to the rest of the Gulf, and certainly relative to the pelagic areas that fall into Q4. Further, our eight targets were predominantly coastal targets, thus even at the level of constructing the maps, the pelagic sites would rank lowest. Furthermore, although some respondents indicated their expertise was for a specific region of the Gulf, we generalized across the entire distribution of a given target both from the literature and from the survey responses (not for the ecoregion). That said, there is relatively good agreement between the two threats maps. Both maps reflect generally low threat to pelagic areas in the center of the Gulf, partially because of the coastal nature of the threats used in the ecoregional assessment cost layer and partially due to the primarily coastal nature of our eight targets. Both maps show higher threat or cost surrounding areas like La Paz and Bahía Magdalena and lowest threat levels off the coast of Sinaloa-Nayarit. Additionally, the primarily coastal nature of our eight targets would require inclusion of inland watersheds as priority actions, (Álvarez-Romero et al. 2011, Crist et al. 2013), which has not been considered in this work.

Our analysis of the irreplaceability and vulnerability in the Gulf may help to identify a path forward from conservation prioritization to conservation action. Depending on risk-aversion and preferences for vulnerable or irreplaceable conservation targets, managers could use our framework to identify which sites are in most urgent need of conservation action. Our approach aims to conserve targets that should be defined according to the specific conservation values of the area and the conservation interests of different stakeholders (e.g. scientists, policy makers and managers, NGOs). In general, minimal spatial information of the targets is available, and our index of irreplaceablilty relies on species' attributes commonly available (international and national conservation status, general life history characteristics). Furthermore, the threat index is estimated using an expert-based approach that can work even in locations where formal knowledge is scarce or highly fragmented (i.e., Hannah et al. 1998). This general approach could also be expanded to include other dimensions, such as ecological connectivity and socioeconomic priorities, and may be broadly applied to other conservation planning problems.

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