ECOLOGICAL INTEGRITY – RISK ASSESSMENT

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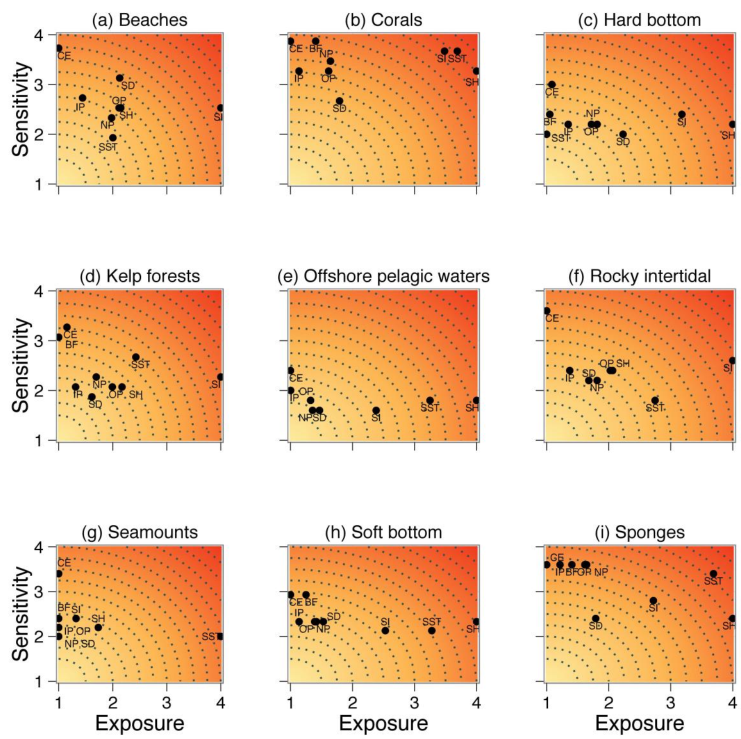
OVERVIEW

Coastal habitats-- including kelp forests, beaches, and rocky shorelines-- in the Monterey Bay National Marine Sanctuary were at highest risk due to human modifications, pollution, and climate.

EXECUTIVE SUMMARY

An ecosystem risk assessment can provide insight into the potential negative effects of drivers and pressures on ecosystem components. We assessed the environmental risks to marine habitats in a case study region, the Monterey Bay National Marine Sanctuary. A detailed look at coast-wide trends is also provided in the Human Pressures chapter of this report. This habitat risk assessment served as a proxy approach to understanding risk to ecological integrity, under the assumption that habitats act as umbrellas for communities of species and a variety of ecosystem processes. We focused the risk assessment on evaluating the potential for a reduction in the quantity or quality of habitats to the point where their ecosystem functions (e.g., water filtration, current or wave attenuation, nurseries) are impaired.



Data-based assessment of risk to marine habitats in the Monterey Bay National Marine Sanctuary. BF = bottom-tended fishing, CE = coastal engineering, IP = inorganic pollution, NP = nutrient pollution, OP = organic pollution, SST = sea surface temperature, SD = sediment decreases, SI = sediment increases, SH = shipping.

Using a data-based approach, we found that some habitats, like those containing corals and sponges, were at higher risk to many drivers and pressures, while others, like kelp forests and soft bottom habitats, experienced high risk due to a more limited subset. For each habitat, sea-based pressures, such as sea surface temperature changes and shipping, tended to exceed land-based pressures like coastal pollution. At the same time, individual drivers and pressures posed greater risk to nearshore habitats (beaches, kelp forests, rocky shores) than offshore habitats (soft bottom and offshore pelagic habitats). Comparison of these results with those from an expert-based survey showed general agreement, though there was a fair degree of uncertainty associated with survey responses. Furthermore, the expert-based risk assessment was generally less conservative than the data-based assessment in relation to pressures caused by bottom-tended fishing, but more conservative in relation to pressures resulting from coastal pollution.

We evaluated risk as a function of the exposure and sensitivity of each habitat to each activity or pressure in order to provide insight into potential mitigation measures. Habitats at high risk due to high exposure (e.g., sediment increases in habitats containing sponges) lend themselves to management interventions focused on reducing exposure. In contrast, where habitats were at high risk due to high sensitivity (e.g., corals in habitats exposed to coastal pollution), managers might do better to focus on preventing increased exposure or preparing for habitat decline if exposure is already high. In the future, we hope to integrate our synthesis of the information available in the scientific and management literature with expert perceptions in order to generate a single, cohesive ecosystem risk assessment.

DETAILED REPORT

GENERAL DESCRIPTION AND BACKGROUND

Risk is defined as the likelihood that a subject will experience adverse consequences due to exposure to particular hazards (Burgman 2005). A risk assessment is an analytical approach for quantifying that likelihood and those consequences. In the context of the CCIEA, a risk assessment evaluates the degree to which pressures associated with human activities or natural processes interfere with the achievement of management objectives related to particular ecosystem components (Levin et al. 2009, Samhouri and Levin 2012). We define a pressure as a natural or human-induced element of a system that precipitates an unwanted outcome, like the decline in abundance of a population or a reduction in the quantity or quality of a habitat. Ecosystem components, defined in the Preface, are the biological, physical, or human dimension entities that policy makers, managers, or citizens are trying to manage or conserve. Unlike management scenario evaluations, risk assessment does not make projections about future states. Rather, it uses our best understanding of current linkages between pressures and states to evaluate risk to ecosystem components over a short time horizon (5-10 years). In that sense, this section represents a way of linking the chapter on Anthropogenic Drivers and Pressures to the status of the Ecological Integrity component.

The Ecological Integrity component refers to the structure and function of marine and coastal ecosystems and ecological communities. This risk assessment is thus one way of linking the chapter on Anthropogenic Drivers and Pressures to other CCIEA components. Assessing the risk of marine habitat decline is one proxy approach to understanding risk to ecosystem structure and function, because habitats serve as umbrellas for communities of species and a variety of ecosystem processes (Hayes and Landis, 2004, Tett et al. 2007, Halpern et al. 2009, Stelzenmüller et al. 2010). We focused on evaluating the potential for a reduction in the quantity or quality of habitats to the point where their ecosystem functions (e.g., water filtration, current or wave attenuation, nurseries) are impaired.

Here we demonstrate the utility of applying one specific risk assessment framework to marine habitats within the Monterey Bay National Marine Sanctuary (MBNMS). Methodologies for risk assessment are diverse and rapidly evolving. Our application provides a template for future risk assessments that would span all of the CCIEA components.

DATA AND METHODOLOGY

We conducted the risk assessment using two techniques. The first technique relied on data and literature that described associations between human activities, pressures, and habitats. The second technique was based on elicitation of expert opinion regarding the risk posed to habitats within MBNMS due to human activities and pressures. By evaluating risk using these two different approaches, we hoped to gain an understanding of how synthesis of information available in the scientific and management literature compares and complements expert perceptions.

DATA-BASED RISK ASSESSMENT: ACTIVITIES, PRESSURES, AND HABITATS

For the data-based risk assessment, we quantified the risk that three categories of pressures—modifications to the ocean bottom, pollution, and climate change—will lead to negative effects on nine habitat types within the MBNMS. This subset of pressures was selected based on an extensive dialogue with managers and scientists at the MBNMS, and represents regional concerns. Though we recognize the importance of historical pressures, our analysis focused on present-day pressures to which the habitats have been exposed within the past ten years. The specific pressures on which we focused are listed in Table EN.R.1, and the habitats are listed in Table EN.R.2 and displayed in Figure EN.R.1.

We purposefully did not assess risk to beach, rocky intertidal, and offshore pelagic habitats from bottom-tended fishing. We made this choice to avoid confusion, as modifications to the ocean bottom due to trawling are physically impossible (or nearly so) in these habitats. In contrast, other pressures have clear potential to generate risk to habitats (e.g., bottom-tended fishing in coral and sponge habitats, pollutants associated with ship traffic that may create risk for intertidal and pelagic habitats).

Table EN.R.1. Activities and pressures evaluated as part of the risk assessment for ecosystem integrity in Monterey Bay National Marine Sanctuary.

Activity or pressure	Land- or sea-based	Data source
Modifications to the ocean bottom		
Bottom trawling	SB	California logbook trawl data, 2004-2009*
Increases and decreases in sediment loads	LB	SRTM60plus, PRISM, Syvitski et al. 2003, Halpern et al. 2009
Coastal engineering	LB	NOAA ESI
Pollution		
Organic pollution	LB	Halpern et al. 2008
Inorganic pollution	LB	NGDC, EPA, Halpern et al. 2009
Nutrient pollution	LB	USGS, NADP, Halpern et al. 2009
Ship traffic	SB	CalTrans, WADOT, Halpern et al. 2009
Climate		
Sea surface temperature changes	SB	Halpern et al. 2008

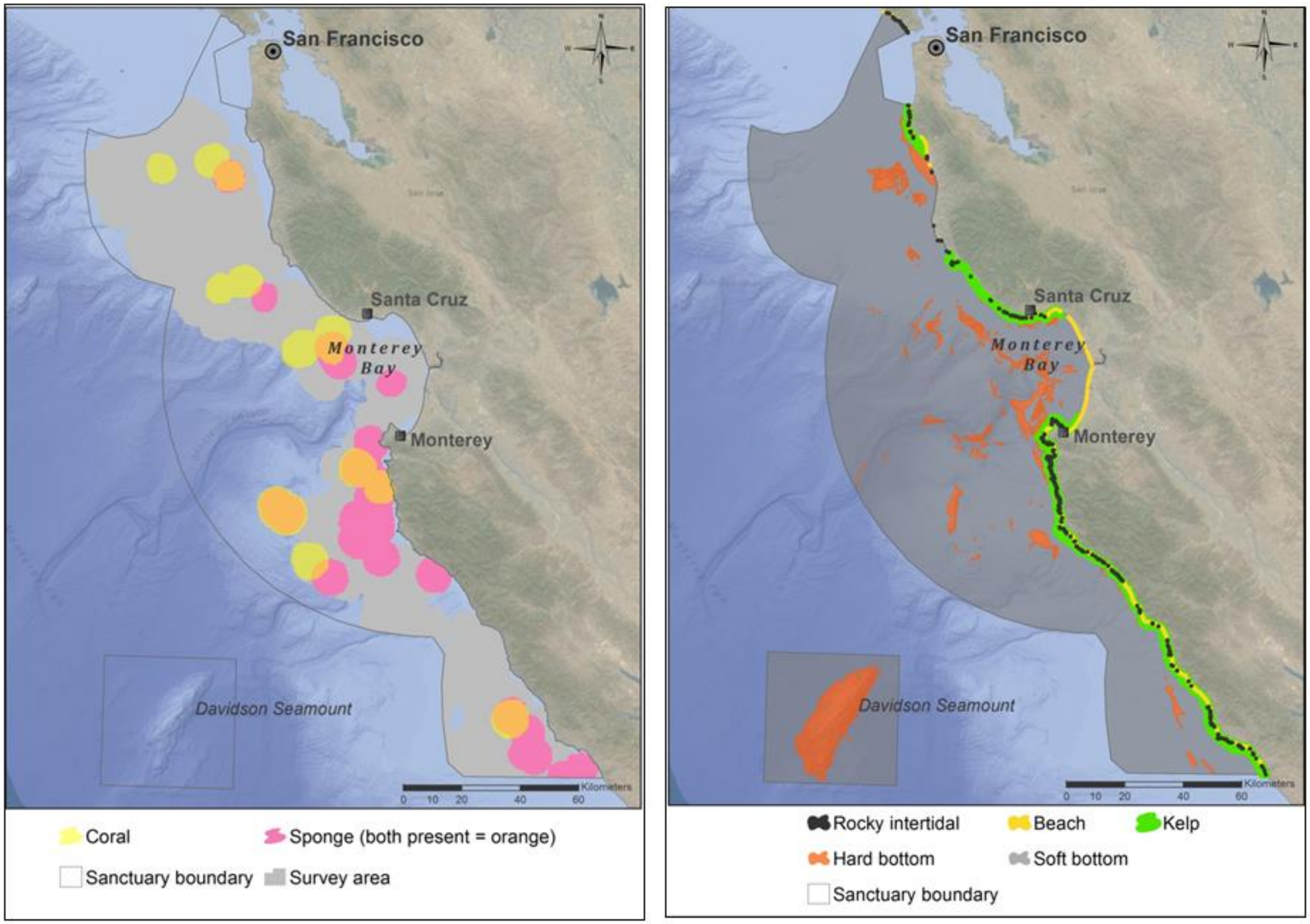
*Includes vessels fishing for California halibut whether or not they have limited entry permits. Does not include microblocks with 1-2 vessels, or effort data from demersal seine and mid-water trawls. As presented at the PFMC meeting on 4 Nov 2010 (http://www.pcouncil.org/wp-content/uploads/HC_AGENDA_NOV2010BB.pdf). Credit: J. Mason, SWFSC

Table EN.R.2. The risk assessment for ecosystem integrity in Monterey Bay National Marine Sanctuary focused on the habitats listed below. Note that corals and sponges are biogenic features within hard bottom habitats, and that the nearshore/offshore designation denotes the location in which the habitat is predominantly found.

Habitat	Nearshore or Offshore	Data source
Beaches	N	NOAA Environmental Sensitivity Index maps
Corals§	O	NWFSC West Coast Groundfish Bottom Trawl Survey*
Hard bottom	N	Moss Landing Marine Laboratory
Kelp forests§	N	California Department of Fish and Game
Offshore pelagic	O	all waters surrounding benthos >30 m depth⌘
Rocky intertidal	N	NOAA Environmental Sensitivity Index maps
Seamount	O	National Centers for Coastal Ocean Science
Soft bottom	O	Moss Landing Marine Laboratory
Sponges§	O	NWFSC West Coast Groundfish Bottom Trawl Survey*

*Credit: K. Whitmire §Denotes living habitat. ⌘S. DeBeukelaer, personal communication

Figure EN.R.1. Overview of habitats within the Monterey Bay National Marine Sanctuary on which the risk assessment focused. Data sources provided in Table EN.R.2**.**



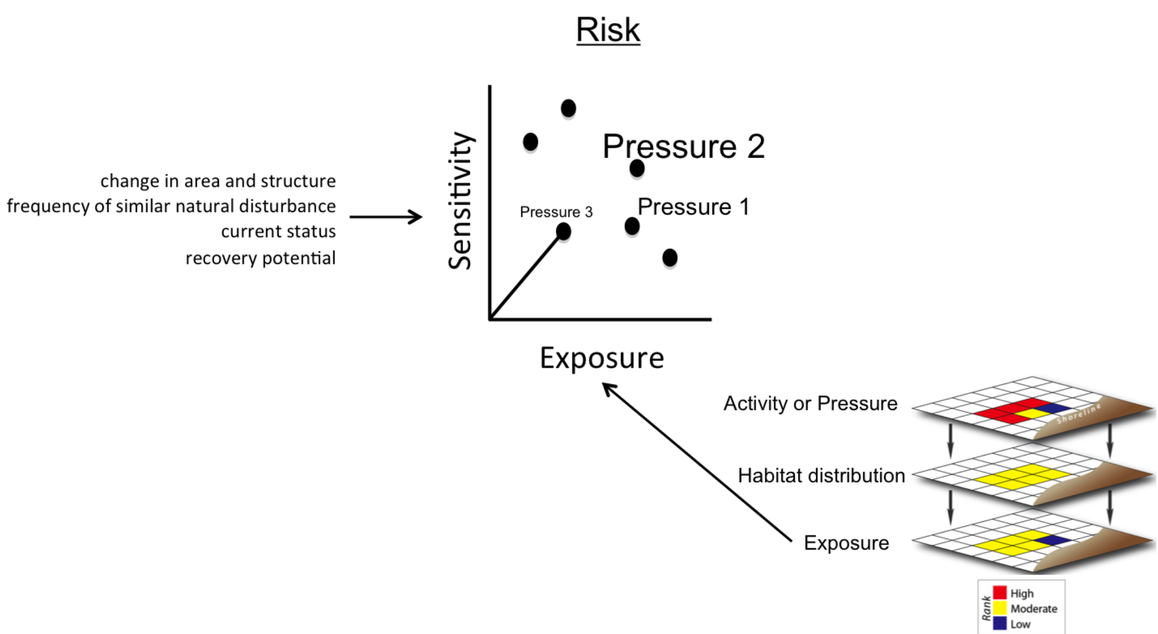
DATA-BASED RISK ASSESSMENT: ESTIMATING RISK

Our data-based risk assessment was based on the exposure E and the sensitivity S of each habitat to the activities and pressures listed in Table EN.R.1. The relative risk R_{ij} to habitat i from pressure j was calculated as:

$$R_{ij} = \sqrt{(E_{ij} - 1)^2 + (S_{ij} - 1)^2}, \quad (1)$$

implying that risk increases with Euclidean distance from the origin and each axis receives equivalent weight (see Fig. EN.R.2). We evaluated risk over the next 5 – 10 years, assuming that activities and pressures continue unchanged. Note that the assessment focused on the risk of decline of each habitat within the MBNMS, rather than the risk of decline throughout a broader geographic range. As mentioned above, we defined habitat decline as a reduction in the quantity or quality of habitats to the point where their ecosystem functions (e.g., water filtration, current or wave attenuation, nurseries) are impaired. More details about the mechanics of the framework are provided in Andrews et al. (2011) and Samhouri and Levin (2010). For a similar treatment, also see Tallis et al. (2011).

Figure EN.R.2. Conceptual flow for data-based habitat risk assessment. The exposure and sensitivity of each habitat to each activity or pressure was used to estimate the risk of a reduction in the quantity or quality of habitats to the point where their ecosystem functions were impaired. Figure credit: J. Samhouri, G. Williams, J. Davies.



EXPOSURE

We estimated exposure quantitatively and in a spatially explicit manner for all habitats. Specifically, we measured exposure as the overlap between the spatial distribution of each habitat and the intensity of each activity or pressure using GIS data. Intensity was scored as a continuous variable with values in the range 0-1; values were rescaled to the maximum on the original scale. Details about how intensity values were generated are described more fully in Halpern et al. (2009). All activity/pressure data layers were converted from raster grid format to shape format. We used ESRI ArcGIS version 10 to obtain an exposure value by completing a union of each habitat data layer with each activity or pressure data layer. This procedure effectively weighted the activity intensity scores by the occurrence of each habitat within the MBNMS. For the final exposure score, we summed the area-weighted exposure intensity values for each habitat-activity/pressure combination. To evaluate relative risk to each habitat from the nine activities and pressures, we standardized the weighted sums across all activities and pressures within each habitat to values between 1 (minimal exposure) and 4 (maximal exposure). To characterize the habitat at greatest relative risk from each activity or pressure, we standardized the weighted sums across all habitats within each activity or pressure to values between 1 (minimal exposure) and 4 (maximal exposure). Figures EN.R.3-6 represent the unions of habitat and activity/pressure layers for several example combinations in nearshore and offshore regions of the MBNMS.

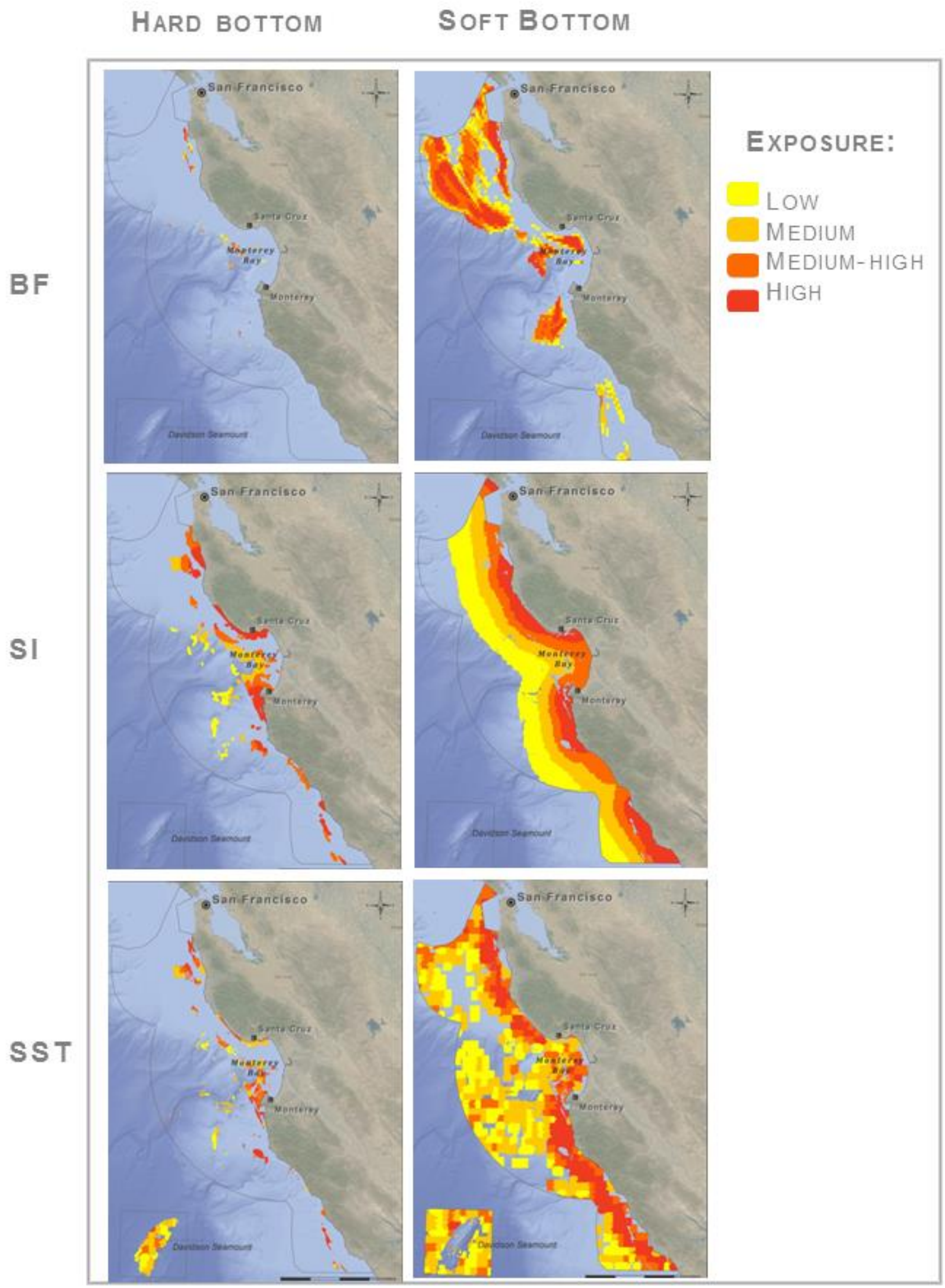


Figure EN.R.3. Exposure of hard and soft bottom habitats to bottom-tended fishing (trawling; BF), sediment increases (SI), and changes in sea surface temperature (SST) within the Monterey Bay National Marine Sanctuary. Categories of exposure are relative and are based on quantiles from intensity scores for MBNMS as originally presented in Halpern et al. (2009).

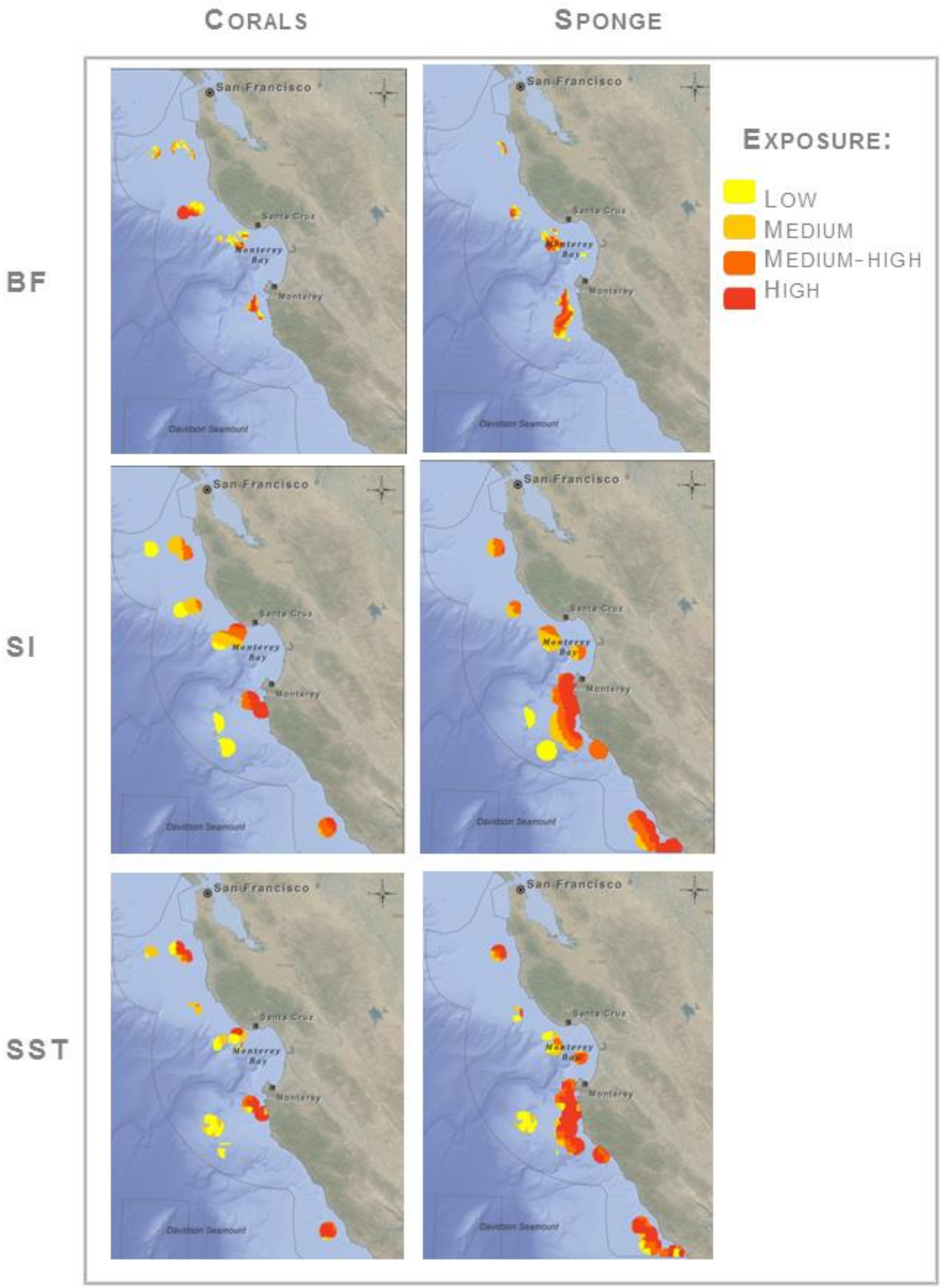


Figure EN.R.4. Exposure of coral and sponge habitats to bottom-tended fishing (trawling; BF), sediment increases (SI), and changes in sea surface temperature (SST) within the Monterey Bay National Marine Sanctuary. Categories of exposure are relative and are based on quantiles from intensity scores for MBNMS as originally presented in Halpern et al. (2009).

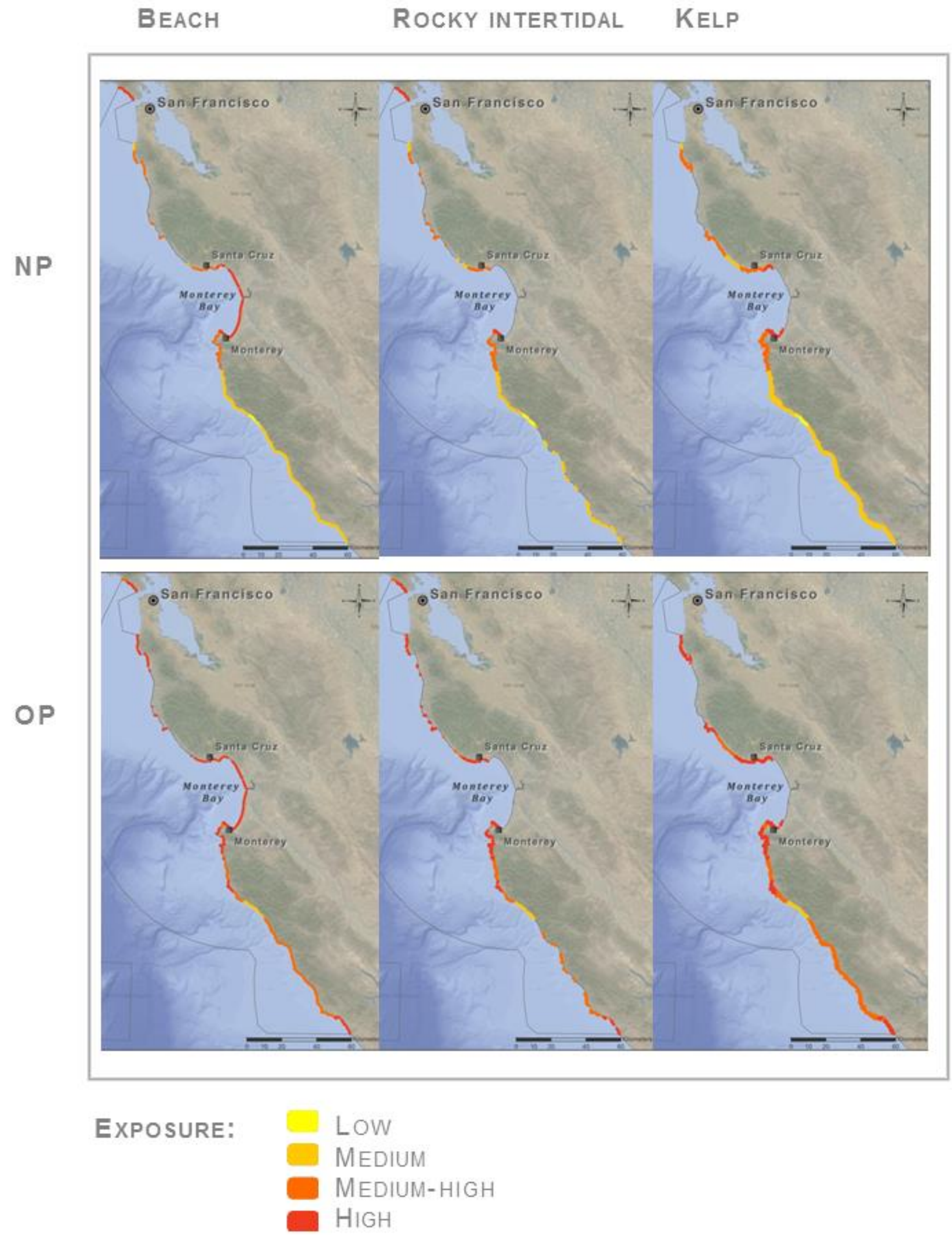


Figure EN.R.5. Exposure of beach, rocky intertidal, and kelp habitats to nutrient pollution (NP) and organic pollution (OP) within the Monterey Bay National Marine Sanctuary. Categories of exposure are relative and are based on quantiles from intensity scores for MBNMS as originally presented in Halpern et al. (2009).

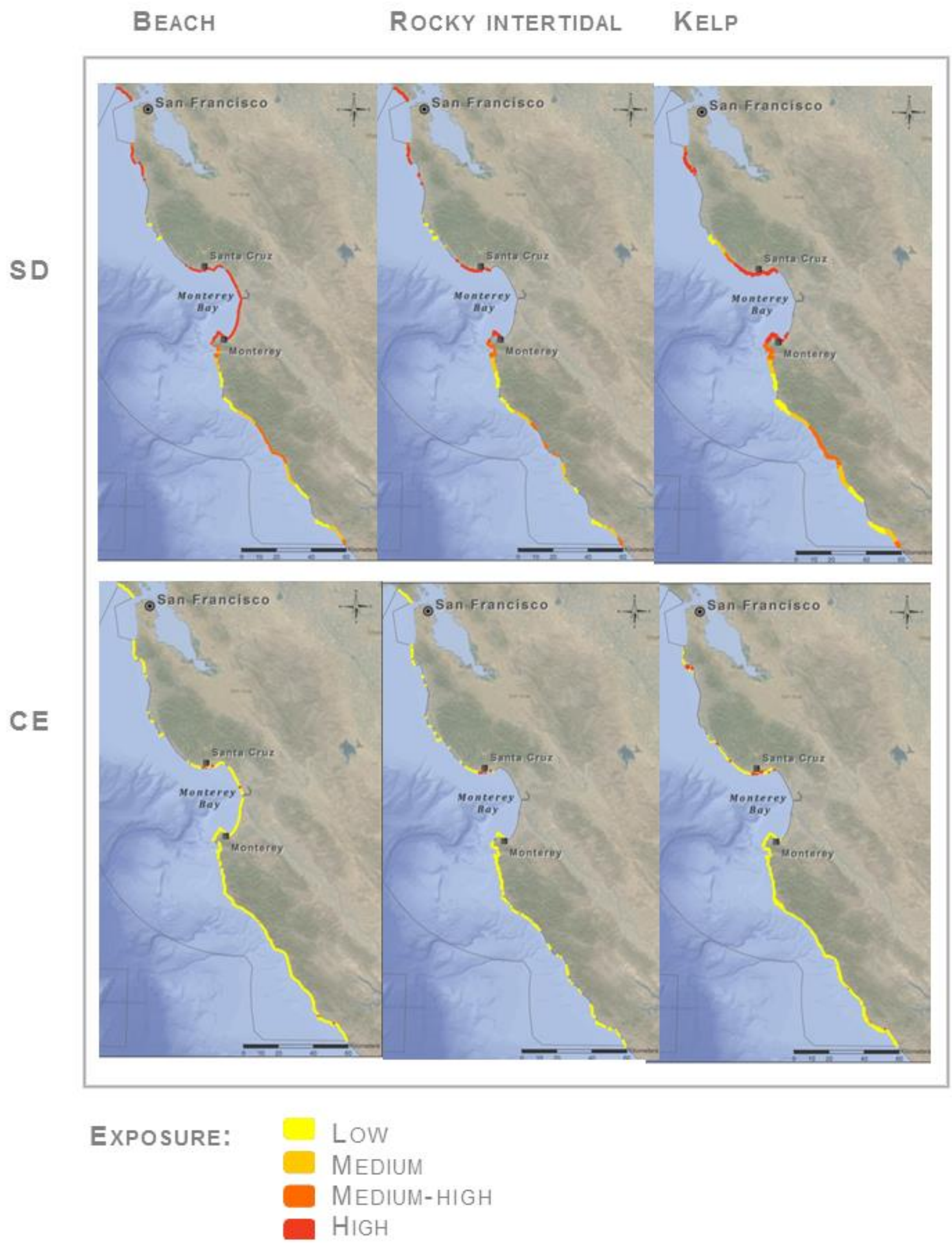


Figure EN.R.6. Exposure of beach, rocky intertidal, and kelp habitats to sediment decreases (SD) and coastal engineering (CE) within the Monterey Bay National Marine Sanctuary. Categories of exposure are relative and are based on quantiles from intensity scores for MBNMS as originally presented in Halpern et al. (2009). A a ccomodate

SENSITIVITY

We estimated sensitivity qualitatively based on three activity/pressure-specific criteria, in addition to criteria that were invariant across activities and pressures (Table EN.R.3). Each habitat-activity/pressure combination was scored on a scale from 1 (low) to 4 (high) for each criterion; categories were based on Tallis et al. (2012). Scores for all criteria were assigned based on inferences from the primary and grey literatures about the expected responses of habitats if they were exposed to activities and pressures over the next 5 – 10 years. In all cases we attempted to provide ratings specific to the California Current; however, paucity of regional data did not always allow for that. We included a data quality rating (1: low, 4: high) for each criterion as a means of portraying uncertainty related to scoring assignments (Table EN.R.4). To calculate the final Sensitivity score, we first averaged the 3 sub-criteria related to the ability of a habitat to recover from perturbation (5a-c in Table EN.R.3), and then averaged this composite criterion with the other four criteria listed in Table EN.R.3 (change in area, change in structure, frequency of natural disturbance, and current status) for each habitat-activity/pressure combination.

Table EN.R.3. Sensitivity criteria and scoring descriptions.

Sensitivity criteria	Description	1 (low)	2	3	4 (high)
1. Change in area[a]	The percent change in areal extent of a habitat when exposed to a given pressure	0 - 10% loss in area	10 - 30% loss in area	30 - 50% loss in area	>50% loss in area
2. Change in structure[a]	For biotic habitats, the change in structure is the percentage change in structural density of the habitat when exposed to a given pressure. For abiotic habitats, the change in structure is the amount of structural damage sustained by the habitat when exposed to a given pressure.	0 - 10% loss in structure	Low loss in structure (for biotic habitats, 10-30% loss in density, for abiotic habitats, little to no structural damage)	Moderate loss in structure (for biotic habitats, 30-50% loss in density, for abiotic habitats, partial structural damage)	High loss in structure (for biotic habitats, >50% loss in density, for abiotic habitats, total structural damage)
3. Frequency of natural disturbance[a]	The frequency of natural disturbances of a similar type to the pressure; habitats subject to regular disturbance similar in kind to a pressure should be more resistant to it	Daily	Weekly to monthly	Monthly to annually	Annually or less often
4. Current status	The regional status of the habitat; increasingly critical status signifies a decrease in the ability of the habitat to recover from the impacts of the pressure	No concern; negligible difference from historical	Low concern (eg, impact studies exist but do not reveal major problems); somewhat degraded compared to historical	Moderate concern (including threatened status); substantially degraded compared to historical	High concern (endangered); unrecognizable compared to historical status
5a. Replenishment[b]	Includes natural recruitment rate, or the rate at which new propagules enter a population. For abiotic habitats, sensitivity is assumed to be high as replenishment only occurs on geological time scales.	Recruitment events more often than annually	Recruitment events annually	Recruitment events every 1-2 years	Recruitment events less frequently than every 2 years

5b. Recovery time[b]	For biotic habitats, we refer to recovery time of the habitat as a whole (e.g., a mature kelp forest) rather than recovery time of individuals. For abiotic habitats, shorter recovery times for habitats such as mudflats decrease the sensitivity of exposure to human activities, whereas for habitats made of bedrock, recovery will occur on geological time scales.	Recovery time <1 year	Recovery time 1-10 years	Recovery time >10 years	Recovery time >100 years
5c. Population connectivity[b]	Realized exchange with other populations based on spatial patchiness of distribution, degree of isolation, and potential dispersal capability; based on monitoring surveys, and population genetic or direct tracking estimates. For abiotic habitats, sensitivity is assumed to be high as connectivity is only relevant on geological time scales.	Regular movement/exchange between the focal regional population and other populations; high dispersal distance (>100km)	Occasional movement/exchange between the focal regional population and other populations; moderate dispersal distance (10-100km)	Low movement/exchange between the focal regional population and other populations; low dispersal distance (1-10km)	Lowest movement/exchange between the focal regional population and other populations; low dispersal distance (<1km)

[a]Indicates criterion varies among activities and pressures; all other criterion are invariant across activities and pressures.
[b]These criteria were averaged to create a composite criterion representing the ability of a habitat to recover from perturbation.

Table EN.R.4. Data quality ratings and descriptions.

Data Quality	Description	Example
1	Very limited data. Information based on expert opinion surveys or on general literature reviews from a wide range of habitats.	No empirical literature exists to justify scoring for a focal habitat in relation to a particular activity/pressure but reasonable inference can be made by the person conducting the risk assessment.
2	Limited data. Estimates with high variation and limited confidence, or based on studies of similar habitats or of the focal habitat in other regions.	Scoring based on a study of a similar habitat outside of the study region.
3	Adequate data. Information is based on limited spatial or temporal coverage, moderately strong or indirect statistical relationships, or for some other reason is deemed not sufficiently reliable to be designated as "best data."	Use of presence-absence data from ad hoc sampling efforts; use of relatively old information; etc.
4	Best data. Substantial information exists to support the score and is based on data collected for the habitat in the study region.	Data-rich assessment of habitat status, with reference to historical extent and current trends.

SYNTHESIS

In addition to evaluating risk for each activity/pressure–habitat combination, we highlighted locations within the Monterey Bay National Marine Sanctuary where risk scores for particular habitats were uniformly high across multiple activities and pressures. We also tested for differences in risk due to land- versus sea-based activities and pressures across habitats and for differences in risk due to alternative activities and pressures in nearshore versus offshore habitats considered collectively.

For beaches, kelp forests, and the rocky intertidal, we mapped locations characterized by medium-high to high exposure (a score between 3-4) for each of the following: nutrient pollution, organic pollution, and sediment decreases. For hard and soft bottom habitats, including locations known to have corals and sponges, we mapped locations characterized by medium-high to high exposure for each of the following: bottom-tended fishing, sea surface temperature changes, and sediment increases.

For the land- vs. sea-based and nearshore vs. offshore risk comparisons, we conducted the analyses using generalized linear models in R, and corrected for multiple comparisons using the glht function in the multcomp package. .

EXPERT-BASED RISK ASSESSMENT

The expert-based risk assessment was conducted in collaboration with managers and scientists at MBNMS. To protect their privacy, survey respondents remain anonymous. As in the data-based risk assessment, the conceptual approach was to elicit expert perceptions of exposure and sensitivity of MBNMS habitats to a variety of activities and pressures. Exposure questions addressed the spatial footprint of activities and pressures within habitats in addition to the temporal overlap of activities and pressures with habitats. Sensitivity questions addressed the degree of loss and rate of recovery of habitats if exposed to activities and pressures.

The survey focused predominantly on the risk posed by coastal pollution and bottom-tended fishing to habitats within the MBNMS. We did not include comprehensive questions about other activities and pressures in order to constrain the total amount of time required to complete the survey. A few questions focused on other activities and pressures including those addressed in the data-based risk assessment described above and: aquaculture, invasive species, marine debris, ocean acidification, and ocean-based pollution. The habitats included all of those listed in Table EN.R.2 except seamounts, in addition to the deep sea. Respondents were asked about their level of certainty regarding the survey questions. The full survey can be found here. The survey includes the exact information respondents were given regarding definitions of habitat types, activities, and pressures.

Respondents were asked to provide categorical responses to the survey questions. In the analyses below, we have tried to represent these answers in two ways. First, we simply illustrate the number of respondents choosing each level of categorical response for each question. Second, we associated integer scores between 1 and 4 with each level of categorical response for each question, such that a score of 1 indicated least exposed or sensitive and a score of 4 indicated most exposed or sensitive. Using this second approach, overall risk was calculated according to Equation 1. We recognize that the arbitrary scaling we have chosen for these categorical responses has a direct influence on assessment of risk levels and that variation among experts in their responses can be, but has not been, incorporated directly in the estimation of risk (Kuhnert et al. 2010). These challenges will be confronted in future versions of the CCIEA.

COMPARISON OF DATA- AND EXPERT-BASED RISK ASSESSMENTS

We compared the data- and expert-based risk assessments by plotting exposure, sensitivity, and risk scores derived from each method against one another. Because experts appeared to interpret a survey question regarding the degree of habitat loss expected due to bottom-tended fishing and coastal pollution in terms of the living communities associated with each habitat (see responses in Figs. EN.R.16, 18 below), we eliminated this question from the comparison of the data- and expert-based risk assessments. All other questions in our survey were clearly focused on the physical habitats, so we have retained them in the comparison of results from the data- and expert-based assessments. Positive deviations from a 1:1 line in the figures associated with these comparisons indicated that the expert-based assessment was greater (more conservative) than the data-based assessment, and vice versa.

RESULTS

DATA-BASED RISK ASSESSMENT

Relative risk to each habitat

For each habitat within MBNMS, relative risk due to the different activities and pressures varied substantially (Fig. EN.R.7). Some habitats, like corals and sponges (Figs. EN.R.7a, i), tended to be at higher risk to multiple activities and pressures, while other habitats, like kelp forests and soft bottom habitats (Figs. EN.R.7d, h), experienced high risk due to some activities and pressures but not others. Habitats assessed with consistently high risk across activities and pressures often showed high sensitivity scores, whereas exposure scores spanned a wide range for habitats experiencing risk that varied widely in intensity across activities and pressures.

Risk due to land-based activities and pressures differed among habitats (p = 0.04 for glm including interaction between habitat and land/sea pressures), though there was a general tendency for risk due to sea-based activities and pressures to exceed that due to land-based activities and pressures, except in beach and rocky intertidal habitats (Figure EN.R.8). However, the only statistically significant difference occurred in offshore pelagic habitats where sea-based risk surpassed land-based risk ($p = 0.01$ for term representing interaction between land/sea pressures and offshore pelagic habitat). Summary scores for exposure, sensitivity, and risk can be found in Table EN.R.5.

Relative risk from each activity and pressure

Relative risk due to each individual activity and pressure varied across the habitats we evaluated in the MBNMS (Fig. EN.R.9). For instance, risk scores tended to be consistently high across nearly all habitats for coastal engineering (Fig. EN.R.9b), sea surface temperature changes (Fig. EN.R.9f), and shipping (Fig. EN.R.9i), but more variable for bottom-tended fishing (Fig. EN.R.9a), organic pollution (Fig. EN.R.9e), and sediment decreases (Fig. EN.R.9g). For the higher risk activities and pressures, comparable risk scores were generated more by exposure in some cases (e.g., sea surface temperature changes; Fig EN.R.9f) and by sensitivity in others (e.g., coastal engineering; Fig EN.R.9b). Summary scores for exposure, sensitivity, and risk can be found in Table EN.R.6.

Differences in risk to nearshore and offshore habitats varied among pressures ($p = 0.01$ for glm including interaction between pressure and nearshore/offshore habitat), though there was a general tendency for risk in nearshore habitats to exceed risk in offshore habitats except in the case of bottom-tended fishing gear (Figure EN.R.10). However, risk in nearshore habitats was statistically significantly greater than in offshore habitats only for sediment increases, sediment decreases, and organic pollution ($p = 0.03$, $p=0.052$, and $p =0.053$, respectively, for interaction terms between habitat type and pressures).

Habitats were highly exposed to multiple activities and pressures in a restricted set of areas within MBNMS (Figure EN.R.11). Coastal habitats including beaches, kelp forests, and the rocky intertidal were characterized by medium-high to high exposure scores at the northern boundary of the Sanctuary and within Monterey Bay. Hard and soft bottom habitats, including those with sponges and corals, were characterized by medium-high to high exposure scores offshore from Half Moon Bay (north of Santa Cruz) and southwest of Carmel Bay (south of Monterey).

Sensitivity scores

Details about the sensitivity scores, rationale, and references can be found in Table EN.R.7 (for activity/pressure invariant criteria) and Tables EN.R.8-10 (for criteria scores are activity/pressure specific).

Figure EN.R.7. Relative risk to (a) beaches, (b) corals, (c) hard bottom, (d) kelp forests, (e) offshore pelagic waters, (f) rocky intertidal, (g) seamounts, (h) soft bottom, and (i) sponges in the Monterey Bay National Marine Sanctuary due to 9 different pressures. BF = bottom-tended fishing, CE = coastal engineering, IP = inorganic pollution, NP = nutrient pollution, OP = organic pollution, SST = sea surface temperature, SD = sediment decreases, SI = sediment increases, SH = shipping

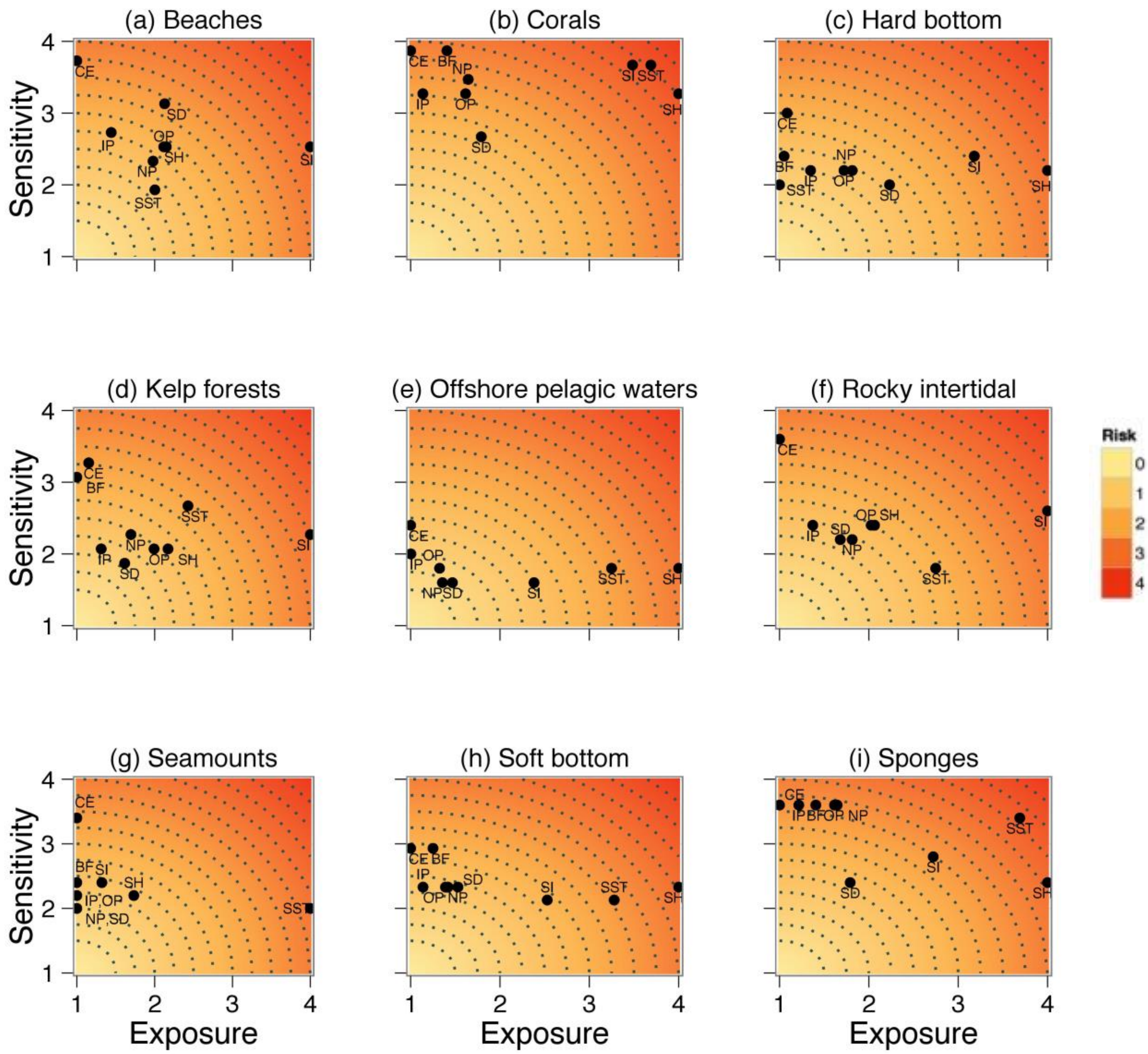


Figure EN.R.8. Average land- vs. sea-based risk scores for habitats in the Monterey Bay National Marine Sanctuary. Bars represent means ± 1SE. * indicates $p < 0.05$.

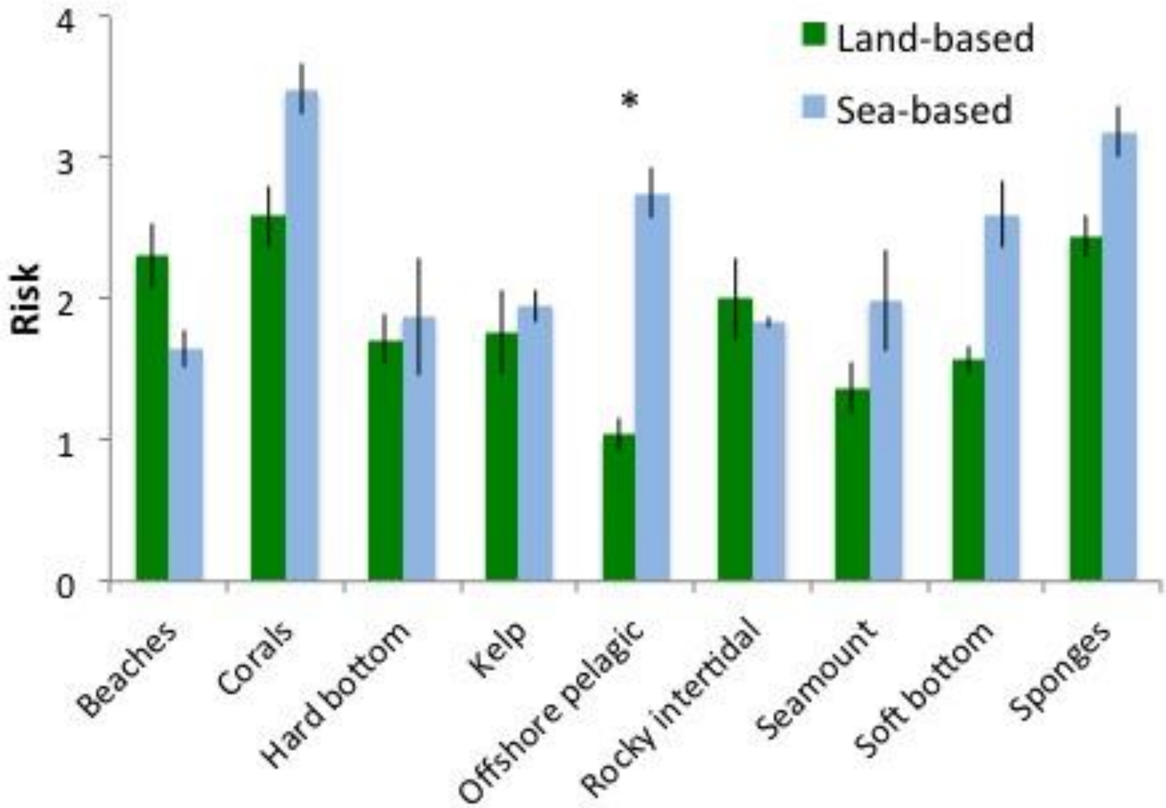


Figure EN.R.9. Relative risk due to bottom-tended fishing in the Monterey Bay National Marine Sanctuary for the following habitats: B = beaches, C = corals, HB = hard bottom, KF = kelp forest, OP = offshore pelagic, RI = rocky intertidal, S = sponges, SB = soft bottom, SM = seamount.

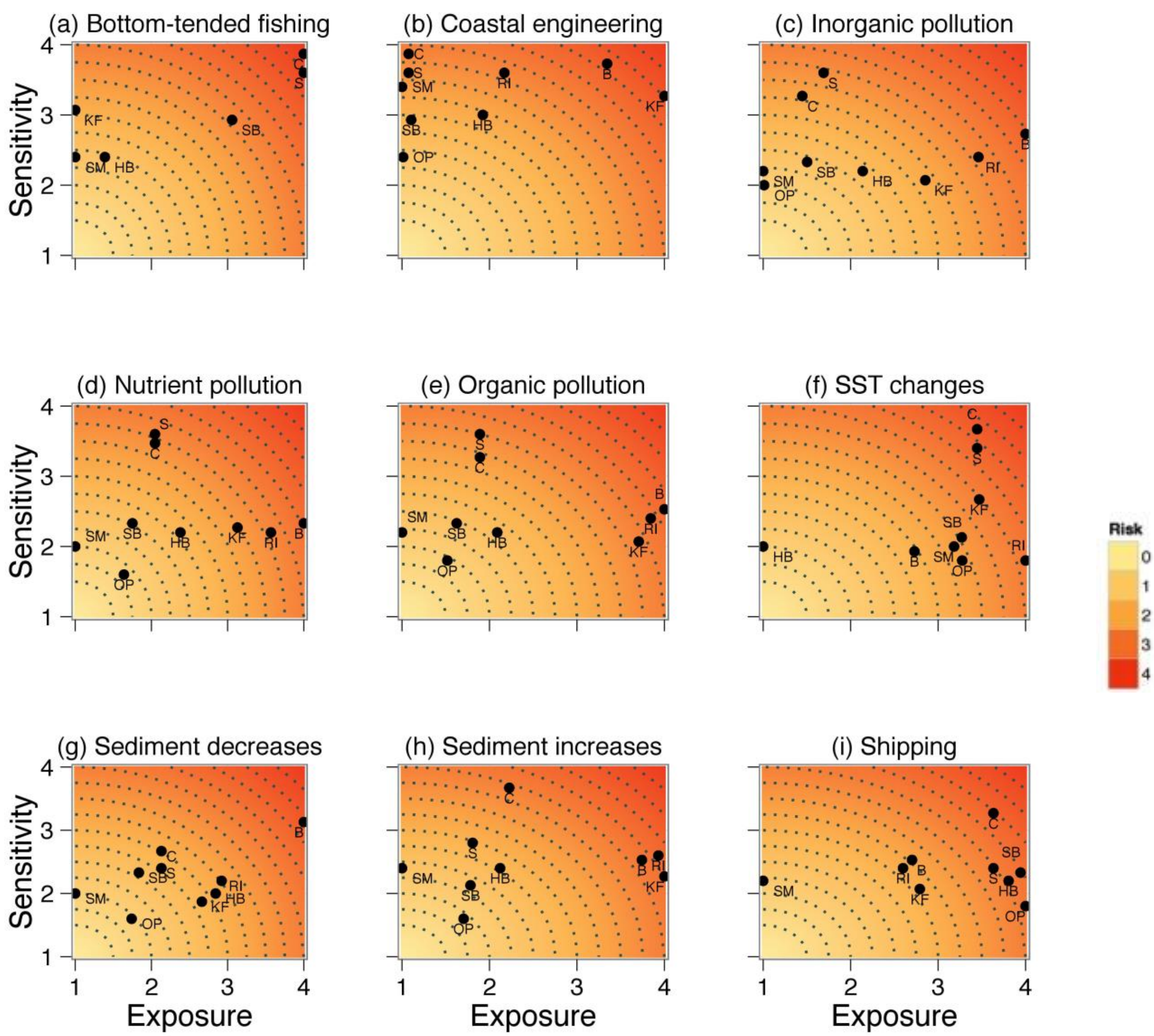
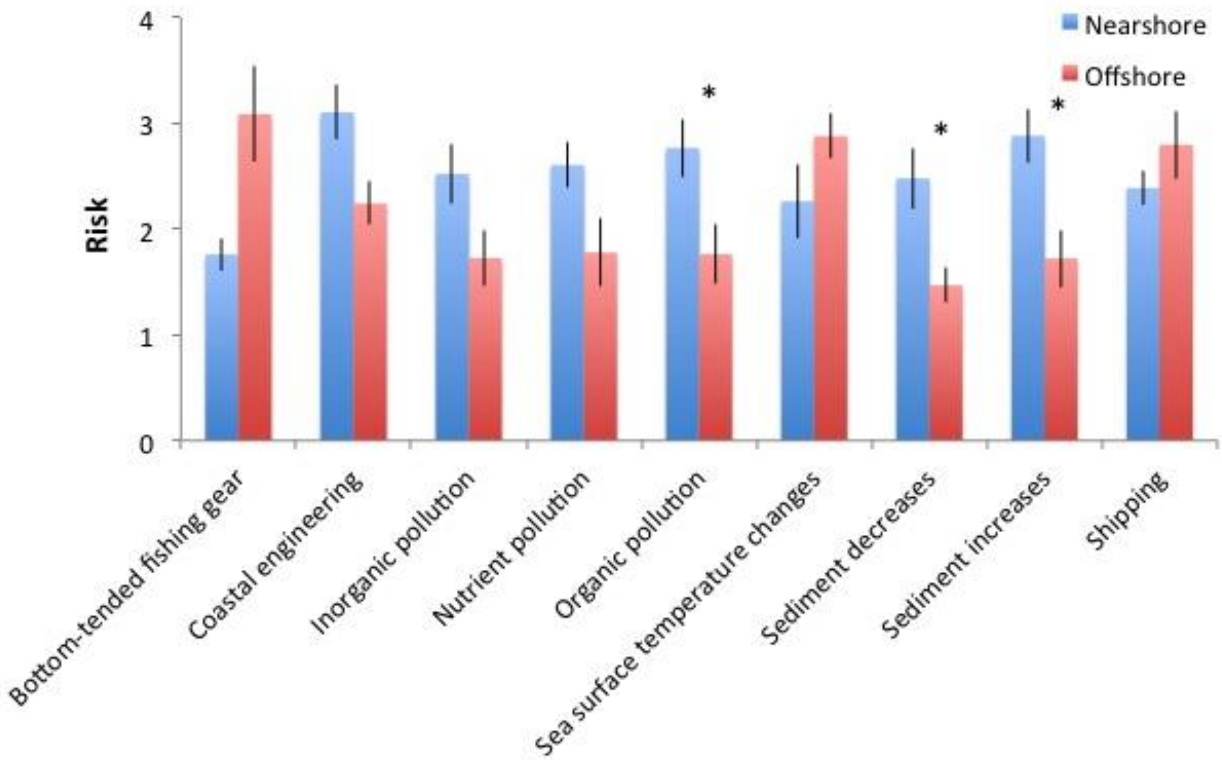


Figure EN.R.10. Average nearshore vs. offshore risk due to different activities and pressures in the Monterey Bay National Marine Sanctuary. Bars represent means ± 1SE. * indicates $p \leq 0.05$.



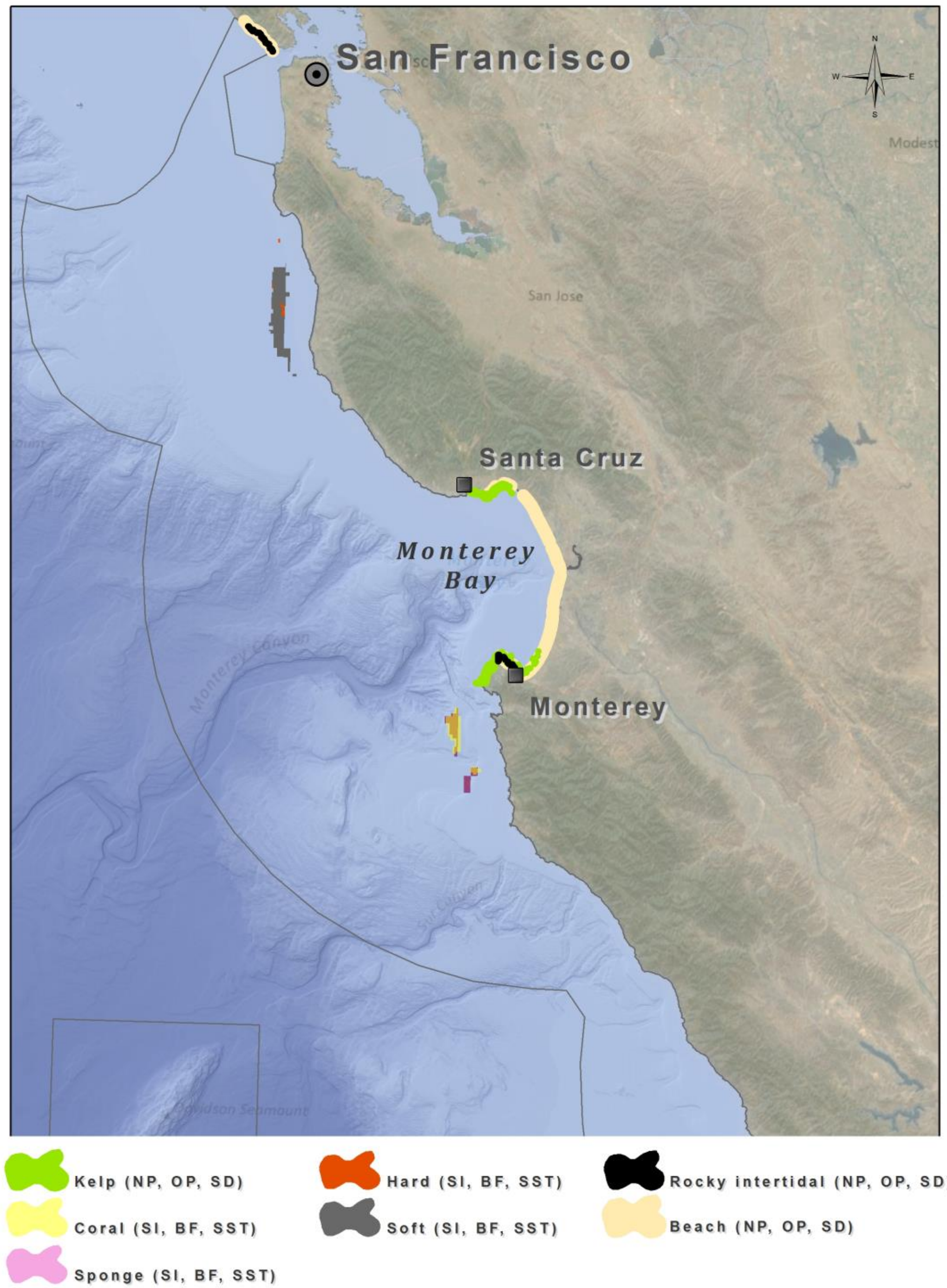


Figure EN.R.11. Map highlighting locations where habitats within MBNMS experience relatively high exposure (scores of 3-4) from three activities and pressures. For beaches, kelp forests, and the rocky intertidal, this analysis focused on nutrient pollution (NP), organic pollution (OP), and sediment decreases (SD). For hard and soft bottom habitats, including locations known to have corals and sponges, this analysis focused on bottom-tended fishing (BF), sea surface temperature changes (SST), and sediment increases (SI).

Table EN.R.5. Relative exposure, sensitivity, and risk due to different activities and pressures for each habitat.

			Relative to other pressures for each habitat		
Habitat	**Pressure**	**Land- or sea-based**	**Exposure**	**Sensitivity**	**Risk**
Beaches	Bottom-tended fishing gear	SB	n/a	n/a	n/a
Beaches	Coastal engineering	LB	1.00	3.73	2.73
Beaches	Inorganic pollution	LB	1.44	2.73	1.79
Beaches	Nutrient pollution	LB	1.98	2.33	1.65
Beaches	Organic pollution	LB	2.12	2.53	1.90
Beaches	Sea surface temperature changes	SB	2.00	1.93	1.37
Beaches	Sediment decreases	LB	2.13	3.13	2.41
Beaches	Sediment increases	LB	4.00	2.53	3.37
Beaches	Shipping	SB	2.15	2.53	1.92
Corals	Bottom-tended fishing gear	SB	1.41	3.87	2.90
Corals	Coastal engineering	LB	1.00	3.87	2.87
Corals	Inorganic pollution	LB	1.14	3.27	2.27
Corals	Nutrient pollution	LB	1.64	3.47	2.55
Corals	Organic pollution	LB	1.62	3.27	2.35
Corals	Sea surface temperature changes	SB	3.69	3.67	3.79
Corals	Sediment decreases	LB	1.79	2.67	1.84
Corals	Sediment increases	LB	3.48	3.67	3.64
Corals	Shipping	SB	4.00	3.27	3.76
Hard bottom	Bottom-tended fishing gear	SB	1.05	2.40	1.40
Hard bottom	Coastal engineering	LB	1.08	3.00	2.00
Hard bottom	Inorganic pollution	LB	1.35	2.20	1.25
Hard bottom	Nutrient pollution	LB	1.81	2.20	1.45
Hard bottom	Organic pollution	LB	1.72	2.20	1.40
Hard bottom	Sea surface temperature changes	SB	1.00	2.00	1.00
Hard bottom	Sediment decreases	LB	2.23	2.00	1.59
Hard bottom	Sediment increases	LB	3.18	2.40	2.59
Hard bottom	Shipping	SB	4.00	2.20	3.23
Kelp	Bottom-tended fishing gear	SB	1.00	3.07	2.07
Kelp	Coastal engineering	LB	1.15	3.27	2.27
Kelp	Inorganic pollution	LB	1.31	2.07	1.11
Kelp	Nutrient pollution	LB	1.70	2.27	1.44
Kelp	Organic pollution	LB	1.99	2.07	1.46
Kelp	Sea surface temperature changes	SB	2.43	2.67	2.19
Kelp	Sediment decreases	LB	1.61	1.87	1.06
Kelp	Sediment increases	LB	4.00	2.27	3.26
Kelp	Shipping	SB	2.17	2.07	1.58
Offshore pelagic	Bottom-tended fishing gear	SB	n/a	n/a	n/a

Offshore pelagic	Coastal engineering	LB	1.00	2.40	1.40
Offshore pelagic	Inorganic pollution	LB	1.00	2.00	1.00
Offshore pelagic	Nutrient pollution	LB	1.36	1.60	0.70
Offshore pelagic	Organic pollution	LB	1.32	1.80	0.86
Offshore pelagic	Sea surface temperature changes	SB	3.25	1.80	2.39
Offshore pelagic	Sediment decreases	LB	1.47	1.60	0.76
Offshore pelagic	Sediment increases	LB	2.38	1.60	1.51
Offshore pelagic	Shipping	SB	4.00	1.80	3.10
Rocky intertidal	Bottom-tended fishing gear	SB	n/a	n/a	n/a
Rocky intertidal	Coastal engineering	LB	1.00	3.60	2.60
Rocky intertidal	Inorganic pollution	LB	1.37	2.40	1.45
Rocky intertidal	Nutrient pollution	LB	1.81	2.20	1.45
Rocky intertidal	Organic pollution	LB	2.03	2.40	1.74
Rocky intertidal	Sea surface temperature changes	SB	2.75	1.80	1.92
Rocky intertidal	Sediment decreases	LB	1.68	2.20	1.38
Rocky intertidal	Sediment increases	LB	4.00	2.60	3.40
Rocky intertidal	Shipping	SB	2.06	2.40	1.76
Seamount	Bottom-tended fishing gear	SB	1.00	2.40	1.40
Seamount	Coastal engineering	LB	1.00	3.40	2.40
Seamount	Inorganic pollution	LB	1.00	2.20	1.20
Seamount	Nutrient pollution	LB	1.00	2.00	1.00
Seamount	Organic pollution	LB	1.00	2.20	1.20
Seamount	Sea surface temperature changes	SB	4.00	2.00	3.16
Seamount	Sediment decreases	LB	1.00	2.00	1.00
Seamount	Sediment increases	LB	1.32	2.40	1.44
Seamount	Shipping	SB	1.73	2.20	1.41
Soft bottom	Bottom-tended fishing gear	SB	1.25	2.93	1.95
Soft bottom	Coastal engineering	LB	1.00	2.93	1.93
Soft bottom	Inorganic pollution	LB	1.14	2.33	1.34
Soft bottom	Nutrient pollution	LB	1.42	2.33	1.40
Soft bottom	Organic pollution	LB	1.39	2.33	1.39
Soft bottom	Sea surface temperature changes	SB	3.28	2.13	2.55
Soft bottom	Sediment decreases	LB	1.53	2.33	1.43
Soft bottom	Sediment increases	LB	2.53	2.13	1.90
Soft bottom	Shipping	SB	4.00	2.33	3.28
Sponges	Bottom-tended fishing gear	SB	1.41	3.60	2.63
Sponges	Coastal engineering	LB	1.00	3.60	2.60
Sponges	Inorganic pollution	LB	1.22	3.60	2.61
Sponges	Nutrient pollution	LB	1.64	3.60	2.68
Sponges	Organic pollution	LB	1.62	3.60	2.67
Sponges	Sea surface temperature changes	SB	3.69	3.40	3.60
Sponges	Sediment decreases	LB	1.79	2.40	1.61
Sponges	Sediment increases	LB	2.72	2.80	2.49

Sponges	Shipping	SB	4.00	2.40	3.31

Table EN.R.6. Relative exposure, sensitivity, and relative risk to each habitat from different activities and pressures.

			Relative to other habitats for each pressure		
Pressure	**Habitat**	**Nearshore or offshore**	**Exposure**	**Sensitivity**	**Risk**
Bottom-tended fishing gear	Beaches	N	n/a	n/a	n/a
Bottom-tended fishing gear	Corals	O	4.00	3.87	4.15
Bottom-tended fishing gear	Hard bottom	N	1.39	2.40	1.45
Bottom-tended fishing gear	Kelp	N	1.00	3.07	2.07
Bottom-tended fishing gear	Offshore pelagic	O	n/a	n/a	n/a
Bottom-tended fishing gear	Rocky intertidal	N	n/a	n/a	n/a
Bottom-tended fishing gear	Seamount	O	1.00	2.40	1.40
Bottom-tended fishing gear	Soft bottom	O	3.06	2.93	2.82
Bottom-tended fishing gear	Sponges	O	4.00	3.60	3.97
Coastal engineering	Beaches	N	3.35	3.73	3.60
Coastal engineering	Corals	O	1.08	3.87	2.87
Coastal engineering	Hard bottom	N	1.92	3.00	2.20
Coastal engineering	Kelp	N	4.00	3.27	3.76
Coastal engineering	Offshore pelagic	O	1.01	2.40	1.40
Coastal engineering	Rocky intertidal	N	2.17	3.60	2.85

Coastal engineering	Seamount	O	1.00	3.40	2.40
Coastal engineering	Soft bottom	O	1.10	2.93	1.94
Coastal engineering	Sponges	O	1.08	3.60	2.60
Inorganic pollution	Beaches	N	4.00	2.73	3.46
Inorganic pollution	Corals	O	1.45	3.27	2.31
Inorganic pollution	Hard bottom	N	2.14	2.20	1.65
Inorganic pollution	Kelp	N	2.85	2.07	2.14
Inorganic pollution	Offshore pelagic	O	1.01	2.00	1.00
Inorganic pollution	Rocky intertidal	N	3.46	2.40	2.83
Inorganic pollution	Seamount	O	1.00	2.20	1.20
Inorganic pollution	Soft bottom	O	1.50	2.33	1.42
Inorganic pollution	Sponges	O	1.69	3.60	2.69
Nutrient pollution	Beaches	N	4.00	2.33	3.28
Nutrient pollution	Corals	O	2.05	3.47	2.68
Nutrient pollution	Hard bottom	N	2.38	2.20	1.83
Nutrient pollution	Kelp	N	3.13	2.27	2.48
Nutrient pollution	Offshore pelagic	O	1.64	1.60	0.88
Nutrient pollution	Rocky intertidal	N	3.57	2.20	2.84
Nutrient pollution	Seamount	O	1.00	2.00	1.00
Nutrient pollution	Soft bottom	O	1.75	2.33	1.53

Nutrient pollution	Sponges	O	2.05	3.60	2.80
Organic pollution	Beaches	N	4.00	2.53	3.37
Organic pollution	Corals	O	1.89	3.27	2.44
Organic pollution	Hard bottom	N	2.09	2.20	1.62
Organic pollution	Kelp	N	3.71	2.07	2.91
Organic pollution	Offshore pelagic	O	1.52	1.80	0.95
Organic pollution	Rocky intertidal	N	3.84	2.40	3.17
Organic pollution	Seamount	O	1.00	2.20	1.20
Organic pollution	Soft bottom	O	1.62	2.33	1.47
Organic pollution	Sponges	O	1.89	3.60	2.75
Sea surface temperature changes	Beaches	N	2.73	1.93	1.97
Sea surface temperature changes	Corals	O	3.45	3.67	3.62
Sea surface temperature changes	Hard bottom	N	1.00	2.00	1.00
Sea surface temperature changes	Kelp	N	3.47	2.67	2.98
Sea surface temperature changes	Offshore pelagic	O	3.28	1.80	2.41
Sea surface temperature changes	Rocky intertidal	N	4.00	1.80	3.10
Sea surface temperature changes	Seamount	O	3.18	2.00	2.40
Sea surface temperature changes	Soft bottom	O	3.27	2.13	2.54
Sea surface temperature changes	Sponges	O	3.45	3.40	3.43
Sediment decreases	Beaches	N	4.00	3.13	3.68

Sediment decreases	Corals	O	2.13	2.67	2.01
Sediment decreases	Hard bottom	N	2.84	2.00	2.10
Sediment decreases	Kelp	N	2.66	1.87	1.87
Sediment decreases	Offshore pelagic	O	1.74	1.60	0.95
Sediment decreases	Rocky intertidal	N	2.92	2.20	2.27
Sediment decreases	Seamount	O	1.00	2.00	1.00
Sediment decreases	Soft bottom	O	1.84	2.33	1.57
Sediment decreases	Sponges	O	2.13	2.40	1.80
Sediment increases	Beaches	N	3.74	2.53	3.14
Sediment increases	Corals	O	2.23	3.67	2.94
Sediment increases	Hard bottom	N	2.12	2.40	1.79
Sediment increases	Kelp	N	4.00	2.27	3.26
Sediment increases	Offshore pelagic	O	1.70	1.60	0.93
Sediment increases	Rocky intertidal	N	3.93	2.60	3.34
Sediment increases	Seamount	O	1.00	2.40	1.40
Sediment increases	Soft bottom	O	1.78	2.13	1.38
Sediment increases	Sponges	O	1.81	2.80	1.97
Shipping	Beaches	N	2.70	2.53	2.29
Shipping	Corals	O	3.63	3.27	3.47
Shipping	Hard bottom	N	3.81	2.20	3.05

Shipping	Kelp	N	2.79	2.07	2.08
Shipping	Offshore pelagic	O	4.00	1.80	3.10
Shipping	Rocky intertidal	N	2.60	2.40	2.13
Shipping	Seamount	O	1.00	2.20	1.20
Shipping	Soft bottom	O	3.94	2.33	3.23
Shipping	Sponges	O	3.63	2.40	2.98

Table EN.R.7. Scores, rationale, and references for pressure-invariant sensitivity criteria.

Habitat	Score	Data Quality	Rationale	Reference
<u>Current status</u>				
Beaches	3	4	Best available evidence suggests significant short term erosion. Though erosion is a natural process, sea level rise due to climate change and coastal armoring impede retreat of beach habitats landward.	Moore and Griggs 2002, Stamski 2005, Hapke et al. 2009
Corals	4	1	Very little information available about status; however, many feel that coral destruction is commonplace due to human activities such as bottom trawling. In addition, changes in ocean chemistry due to climate change threaten persistence.	Guinotte et al. 2006, ONMS 2009
Hard bottom	1	2	Information on status and trends is sparse; influenced by changes in sediment deposition, some burial has occurred due to landslides near Big Sur, but exhumation of nearshore hard substrate appears more common.	ONMS 2009, Storlazzi et al. 2011
Kelp	2	4	Best available evidence suggests a decline over the last 40 years statewide; harvest is permitted.	Bedford 2001
Offshore pelagic	2	2	Information on status and trends is sparse, however, water quality issues give reason for concern.	ONMS 2009
Rocky intertidal	2	2	Modest, localized impacts due to past landslide disposal in these habitats; land and ocean based warming due to climate change suggest cause for future concern.	ONMS 2009
Seamount	1	1	Considered relatively pristine and currently protected, but information on status and trends is sparse.	DeVogelaere et al. 2005
Soft bottom	2	3	Clear effects of bottom trawling and other disturbances in these habitats; influenced by changes in sediment deposition.	de Marignac et al. 2008

Sponges	3	1	Very little information available about status; however, many feel that sponge destruction is commonplace due to human activities such as bottom trawling and oil and gas development.	ONMS 2009
Replenishment rate				
Beaches	4	4	California beaches are eroding in the long-term, and in central California they are at best not changing in size.	Hapke et al. 2009
Corals	3	2	Recruitment assumed to be low and episodic like tropical scleractinian corals	Consalvey et al. 2006
Hard bottom	4	3	Hard bottom habitat replenishment occurs on geological time scales	Storlazzi et al. 2011
Kelp	1	4	Seasonal in spring and summer	Graham et al. 1997
Offshore pelagic	1	4	Water mass residence time is measured on time scales of days	Broenkow and Smethie 1978, Graham and Largier 1997
Rocky intertidal	4	4	Sediment deposition and removal depends on episodic nature of storms, but in general replenishment occurs on geological time scales of at least decades.	Storlazzi and Field 2000
Seamount	4	3	Seamount formation occurs on geological time scales.	Davis et al. 2002
Soft bottom	4	3	Soft bottom habitat replenishment occurs on geological time scales	Greene et al. 2002
Sponges	3	3	Deep-water sponge recruitment is episodic at best	Leys and Lauzon 1998
Recovery time				
Beaches	3	4	California beaches are eroding in the long-term, and in central California they are at best not changing in size.	Hapke et al. 2009
Corals	3	4	Corals are slow-growing and long-lived, and likely to recover slowly from perturbations.	Andrews et al. 2005
Hard bottom	4	3	Hard bottom habitat recovery occurs on geological time scales	Storlazzi et al. 2011
Kelp	2	4	Natural, strong disturbances due to wave action and subsequent recoveries are common and well-studied, occurring on time scales of years.	Reed et al. 2011
Offshore pelagic	1	4	Water masses are exchanged with those outside the MBNMS region on time scales of days	Broenkow and Smethie 1978, Graham and Largier 1997

Rocky intertidal	4	3	Sediment deposition and removal depends on episodic nature of storms, but in general recovery rates of rocky shores occur on geological time scales.	Storlazzi and Field 2000
Seamount	4	3	Seamount recovery occurs on geological time scales, if at all.	Davis et al. 2002
Soft bottom	3	3	Soft bottom habitat recovery occurs on geological time scales	Greene et al. 2002
Sponges	3	3	Deep-water sponges are slow-growing and long-lived, and likely to recover slowly from perturbations.	Leys and Lauzon 1998
<u>Connectivity</u>				
Beaches	4	3	Beach habitat connectivity only relevant on geological time scales	Moore and Griggs 2002, Hapke et al. 2009
Corals	4	4	Coral dispersal distances average 0.044–0.785 km	Kinlan and Gaines 2003
Hard bottom	4	3	Hard bottom habitat connectivity only relevant on geological time scales	Storlazzi et al. 2011
Kelp	4	4	*Macrocystis pyrifera* dispersal distances average 10-40m	Shanks et al. 2003
Offshore pelagic	1	4	Water mass exchange outside of the MBNMS region is on time scales of days	Broenkow and Smethie 1978, Graham and Largier 1997
Rocky intertidal	4	3	Rocky intertidal habitat connectivity only relevant on geological time scales	Storlazzi and Field 2000
Seamount	4	4	Seamount habitat connectivity not relevant	Davis et al. 2002
Soft bottom	4	3	Soft bottom habitat connectivity only relevant on geological time scales	Greene et al. 2002
Sponges	3	4	Coral dispersal distances average 1-4 km	Kinlan and Gaines 2003

Table EN.R.8. Scores, rationale, and references for the pressure-specific sensitivity criteria, change in area.

				Change in area	
Habitat	**Pressure**	**Score**	**Data Quality Score**	**Rationale**	**Reference**
Beaches	Bottom-tended fishing gear	N/A	N/A	N/A	N/A
Beaches	Coastal engineering	4	4	Coastal engineering prevents landward retreat of beaches	Stamski 2005
Beaches	Inorganic pollution	1	1	Pollutants would not have effects on beach area	N/A
Beaches	Nutrient pollution	1	1	Pollutants would not have effects on beach area	N/A
Beaches	Organic pollution	1	1	Pollutants would not have effects on beach area	N/A
Beaches	Sea surface temperature changes	1	1	No known effect of sea surface temperatures on areal extent of beaches	N/A
Beaches	Sediment decreases	4	4	Reduction in sediment loads to beaches would reduce areal extent	Willis and Griggs 2003
Beaches	Sediment increases	4	4	Increase in sediment loads to beaches would increase areal extent	Willis and Griggs 2003
Beaches	Shipping	1	1	Shipping-associated pollutants would not have effects on beach area	N/A
Corals	Bottom-tended fishing gear	4	4	Bottom-tended fishing gear would significantly reduce areal extent of corals	Whitmire and Clarke 2007
Corals	Coastal engineering	4	2	Coastal engineering would directly reduce the areal extent of habitat-forming corals	Stamski 2005

Corals	Inorganic pollution	4	2	Pollutants can significantly reduce area of tropical corals by increasing mortality	Fabricius 2005
Corals	Nutrient pollution	4	2	Pollutants can significantly reduce area of tropical corals by increasing disease prevalence and associated mortality	Bruno et al. 2003
Corals	Organic pollution	4	2	Pollutants can significantly reduce area of tropical corals by increasing mortality	Firman 1995
Corals	Sea surface temperature changes	4	2	Sea surface temperature increases could influence coral calcification rates, physiology, and biochemistry, and enhance mortality	Guinotte et al. 2006
Corals	Sediment decreases	1	2	Reduction in sediment loads to corals may increase areal extent	Fabricius 2005
Corals	Sediment increases	3	2	Increase in sediment loads to corals may reduce areal extent	Fabricius 2005
Corals	Shipping	4	2	Shipping-associated pollutants can significantly reduce area of tropical corals by increasing mortality	Fabricius 2005
Hard bottom	Bottom-tended fishing gear	1	2	No known effect of bottom-tended fishing gear on areal extent of hard bottom habitats	Auster 1998, Turner et al. 1999
Hard bottom	Coastal engineering	4	4	Coastal engineering would significantly modify the areal extent of hard bottom habitat	Stamski 2005
Hard bottom	Inorganic pollution	1	1	Pollutants would not have effects on hard bottom habitat area	N/A
Hard bottom	Nutrient pollution	1	1	Pollutants would not have effects on hard bottom habitat area	N/A
Hard bottom	Organic pollution	1	1	Pollutants would not have effects on hard bottom habitat area	N/A

Hard bottom	Sea surface temperature changes	1	1	No known effect of sea surface temperatures on areal extent of hard bottom habitats	N/A
Hard bottom	Sediment decreases	1	4	Reduction in sediment loads to hard bottom habitat may increase areal extent	Storlazzi and Field 2000, Storlazzi et al. 2011
Hard bottom	Sediment increases	2	4	Increase in sediment loads to hard bottom habitat may reduce areal extent	Storlazzi and Field 2000, Storlazzi et al. 2011
Hard bottom	Shipping	1	1	Shipping-associated pollutants would not have effects on hard bottom habitat area	N/A
Kelp	Bottom-tended fishing gear	4	2	Bottom-tended fishing gear would significantly reduce areal extent of kelp forests	Auster 1998, Turner et al. 1999
Kelp	Coastal engineering	4	2	Coastal engineering would reduce the areal extent of kelp forests	Stamski 2005
Kelp	Inorganic pollution	1	1	Pollutants would not have effects on kelp forest area	N/A
Kelp	Nutrient pollution	2	4	Pollutants (eutrophication) could significantly reduce kelp forest area, though seasonal upwelling and nutrient-rich waters are common in the MBNMS	Zimmerman and Kremer 1984, Dayton 1985, Cloern 2001
Kelp	Organic pollution	1	1	Pollutants would not have effects on kelp forest area	N/A
Kelp	Sea surface temperature changes	4	4	Sea surface temperature increases could increase kelp mortality	Dayton et al. 1992, Graham et al. 2007
Kelp	Sediment decreases	1	3	Reduction in sediment loads to kelp forests may increase areal extent	Reed et al. 1988
Kelp	Sediment increases	2	3	Increase in sediment loads to kelp forests may reduce areal extent	Reed et al. 1988
Kelp	Shipping	1	1	Shipping-associated pollutants would not have effects on kelp forest area	N/A

Offshore pelagic	Bottom-tended fishing gear	N/A	N/A	N/A	N/A
Offshore pelagic	Coastal engineering	1	1	Coastal engineering would not reduce the areal extent of offshore pelagic habitat significantly	N/A
Offshore pelagic	Inorganic pollution	1	1	Pollution would not reduce the areal extent of offshore pelagic habitat significantly	N/A
Offshore pelagic	Nutrient pollution	1	1	Pollution would not reduce the areal extent of offshore pelagic habitat significantly	N/A
Offshore pelagic	Organic pollution	1	1	Pollution would not reduce the areal extent of offshore pelagic habitat significantly	N/A
Offshore pelagic	Sea surface temperature changes	1	1	Sea surface temperature changes would not reduce the areal extent of offshore pelagic habitat significantly	N/A
Offshore pelagic	Sediment decreases	1	1	Sediment decreases would not reduce the areal extent of offshore pelagic habitat significantly	N/A
Offshore pelagic	Sediment increases	1	1	Sediment increases would not reduce the areal extent of offshore pelagic habitat significantly	N/A
Offshore pelagic	Shipping	1	1	Shipping-associated pollutants would not reduce the areal extent of offshore pelagic habitat significantly	N/A
Rocky intertidal	Bottom-tended fishing gear	N/A	N/A	N/A	N/A
Rocky intertidal	Coastal engineering	4	4	Coastal engineering would directly reduce the areal extent of rocky intertidal habitat	Stamski 2005

Rocky intertidal	Inorganic pollution	1	1	Pollutants would not have effects on rocky intertidal habitat area	N/A
Rocky intertidal	Nutrient pollution	1	1	Pollutants would not have effects on rocky intertidal habitat area	N/A
Rocky intertidal	Organic pollution	1	1	Pollutants would not have effects on rocky intertidal habitat area	N/A
Rocky intertidal	Sea surface temperature changes	1	1	No known effect of sea surface temperatures on areal extent of rocky intertidal habitats	N/A
Rocky intertidal	Sediment decreases	1	4	Reduction in sediment loads to rocky intertidal habitat may increase areal extent	Storlazzi and Field 2000
Rocky intertidal	Sediment increases	2	4	Increase in sediment loads to rocky intertidal habitat may reduce areal extent	Storlazzi and Field 2000
Rocky intertidal	Shipping	1	1	Shipping-associated pollutants would not have effects on rocky intertidal habitat area	N/A
Seamount	Bottom-tended fishing gear	1	1	No known effect of bottom-tended fishing gear on areal extent of seamount habitats	Auster 1998, Turner et al. 1999, Whitmire and Clarke 2007
Seamount	Coastal engineering	4	2	Coastal engineering would directly reduce the areal extent of seamount habitat	Stamski 2005
Seamount	Inorganic pollution	1	1	Pollutants would not have effects on seamount habitat area	N/A
Seamount	Nutrient pollution	1	1	Pollutants would not have effects on seamount habitat area	N/A
Seamount	Organic pollution	1	1	Pollutants would not have effects on seamount habitat area	N/A
Seamount	Sea surface temperature changes	1	1	No known effect of sea surface temperatures on areal extent of seamount habitats	N/A

Seamount	Sediment decreases	1	4	Reduction in sediment loads to seamount habitat may increase areal extent	Menard 1955
Seamount	Sediment increases	2	4	Increase in sediment loads to seamount habitat may reduce areal extent	Menard 1955
Seamount	Shipping	1	1	Shipping-associated pollutants would not have effects on seamount habitat area	N/A
Soft bottom	Bottom-tended fishing gear	1	2	No known effect of bottom-tended fishing gear on areal extent of soft bottom habitats	Auster 1998, Turner et al. 1999
Soft bottom	Coastal engineering	4	2	Coastal engineering would directly reduce the areal extent of soft bottom habitat	Stamski 2005
Soft bottom	Inorganic pollution	1	1	Pollutants would not have effects on soft bottom habitat area	N/A
Soft bottom	Nutrient pollution	1	1	Pollutants would not have effects on soft bottom habitat area	N/A
Soft bottom	Organic pollution	1	1	Pollutants would not have effects on soft bottom habitat area	N/A
Soft bottom	Sea surface temperature changes	1	1	No known effect of sea surface temperatures on areal extent of soft bottom habitats	N/A
Soft bottom	Sediment decreases	2	4	Reduction in sediment loads to soft bottom habitat would reduce areal extent	Menard 1955, Greene et al. 2002
Soft bottom	Sediment increases	1	4	Increase in sediment loads to soft bottom habitat would increase areal extent	Menard 1955, Greene et al. 2002
Soft bottom	Shipping	1	1	Shipping-associated pollutants would not have effects on soft bottom habitat area	N/A
Sponges	Bottom-tended fishing gear	4	4	Bottom-tended fishing gear would reduce the areal extent of habitat-forming sponges	Auster 1998, Turner et al. 1999, Whitmire and Clarke 2007

Sponges	Coastal engineering	4	2	Coastal engineering would reduce the areal extent of habitat-forming sponges	Stamski 2005
Sponges	Inorganic pollution	4	2	Pollutants can significantly reduce area of sponge habitat by increasing mortality via disease	Webster 2007
Sponges	Nutrient pollution	4	2	Pollutants can significantly reduce area of sponge habitat by increasing mortality via disease	Webster 2007
Sponges	Organic pollution	4	2	Pollutants can significantly reduce area of sponge habitat by increasing mortality via disease	Webster 2007
Sponges	Sea surface temperature changes	4	2	Sea surface temperature increases could increase mortality of habitat-forming sponges directly or indirectly (via Vibrio virulence)	Olsvig-Whittaker 2010
Sponges	Sediment decreases	1	2	Reduction in sediment loads to habitat-forming sponges may increase areal extent	Airoldi 2003
Sponges	Sediment increases	2	2	Increase in sediment loads to habitat-forming sponges may reduce areal extent	Airoldi 2003
Sponges	Shipping	1	1	Shipping-associated pollutants would not have effects on areal extent of habitat-forming sponges	N/A

Table EN.R.9. Scores, rationale, and references for the pressure-specific sensitivity criteria, change in structure.

		Change in structure			
Habitat	**Pressure**	**Score**	**Data Quality Score**	**Rationale**	**Reference**
Beaches	Bottom-tended fishing gear	N/A	N/A	N/A	N/A
Beaches	Coastal engineering	4	4	Coastal engineering (armoring) significantly modifies beach structure	Stamski 2005
Beaches	Inorganic pollution	2	2	Some pollutants (e.g., plastics) can modify beach structure	Defeo et al. 2009
Beaches	Nutrient pollution	1	1	Pollutants would not have effects on beach structure	N/A
Beaches	Organic pollution	1	1	Pollutants would not have effects on beach structure	N/A
Beaches	Sea surface temperature changes	1	1	No known effect of sea surface temperatures on structure of beaches	N/A
Beaches	Sediment decreases	4	4	Reduction in sediment loads to beaches would modify structure	Willis and Griggs 2003
Beaches	Sediment increases	1	4	Increase in sediment loads to beaches would not modify structure (rugosity)	Willis and Griggs 2003
Beaches	Shipping	1	1	Shipping-associated pollutants would not have effects on structure	N/A
Corals	Bottom-tended fishing gear	4	4	Bottom-tended fishing gear would significantly damage coral structure	Whitmire and Clarke 2007
Corals	Coastal engineering	4	2	Coastal engineering would damage the structure of habitat-forming corals significantly	Stamski 2005
Corals	Inorganic pollution	1	1	Pollutants would not have effects on coral structure	N/A
Corals	Nutrient pollution	2	2	Pollutants (eutrophication) could cause reductions in coral structural complexity (rugosity)	Miller and Hay 1996
Corals	Organic pollution	1	1	Pollutants would not have effects on coral structure	N/A

Corals	Sea surface temperature changes	4	2	Sea surface temperature increases could influence coral calcification rates, physiology, and biochemistry, and enhance mortality	Guinotte et al. 2006
Corals	Sediment decreases	1	2	Reduction in sediment loads to corals would not modify or perhaps enhance structural complexity (rugosity)	Roberts et al. 2006
Corals	Sediment increases	4	2	Excessive increase in sediment loads to corals would reduce structural complexity (rugosity)	Roberts et al. 2006
Corals	Shipping	1	1	Shipping-associated pollutants would not have effects on structure	N/A
Hard bottom	Bottom-tended fishing gear	2	2	Modest effects of bottom-tended fishing gear on structure of hard bottom habitats	Auster 1998, Turner et al. 1999
Hard bottom	Coastal engineering	2	2	Coastal engineering could modify the structural complexity (rugosity) of hard bottom habitat, increasing it on pavement and reducing it on rocky substrate	Stamski 2005
Hard bottom	Inorganic pollution	1	1	Pollutants would not have effects on hard bottom habitat structure	N/A
Hard bottom	Nutrient pollution	1	1	Pollutants would not have effects on hard bottom habitat structure	N/A
Hard bottom	Organic pollution	1	1	Pollutants would not have effects on hard bottom habitat structure	N/A
Hard bottom	Sea surface temperature changes	1	1	No known effect of sea surface temperatures on structure of hard bottom habitats	N/A
Hard bottom	Sediment decreases	1	4	Reduction in sediment loads to hard bottom habitat would not modify or perhaps enhance structural complexity (rugosity)	Airoldi 2003, Storlazzi et al. 2011
Hard bottom	Sediment increases	2	4	Increase in sediment loads to hard bottom habitat would reduce structural complexity (rugosity)	Storlazzi and Field 2000, Storlazzi et al. 2011
Hard bottom	Shipping	1	1	Shipping-associated pollutants would not have effects on hard bottom habitat structure	N/A
Kelp	Bottom-tended fishing gear	4	2	Bottom-tended fishing gear would significantly reduce structural complexity (rugosity) of kelp forests	Auster 1998, Turner et al. 1999

Kelp	Coastal engineering	4	2	Coastal engineering would significantly damage kelp forests	Stamski 2005
Kelp	Inorganic pollution	1	1	Pollutants would not have effects on kelp forest structure	N/A
Kelp	Nutrient pollution	2	4	Pollutants (eutrophication) would initially enhance and eventually significantly reduce kelp structural complexity (rugosity); seasonal upwelling and nutrient-rich waters are common in the MBNMS	Zimmerman and Kremer 1984, Dayton 1985, Cloern 2001
Kelp	Organic pollution	1	1	Pollutants would not have effects on kelp forest structure	N/A
Kelp	Sea surface temperature changes	4	4	Sea surface temperature increases could increase kelp mortality	Dayton et al. 1992, Graham et al. 2007
Kelp	Sediment decreases	1	3	Reduction in sediment loads to kelp forests would not modify or perhaps enhance structural complexity (rugosity)	Reed et al. 1988
Kelp	Sediment increases	2	3	Increase in sediment loads to kelp forests would reduce structural complexity (rugosity)	Reed et al. 1988
Kelp	Shipping	1	1	Shipping-associated pollutants would not have effects on kelp forest habitat structure	N/A
Offshore pelagic	Bottom-tended fishing gear	N/A	N/A	N/A	N/A
Offshore pelagic	Coastal engineering	4	2	Coastal engineering would significantly modify the structure of offshore pelagic habitat significantly	Stamski 2005
Offshore pelagic	Inorganic pollution	2	3	Some pollutants (e.g., plastics) can modify offshore pelagic structure	Thompson et al. 2004
Offshore pelagic	Nutrient pollution	1	1	Pollution would not reduce the structure of offshore pelagic habitat significantly	N/A
Offshore pelagic	Organic pollution	1	1	Pollution would not reduce the structure of offshore pelagic habitat significantly	N/A
Offshore pelagic	Sea surface temperature changes	4	4	Sea surface temperature changes would significantly modify the structure of water masses and physical forcing in offshore pelagic habitat	Di Lorenzo et al. 2005
Offshore pelagic	Sediment decreases	1	1	Sediment decreases would not reduce the structure of offshore pelagic habitat significantly	N/A

Offshore pelagic	Sediment increases	1	1	Sediment increases would not reduce the structure of offshore pelagic habitat significantly	N/A
Offshore pelagic	Shipping	1	1	Shipping-associated pollutants would not modify the structure of offshore pelagic habitat significantly	N/A
Rocky intertidal	Bottom-tended fishing gear	N/A	N/A	N/A	N/A
Rocky intertidal	Coastal engineering	4	4	Depending on the type of coastal engineering, it could enhance or reduce the structural complexity (rugosity) of rocky intertidal habitat	Stamski 2005
Rocky intertidal	Inorganic pollution	1	1	Pollutants would not have effects on rocky intertidal habitat structure	N/A
Rocky intertidal	Nutrient pollution	1	1	Pollutants would not have effects on rocky intertidal habitat structure	N/A
Rocky intertidal	Organic pollution	1	1	Pollutants would not have effects on rocky intertidal habitat structure	N/A
Rocky intertidal	Sea surface temperature changes	1	1	No known effect of sea surface temperatures on structure of rocky intertidal habitats	N/A
Rocky intertidal	Sediment decreases	1	4	Reduction in sediment loads to rocky intertidal habitat would not modify or perhaps enhance structural complexity (rugosity)	Storlazzi and Field 2000
Rocky intertidal	Sediment increases	2	4	Increase in sediment loads to rocky intertidal habitat would reduce structural complexity (rugosity)	Storlazzi and Field 2000
Rocky intertidal	Shipping	1	1	Shipping-associated pollutants would not have effects on rocky intertidal habitat structure	N/A
Seamount	Bottom-tended fishing gear	2	1	Modest effects of bottom-tended fishing gear on structure of seamount habitats	Auster 1998, Turner et al. 1999, Whitmire and Clarke 2007
Seamount	Coastal engineering	4	2	Coastal engineering could alter the structural complexity (rugosity) of seamount habitat	Stamski 2005
Seamount	Inorganic pollution	1	1	Pollutants would not have effects on seamount habitat structure	N/A
Seamount	Nutrient pollution	1	1	Pollutants would not have effects on seamount habitat structure	N/A

Seamount	Organic pollution	1	1	Pollutants would not have effects on seamount habitat structure	N/A
Seamount	Sea surface temperature changes	1	1	No known effect of sea surface temperatures on structure of seamount habitats	N/A
Seamount	Sediment decreases	1	2	Reduction in sediment loads to seamount habitat would not modify or perhaps enhance structural complexity (rugosity)	Tittensor et al. 2009
Seamount	Sediment increases	2	2	Increase in sediment loads to seamount habitat would reduce structural complexity (rugosity)	Tittensor et al. 2009
Seamount	Shipping	1	1	Shipping-associated pollutants would not have effects on seamount habitat structure	N/A
Soft bottom	Bottom-tended fishing gear	4	4	Bottom-tended fishing gear significantly modifies the structure of soft bottom habitats	Engel and Kvitek 1998
Soft bottom	Coastal engineering	1	2	Coastal engineering would increase the structural complexity (rugosity) of soft bottom habitat	Stamski 2005
Soft bottom	Inorganic pollution	1	1	Pollutants would not have effects on soft bottom habitat structure	N/A
Soft bottom	Nutrient pollution	1	1	Pollutants would not have effects on soft bottom habitat structure	N/A
Soft bottom	Organic pollution	1	1	Pollutants would not have effects on soft bottom habitat structure	N/A
Soft bottom	Sea surface temperature changes	1	1	No known effect of sea surface temperatures on structure of soft bottom habitats	N/A
Soft bottom	Sediment decreases	1	4	Reduction in sediment loads to soft bottom habitat would not modify or perhaps enhance structural complexity (rugosity)	Menard 1955, Greene et al. 2002
Soft bottom	Sediment increases	1	4	Increase in sediment loads to soft bottom habitat would not modify structural complexity (rugosity)	Menard 1955, Greene et al. 2002
Soft bottom	Shipping	1	1	Shipping-associated pollutants would not have effects on soft bottom habitat structure	N/A
Sponges	Bottom-tended fishing gear	4	4	Bottom-tended fishing gear would significantly reduce structural complexity (rugosity) of habitat-forming sponges	Auster 1998, Turner et al. 1999, Whitmire and Clarke 2007

Sponges	Coastal engineering	4	2	Coastal engineering would significantly damage habitat-forming sponges	Stamski 2005
Sponges	Inorganic pollution	4	2	Pollutants can significantly reduce structural complexity of sponge habitat by increasing mortality via disease	Webster 2007
Sponges	Nutrient pollution	4	2	Pollutants can significantly reduce structural complexity of sponge habitat by increasing mortality via disease	Webster 2007
Sponges	Organic pollution	4	2	Pollutants can significantly reduce structural complexity of sponge habitat by increasing mortality via disease	Webster 2007
Sponges	Sea surface temperature changes	4	2	Sea surface temperature increases could increase mortality of habitat-forming sponges directly or indirectly (via Vibrio virulence)	Olsvig-Whittaker 2010
Sponges	Sediment decreases	1	2	Reduction in sediment loads to habitat-forming sponges would not modify or perhaps enhance structural complexity (rugosity)	Airoldi 2003
Sponges	Sediment increases	2	2	Increase in sediment loads to habitat-forming sponges would reduce structural complexity (rugosity)	Airoldi 2003
Sponges	Shipping	1	1	Shipping-associated pollutants would not have effects on structure of habitat-forming sponges	N/A

Table EN.R.10. Scores, rationale, and references for the pressure-specific sensitivity criteria, frequency of natural disturbance.

Habitat	Pressure	Frequency of natural disturbance Score	Data Quality Score	Rationale	Reference
Beaches	Bottom-tended fishing gear	N/A	N/A	N/A	N/A
Beaches	Coastal engineering	4	4	Coastal engineering is a completely artificial occurrence, except in cases of major seismic activity on geological time scales	Stamski 2005
Beaches	Inorganic pollution	4	2	High concentrations of inorganic pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Beaches	Nutrient pollution	3	4	Seasonal coastal upwelling introduces high nutrient concentrations	Huyer 1983
Beaches	Organic pollution	4	2	High concentrations of organic pollutants (pesticides) are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Beaches	Sea surface temperature changes	1	2	Periodic warming and cooling of sea surface temperatures is characteristic of the California Current ecosystem (e.g., ENSO)	Bograd and Lynn 2001
Beaches	Sediment decreases	1	4	Variable sediment dynamics are a natural process	Willis and Griggs 2003
Beaches	Sediment increases	1	4	Variable sediment dynamics are a natural process	Willis and Griggs 2003
Beaches	Shipping	4	2	High concentrations of pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Corals	Bottom-tended fishing gear	4	1	There is no natural analog to bottom-tended fishing gear in coral habitat	N/A
Corals	Coastal engineering	4	4	Coastal engineering is a completely artificial occurrence, except in cases of major seismic activity on geological time scales	Stamski 2005
Corals	Inorganic pollution	4	2	High concentrations of inorganic pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Corals	Nutrient pollution	4	4	Seasonal coastal upwelling introduces high nutrient concentrations in shallow waters,	Pilskaln et al. 1996

				but these effects attenuate at deeper depths	
Corals	Organic pollution	4	2	High concentrations of organic pollutants (pesticides) are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Corals	Sea surface temperature changes	3	4	Seasonal variability in temperature is modest in sub-surface waters off of MBNMS	Lynn and Simpson 1987
Corals	Sediment decreases	4	2	Sediment increases and decreases occur naturally but at much slower rates than anthropogenically forced sediment dynamics	Roberts et al. 2006
Corals	Sediment increases	4	2	Sediment increases and decreases occur naturally but at much slower rates than anthropogenically forced sediment dynamics	Roberts et al. 2006
Corals	Shipping	4	2	High concentrations of pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Hard bottom	Bottom-tended fishing gear	4	1	There is no natural analog to bottom-tended fishing gear in hard bottom habitat	N/A
Hard bottom	Coastal engineering	4	4	Coastal engineering is a completely artificial occurrence, except in cases of major seismic activity on geological time scales	Stamski 2005
Hard bottom	Inorganic pollution	4	2	High concentrations of inorganic pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Hard bottom	Nutrient pollution	4	4	Seasonal coastal upwelling introduces high nutrient concentrations in shallow waters, but these effects attenuate at deeper depths	Pilskaln et al. 1996
Hard bottom	Organic pollution	4	2	High concentrations of organic pollutants (pesticides) are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Hard bottom	Sea surface temperature changes	3	4	Seasonal variability in temperature is modest in sub-surface waters off of MBNMS	Lynn and Simpson 1987
Hard bottom	Sediment decreases	3	4	Sediment increases and decreases occur naturally but at much slower rates than anthropogenically forced sediment dynamics	Storlazzi et al. 2011

Hard bottom	Sediment increases	3	4	Sediment increases and decreases occur naturally but at much slower rates than anthropogenically forced sediment dynamics	Storlazzi et al. 2011
Hard bottom	Shipping	4	2	High concentrations of pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Kelp	Bottom-tended fishing gear	3	4	The only natural analog to effects from bottom-tended fishing is storms, but the impacts of storms on the benthos are more transient	Dayton et al. 1992, Reed et al. 2011
Kelp	Coastal engineering	4	4	Coastal engineering is a completely artificial occurrence, and has no natural analog except on geological time scales	Graham et al. 2003
Kelp	Inorganic pollution	4	2	High concentrations of inorganic pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Kelp	Nutrient pollution	3	4	Seasonal coastal upwelling introduces high nutrient concentrations	Huyer 1983
Kelp	Organic pollution	4	2	High concentrations of organic pollutants (pesticides) are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Kelp	Sea surface temperature changes	1	3	Kelp is highly accustomed to sea surface temperature variation through space and time	Jackson 1977
Kelp	Sediment decreases	3	3	Kelp forests are characterized by episodic delivery and removal of sediments via storms	Reed et al. 1988
Kelp	Sediment increases	3	3	Kelp forests are characterized by episodic delivery and removal of sediments via storms	Reed et al. 1988
Kelp	Shipping	4	2	High concentrations of pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Offshore pelagic	Bottom-tended fishing gear	N/A	N/A	N/A	N/A
Offshore pelagic	Coastal engineering	4	4	Coastal engineering is a completely artificial occurrence, and has no natural analog	Stamski 2005
Offshore pelagic	Inorganic pollution	4	2	High concentrations of inorganic pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004

Offshore pelagic	Nutrient pollution	3	4	Seasonal coastal upwelling introduces high nutrient concentrations	Huyer 1983
Offshore pelagic	Organic pollution	4	2	High concentrations of organic pollutants (pesticides) are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Offshore pelagic	Sea surface temperature changes	1	2	Periodic warming and cooling of sea surface temperatures is characteristic of the California Current ecosystem (e.g., ENSO)	Bograd and Lynn 2001
Offshore pelagic	Sediment decreases	3	4	Sediment increases and decreases occur naturally but at much slower rates than anthropogenically forced sediment dynamics	Pilskaln et al. 1998
Offshore pelagic	Sediment increases	3	4	Sediment increases and decreases occur naturally but at much slower rates than anthropogenically forced sediment dynamics	Pilskaln et al. 1998
Offshore pelagic	Shipping	4	2	High concentrations of pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Rocky intertidal	Bottom-tended fishing gear	N/A	N/A	N/A	N/A
Rocky intertidal	Coastal engineering	4	4	Coastal engineering is a completely artificial occurrence, except in cases of major seismic activity on geological time scales	Stamski 2005
Rocky intertidal	Inorganic pollution	4	2	High concentrations of inorganic pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Rocky intertidal	Nutrient pollution	3	4	Seasonal coastal upwelling introduces high nutrient concentrations	Huyer 1983
Rocky intertidal	Organic pollution	4	2	High concentrations of organic pollutants (pesticides) are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Rocky intertidal	Sea surface temperature changes	1	2	Rocky intertidal habitats are characterized by exposure to high variability in sea surface temperatures	Helmuth et al. 2002
Rocky intertidal	Sediment decreases	3	4	Sediment increases and decreases occur naturally but at much slower rates than anthropogenically forced sediment dynamics	Storlazzi and Field 2000

Rocky intertidal	Sediment increases	3	4	Sediment increases and decreases occur naturally but at much slower rates than anthropogenically forced sediment dynamics	Storlazzi and Field 2000
Rocky intertidal	Shipping	4	2	High concentrations of pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Seamount	Bottom-tended fishing gear	4	1	There is no natural analog to bottom-tended fishing gear in seamount habitat	N/A
Seamount	Coastal engineering	4	4	Coastal engineering is a completely artificial occurrence, except in cases of major seismic activity on geological time scales	Stamski 2005
Seamount	Inorganic pollution	4	2	High concentrations of inorganic pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Seamount	Nutrient pollution	3	4	Seasonal coastal upwelling introduces high nutrient concentrations	Huyer 1983
Seamount	Organic pollution	4	2	High concentrations of organic pollutants (pesticides) are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Seamount	Sea surface temperature changes	3	4	Seasonal variability in temperature is modest in sub-surface waters off of MBNMS	Lynn and Simpson 1987
Seamount	Sediment decreases	3	4	Monterey deep-sea fan drives sediment dynamics on Davidson seamount, but anthropogenic sediment dynamics are much faster	Menard 1955
Seamount	Sediment increases	3	4	Monterey deep-sea fan drives sediment dynamics on Davidson seamount, but anthropogenic sediment dynamics are much faster	Menard 1955
Seamount	Shipping	4	2	High concentrations of pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Soft bottom	Bottom-tended fishing gear	4	1	There is no natural analog to bottom-tended fishing gear in soft bottom habitat	N/A
Soft bottom	Coastal engineering	4	4	Coastal engineering is a completely artificial occurrence, except in cases of major seismic activity on geological time scales	Stamski 2005
Soft bottom	Inorganic pollution	4	2	High concentrations of inorganic pollutants are almost exclusively a	Islam and Tanaka 2004

				result of anthropogenic activities	
Soft bottom	Nutrient pollution	4	4	Seasonal coastal upwelling introduces high nutrient concentrations in shallow waters, but these effects attenuate at deeper depths	Pilskaln et al. 1996
Soft bottom	Organic pollution	4	2	High concentrations of organic pollutants (pesticides) are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Soft bottom	Sea surface temperature changes	3	4	Seasonal variability in temperature is modest in sub-surface waters off of MBNMS	Lynn and Simpson 1987
Soft bottom	Sediment decreases	3	4	Monterey deep-sea fan drives sediment dynamics in large tracts of soft bottom habitat, but anthropogenic sediment dynamics are much faster	Menard 1955
Soft bottom	Sediment increases	3	4	Monterey deep-sea fan drives sediment dynamics in large tracts of soft bottom habitat, but anthropogenic sediment dynamics are much faster	Menard 1955
Soft bottom	Shipping	4	2	High concentrations of pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Sponges	Bottom-tended fishing gear	4	1	There is no natural analog to bottom-tended fishing gear in sponge habitat	N/A
Sponges	Coastal engineering	4	4	Coastal engineering is a completely artificial occurrence, except in cases of major seismic activity on geological time scales	Stamski 2005
Sponges	Inorganic pollution	4	2	High concentrations of inorganic pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Sponges	Nutrient pollution	4	4	Seasonal coastal upwelling introduces high nutrient concentrations in shallow waters, but these effects attenuate at deeper depths	Pilskaln et al. 1996
Sponges	Organic pollution	4	2	High concentrations of organic pollutants (pesticides) are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004
Sponges	Sea surface temperature changes	3	4	Seasonal variability in temperature is modest in sub-surface waters off	Lynn and Simpson 1987

				of MBNMS	
Sponges	Sediment decreases	4	2	Sediment increases and decreases occur naturally but at much slower rates than anthropogenically forced sediment dynamics	Roberts et al. 2006
Sponges	Sediment increases	4	2	Sediment increases and decreases occur naturally but at much slower rates than anthropogenically forced sediment dynamics	Roberts et al. 2006
Sponges	Shipping	4	2	High concentrations of pollutants are almost exclusively a result of anthropogenic activities	Islam and Tanaka 2004

EXPERT-BASED RISK ASSESSMENT

We distributed the risk survey to 43 people associated with the MBNMS Research Activity Panel, and of those, 28 provided comprehensive responses. At the broadest level, the survey responses suggested that the current status of habitats in the MBNMS is considered to be fair to good (Fig. EN.R.12). They also implied that coastal pollution and bottom-tended fishing ranked among the top pressures in the region (Fig. EN.R.13), out of a set of nine that were queried (coastal pollution, bottom-tended fishing, ocean warming, aquaculture, invasive species, marine debris, ocean acidification, ocean-based pollution, coastal engineering).

Closer inspection of responses to detailed questions about risk due to coastal pollution and bottom-tended fishing confirmed that risk to habitats due to bottom-tended fishing was considered comparable to risk due to coastal pollution (Figs. EN.R.14-19). This outcome is the result of experts generally perceiving both greater exposure (Figs. EN.R.15, 17) and greater sensitivity (Figs. EN.R.16, 18) of habitats to coastal pollution as compared to bottom-tended fishing. Experts tended to be somewhat more uncertain regarding their coastal pollution responses compared with their bottom-tended fishing responses (Fig. EN.R.19).

Figure EN.R.12. Expert-based assessment of the current status of habitats in the MBNMS.

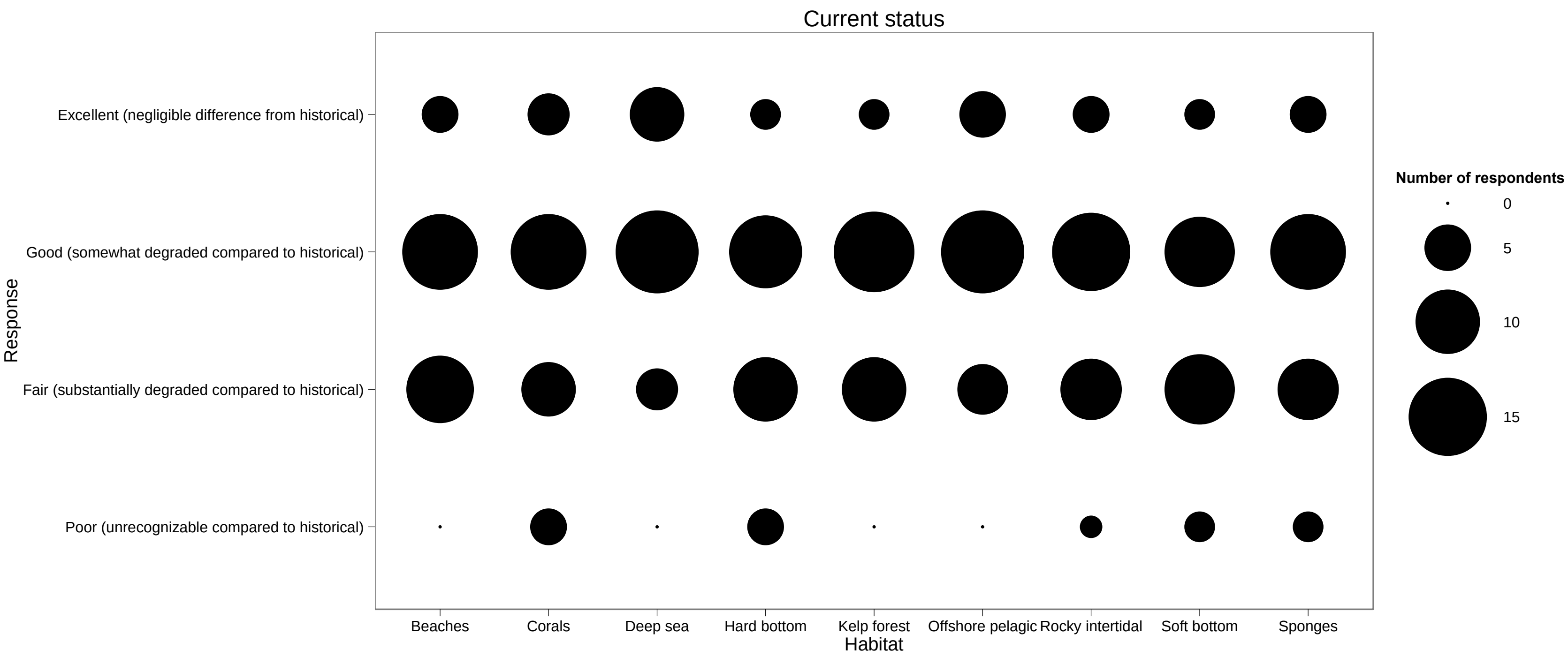


Figure EN.R.13. Expert-based assessment of the relative intensity of different activities and pressures throughout the MBNMS.

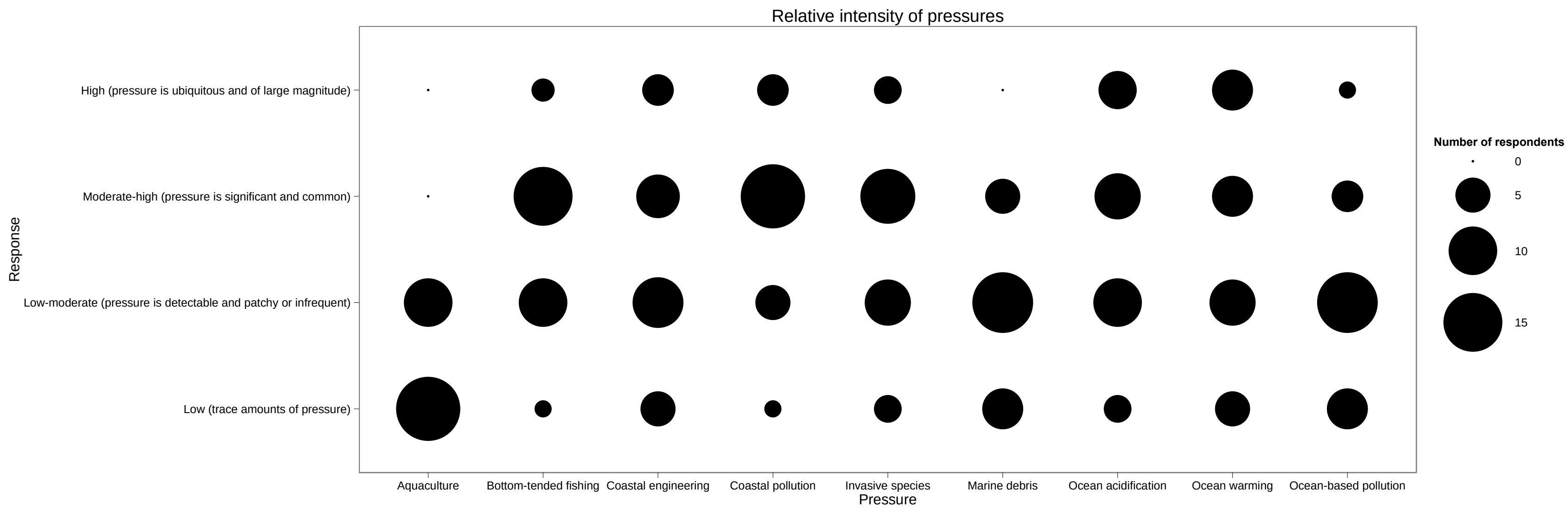


Figure EN.R.14. Expert-based assessment of risk to habitats within the MBNMS due to (a) bottom-tended fishing, and (b) coastal pollution. Data points represent average scores across respondents. B = beaches, C = corals, DS = deep sea, HB = hard bottom, KF = kelp forest, OP = offshore pelagic, RI = rocky intertidal, S = sponges, SB = soft bottom.

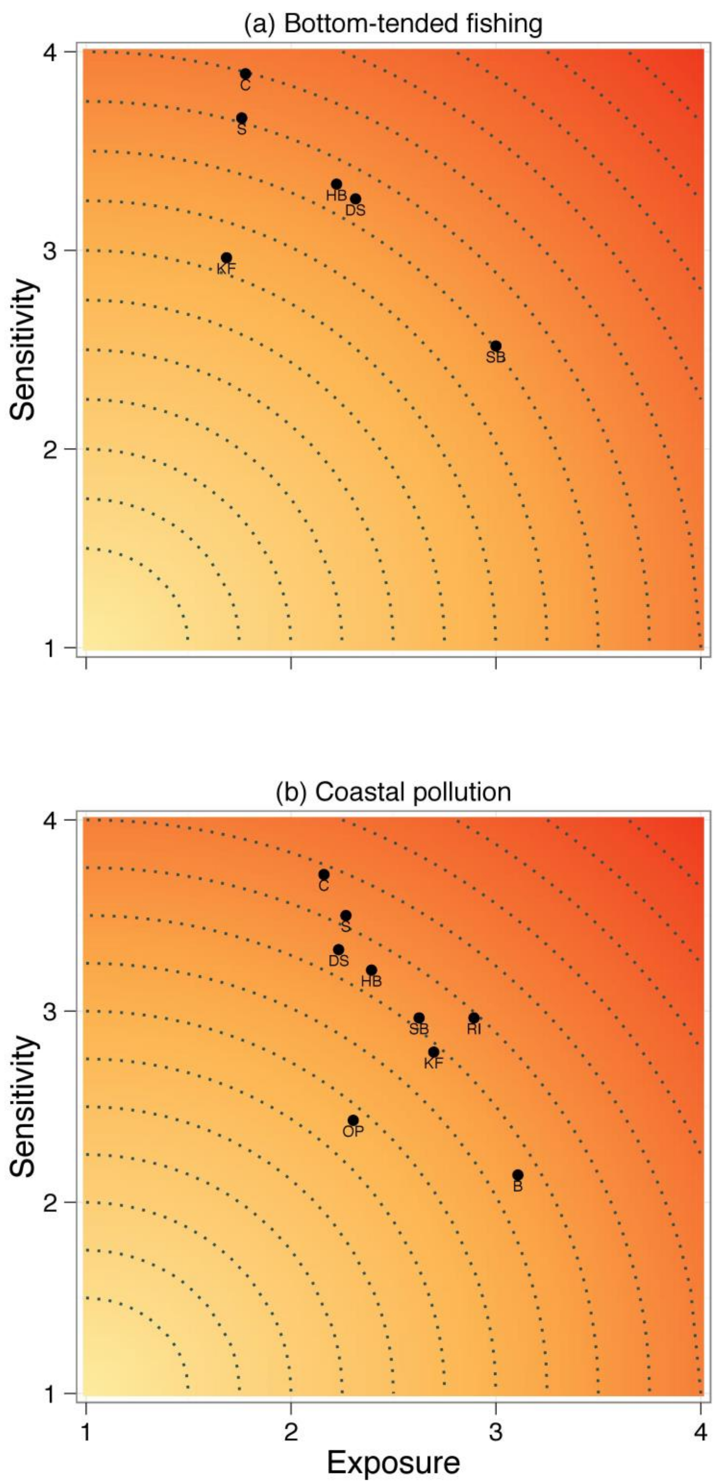
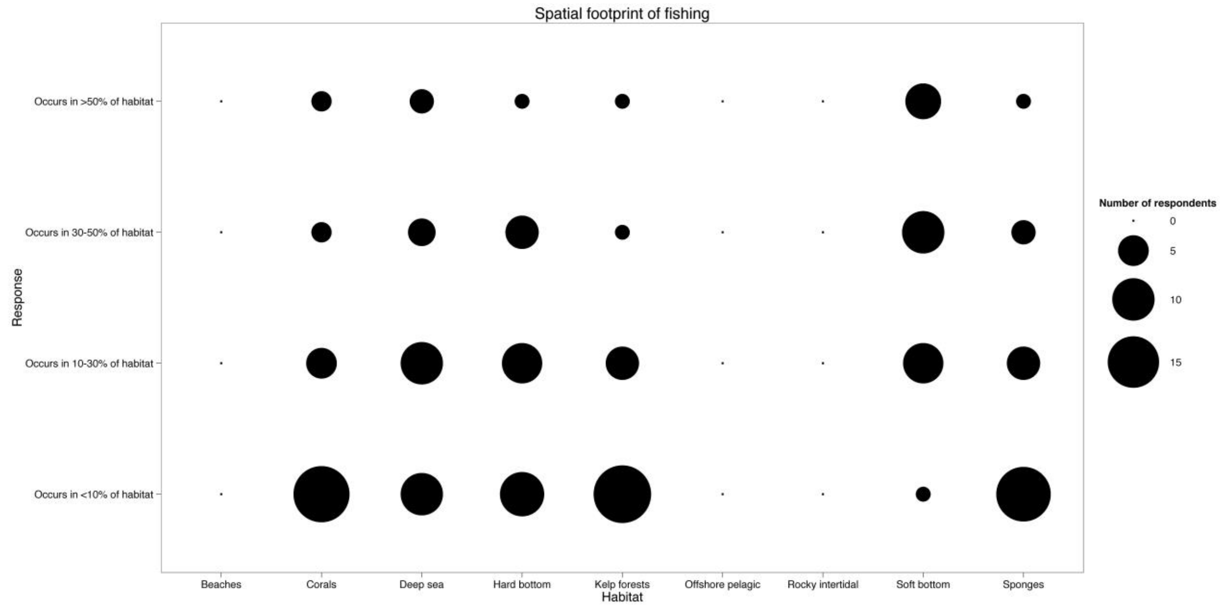


Figure EN.R.15. Expert-based assessment of exposure of habitats to bottom-tended fishing within the MBNMS, based on the spatial footprint of (top) and the temporal overlap with (bottom) bottom-tended fishing.



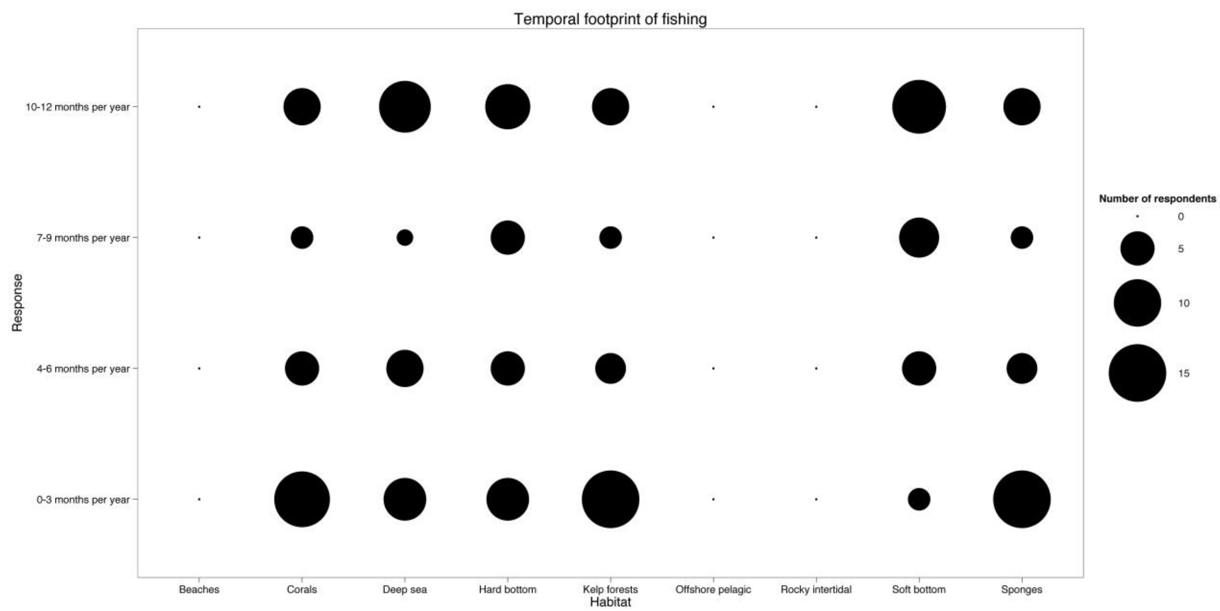
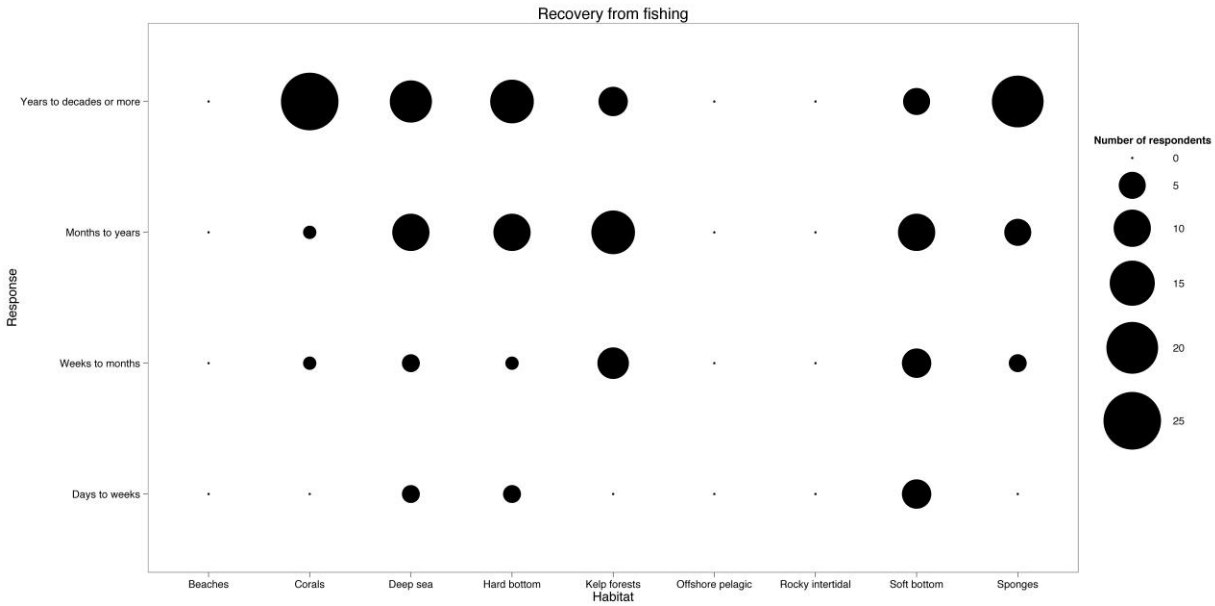


Figure EN.R.16. Expert-based assessment of sensitivity of habitats to bottom-tended fishing within the MBNMS, based on the expected degree of habitat loss (top) and the recovery rate (bottom) from bottom-tended fishing.



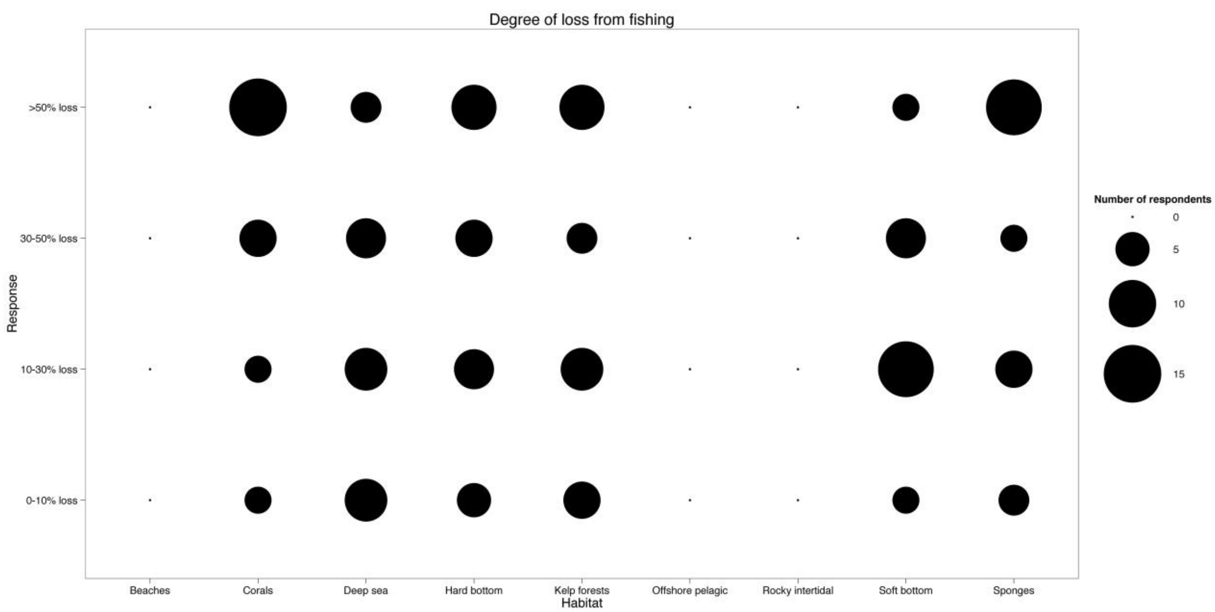
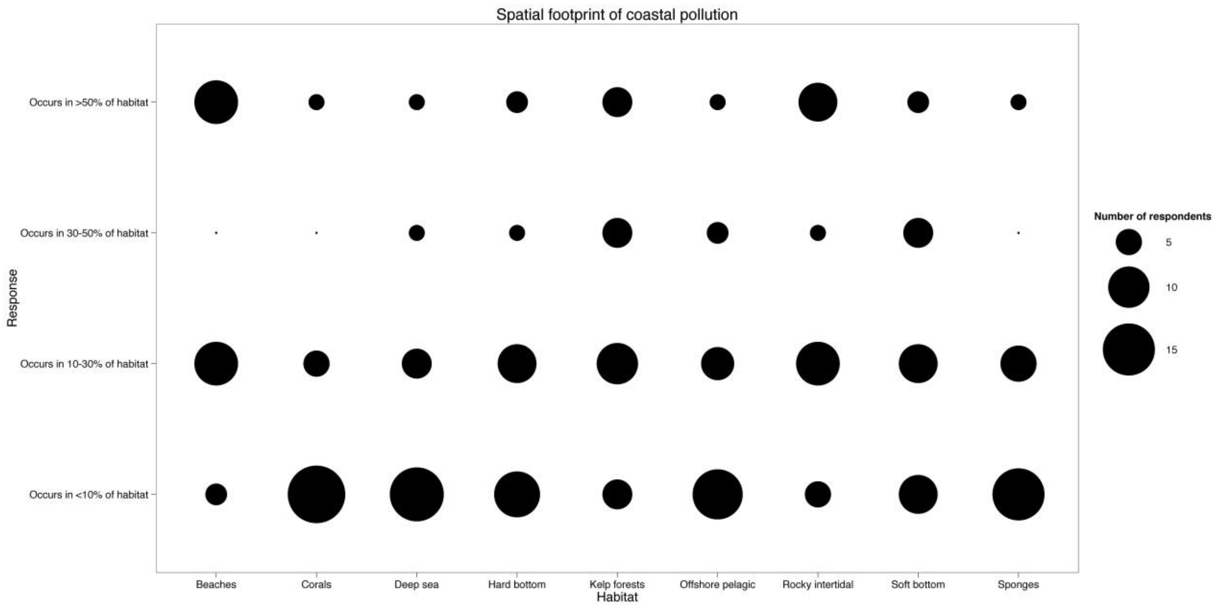


Figure EN.R.17. Expert-based assessment of exposure of habitats to coastal pollution within the MBNMS, based on the spatial footprint of (top) and the temporal overlap with (bottom) coastal pollution.



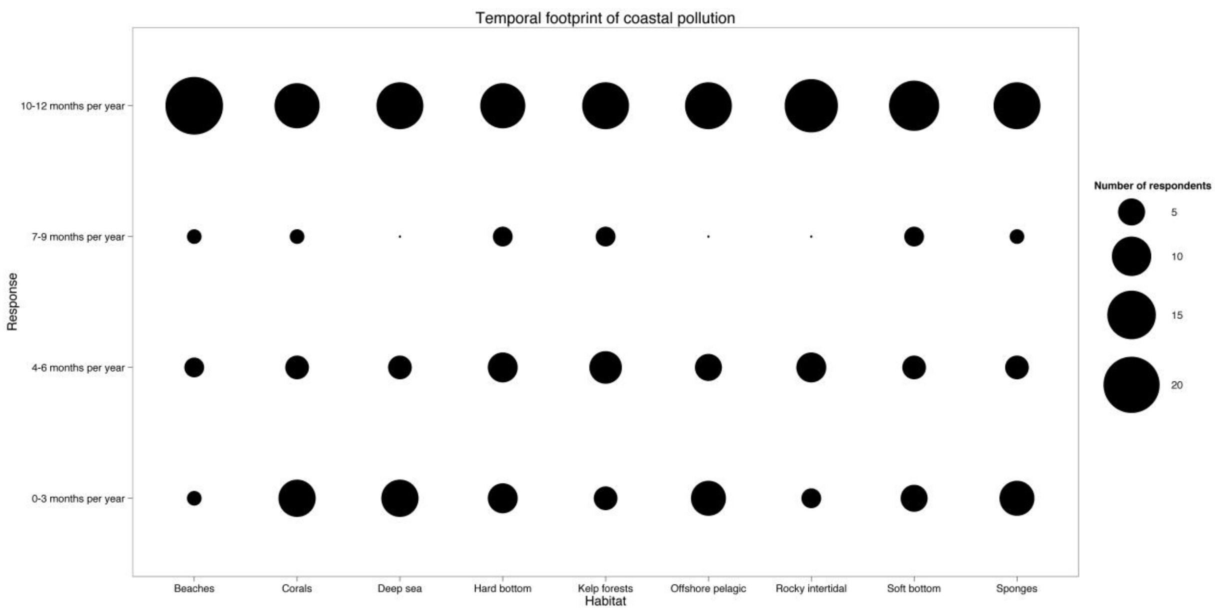


Figure EN.R.18. Expert-based assessment of sensitivity of habitats to coastal pollution within the MBNMS, based on the expected degree of habitat loss (top) and the recovery rate (bottom) from coastal pollution.

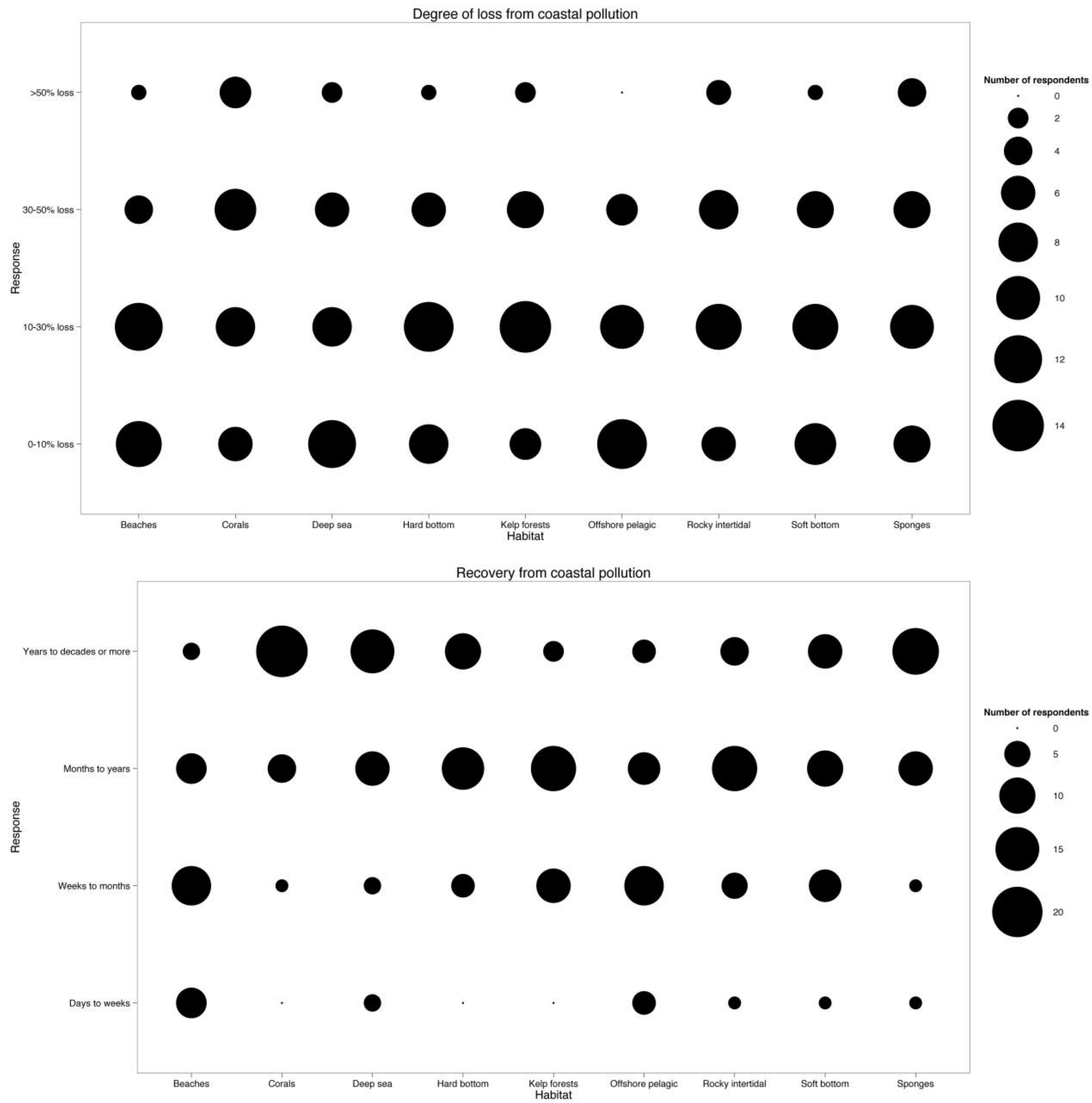
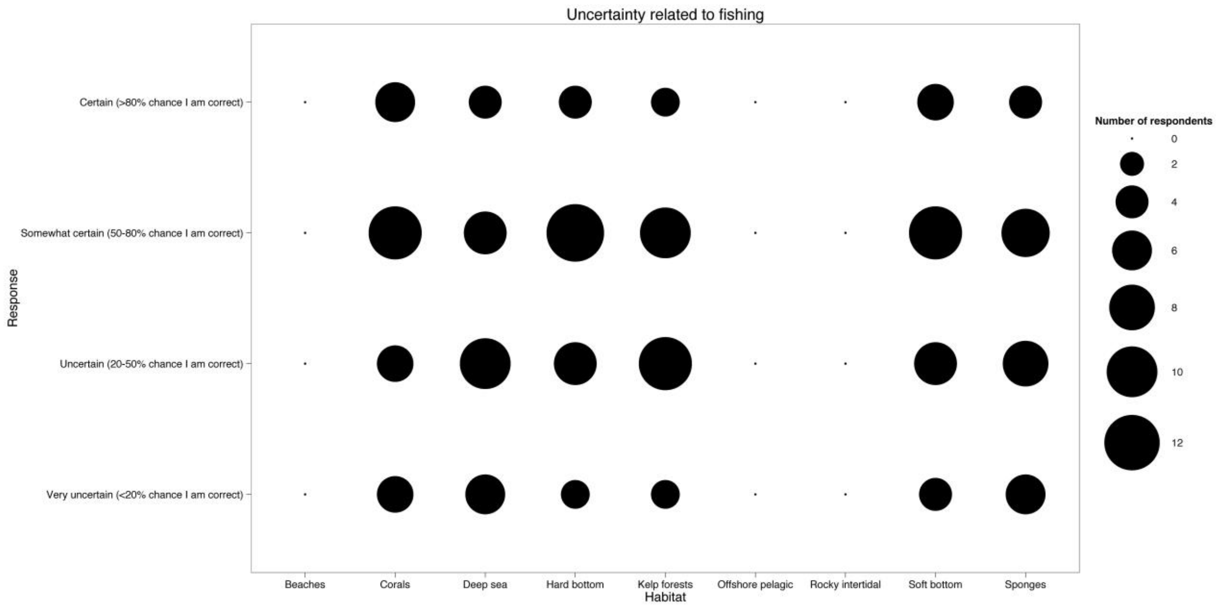
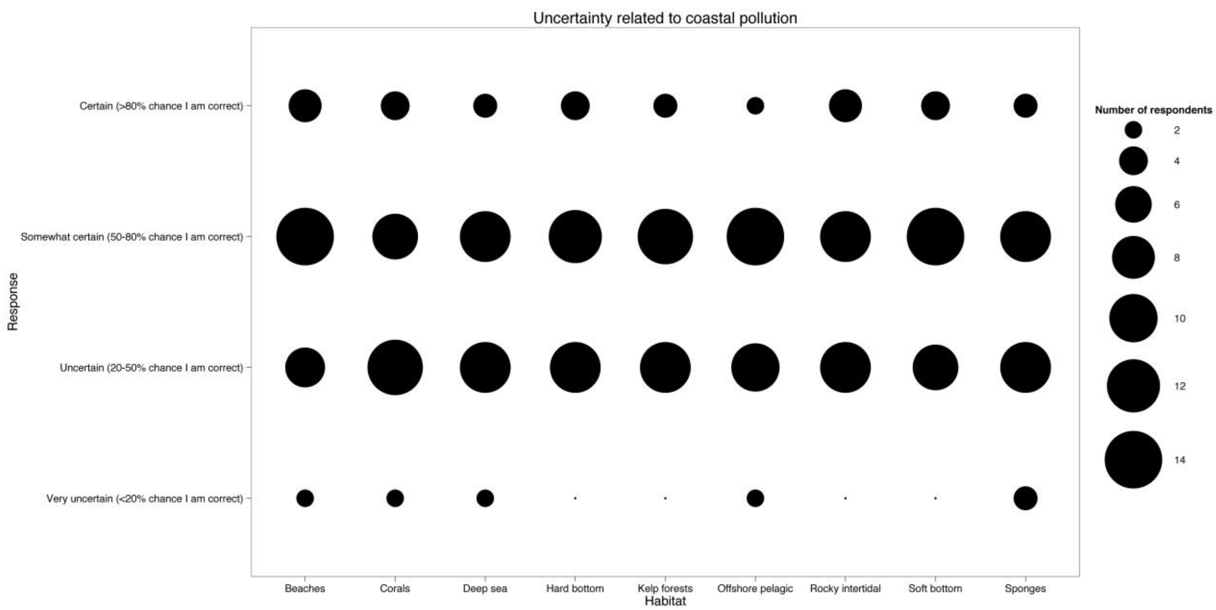


Figure EN.R.19. Expert self-assessment of uncertainty regarding responses related to risk to habitats within the MBNMS from bottom-tended fishing (top) and coastal pollution (bottom).





COMPARISON OF DATA- AND EXPERT-BASED RISK ASSESSMENTS

There was greater agreement between the data- and expert-based assessments for risk due to bottom-tended fishing, and greater disparities between the two assessments for risk due to coastal pollution (compare Figs. EN.R.20-21). Experts and data agreed remarkably well regarding risk to kelp forests from bottom-tended fishing and coastal pollution (Figs. EN.R.20-21). Lack of concordance between data- and expert-based assessments was most obvious for coral, hard bottom, and soft bottom habitats for both types of pressures, but it was not the case that risk to any of these three habitats was consistently over- or under-estimated by a specific method.

For coastal pollution (Fig. EN.R.20), experts generally perceived risk (Fig. EN.R.20c) to be higher in coral, hard bottom, offshore pelagic, and soft bottom habitats, and lower in beach habitats, than suggested by evidence in the data and literature we analyzed. In contrast, for bottom-tended fishing (Fig. EN.R.21), the data-driven assessment suggested that risk was greater for coral, soft bottom, and sponge habitats, and lower in hard bottom habitats, than suggested by the expert survey (Fig. EN.R.21c). For coastal pollution, the expert-based assessment tended to suggest greater sensitivity of habitats than the data-based assessment (Fig. EN.R.20b), but relatively lower exposure of three of the nearshore habitats (beaches, kelp forests, and rocky intertidal habitats; Fig. EN.R.20a). Exposure of corals and sponges to bottom-tended fishing was perceived to be lower by experts (Fig. EN.R.21a), and may have been overestimated in the data-driven assessment because all of the data on coral and sponge habitat locations came from trawl surveys (see Table EN.R.2). At this stage, it is not possible to say with certainty the cause of other discrepancies between these assessments, or which is closest to reality.

Figure EN.R.20. Discrepancies between data- and expert-based risk assessment for coastal pollution in MBNMS. (a) Exposure, (b) Sensitivity, (c) Risk. The line represents the 1:1 line, such that positive deviations indicate that expert-based assessment was greater than data-based assessment, and vice versa.

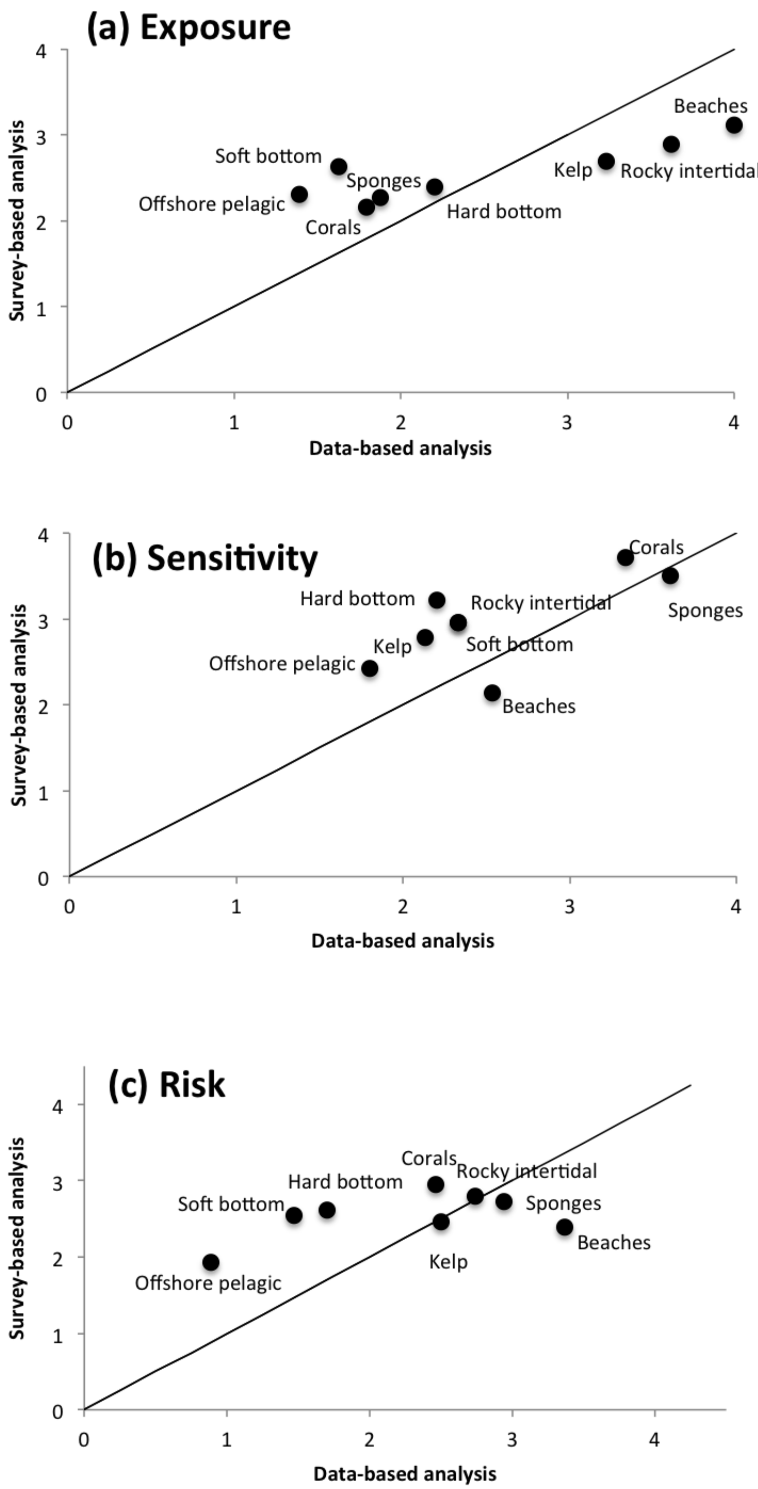
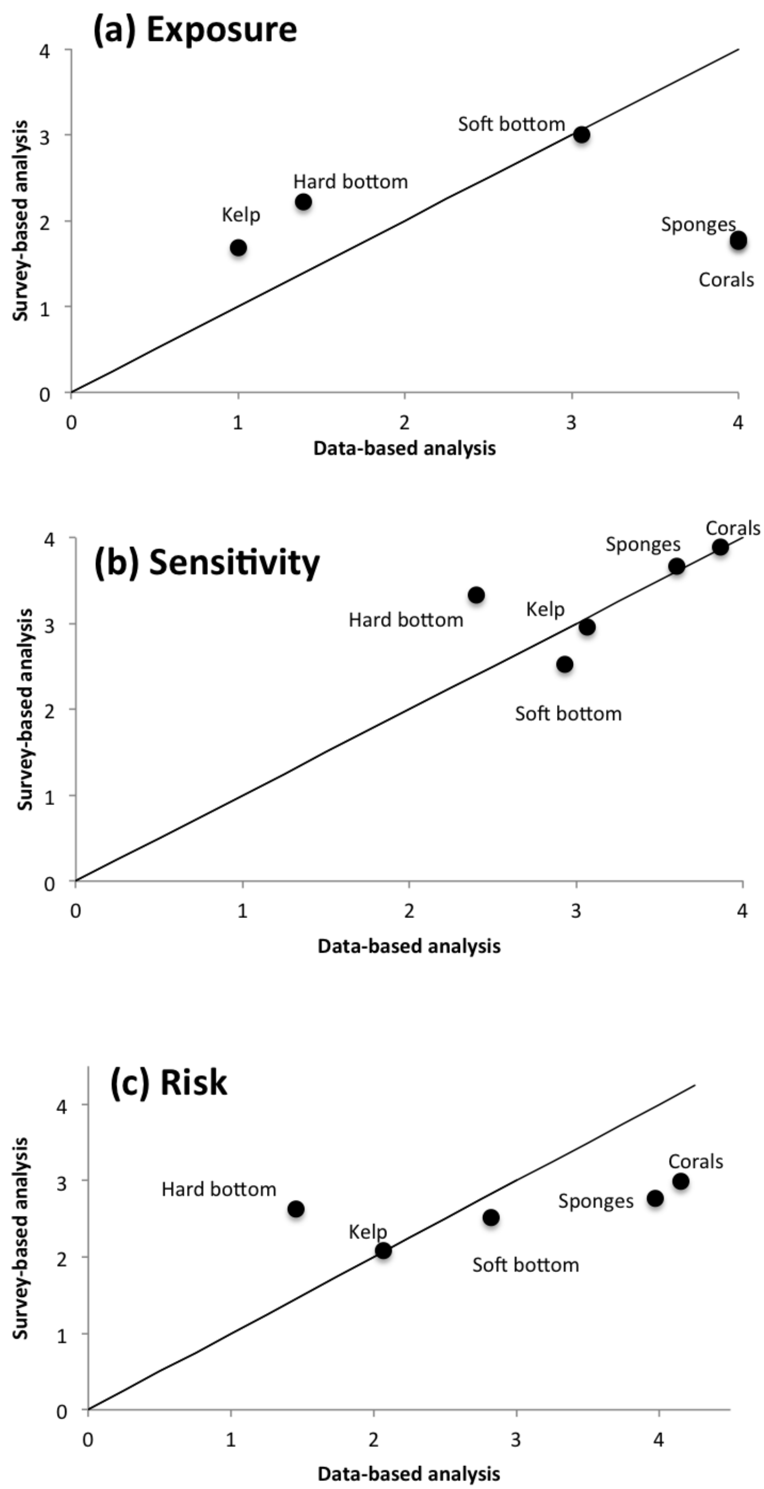


Figure EN.R.21. Discrepancies between data- and expert-based risk assessment for bottom-tended fishing in MBNMS. (a) Exposure, (b) Sensitivity, (c) Risk. The line represents the 1:1 line, such that positive deviations indicate that expert-based assessment was greater than data-based assessment, and vice versa.



CONCLUSIONS – RISK ASSESSMENT

This analysis of risk to marine habitats due to a variety of activities and pressures should provide a useful template for future iterations of the CCIEA. While it does not provide insight into the absolute risk to ecological integrity (e.g., the probability that a marine habitat will be completely destroyed or changed into an unrecognizable form), it does give a broad brush sense of which activities and pressures pose the greatest relative risk to individual habitats, and which habitats are at greatest relative risk from each activity/pressure (Table EN.R.11).

Table EN.R.11. Activities and pressures posing the greatest relative risk to individual habitats within Monterey Bay National Marine Sanctuary (also see Fig. EN.R.7). Results come from the data-based assessment.

Habitat type	Greatest relative risk
Beaches	Sediment changes
Corals	Sea surface temperature changes, Sediment changes, Shipping
Hard bottom	Shipping, Sediment changes
Kelp forests	Sediment changes
Offshore pelagic waters	Shipping, Sea surface temperature changes
Rocky intertidal	Sediment changes
Seamounts	Sea surface temperature changes
Soft bottom	Shipping, Sea surface temperature changes
Sponges	Shipping, Sea surface temperature changes

One apparent contradiction in the data-based risk assessment warrants discussion. Consideration of relative risk to each habitat from all pressures suggested that sea-based pressures tended to pose greater risk than land-based pressures (Fig. EN.R.8). At the same time, consideration of relative risk of different habitats to each pressure implied that nearshore habitats were at greater risk than offshore habitats (Fig. EN.R.10). However, it was not the case that risk due to sea-based pressures was greatest in nearshore habitats. Rather, sea-based pressures tended to generate greater exposure values for each habitat than did land-based pressures, so that risk from sea-based pressures was greater when each habitat was considered individually (Fig. EN.R.7). When the habitats were considered together, nearshore habitats tended to be relatively more exposed than offshore habitats across most pressures (Fig. EN.R.9). Regardless, the differences in risk due to land vs. sea-based pressures and in nearshore vs. offshore habitats were only statistically significant in a handful of cases.

Other studies, similar in kind to this one, have been conducted for the California Current. In the future, it will be useful to compare the analyses of cumulative impacts presented in Halpern et al. (2008, 2009) to this one. It will also be productive to determine the extent to which this risk assessment builds on and improves upon assessments of ecosystem condition within the MBNMS (e.g., (ONMS 2009)). In addition, it would be worth weighting risk scores by the importance of each habitat (e.g., where importance is based on habitat area, species richness, etc.) to generate ecosystem-level summary risk scores for the entire MBNMS. Finally, a variety of approaches have been established for integrating qualitative information (e.g., collected via expert elicitation) with quantitative data (Cheung et al. 2005, Teck et al. 2010, Kuhnert et al. 2010). We look forward to tackling new challenges in producing just such an integrated understanding of risk to ecological integrity in the California Current in the future.

LINKS TO DATA

California Department of Fish and Game

Halpern et al. 2008

Halpern et al. 2009

NOAA ESI

National Centers for Coastal Ocean Science

Monterey Bay National Marine Sanctuary risk survey

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