Appendix

Scoring Rubrics for Sensitivity Attributes and Exposure Factors

California Department of Fish and Wildlife
Climate Vulnerability Assessment
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Table 1. Sensitivity Attributes

Table 1. List of the twelve sensitivity attributes (originally described in Morrison et al. 2015).

Sensitivity Attribute	Goal	Low Score	High Score
1. Habitat Specificity	To determine if the stock is a habitat generalist or habitat specialist while incorporating information on the type and abundance of key habitats	Habitat generalist	Habitat specialist
2. Prey Specificity	Evaluate the relative prey requirements (generalist or specialist) for a given species.	Prey generalist	Prey specialist
3. Adult Mobility	Evaluate the ability of a given species to move to a new location if their current location changes and is no longer favorable for growth and/or survival.	High mobility	Low mobility
4. Dispersal of Early Life Stages	Evaluate the ability of the stock to colonize new habitats as they become available.	High mobility	Low mobility
5. Early Life History Survival and Settlement Requirements	Evaluate the relative importance of early life history survival requirements for a given species.	Generalist with few requirements (definition from Hare et al. 2016 definition)	Specialist with specific requirements (definition from Hare et al. 2016)
6. Complexity in Reproductive Strategy	Evaluate how dependent reproductive success is on specific or complex environmental conditions.	Low complexity; broadcast spawning	High complexity; aggregate spawning
7. Spawning Cycle	Evaluate the duration of the spawning cycle and the potential for disruption of reproduction due to climate change.	Year-round spawning	One event per year

8. Sensitivity to Temperature	Evaluate the temperature tolerance of a given species; when unknown, breath of distribution may be used as a proxy.	Broad thermal limits	Narrow thermal limits
9. Sensitivity to Ocean Acidification	Evaluate a given species sensitivity to ocean acidification (OA); based on its relationship with "sensitive taxa." (Kroeker *et al.*, 2013)	Insensitive taxa	Sensitive taxa
10. Population Growth Rate	Evaluate the relative productivity of a given species as a measure of its ability to rebound after a negative impact.	High population growth	Low population growth
11. Stock Size/Status	Evaluate the relative level of stress from fishing on a given species.	High abundance	Low abundance
12. Other Stressors	Evaluate the relative level of stress on a given species which could negatively impact its ability to respond to changes.	Low level of other stressors	High level of other stressors

1. Habitat specificity

Goal: To determine the breadth of habitat used by a stock and estimate the ability of individuals to shift habitat use under changing conditions.

Background: For the purpose of this assessment, we consider three types of habitat: physical habitat expected to be resilient to changing climate conditions, physical habitat expected to be vulnerable to changing climate conditions, and biogenic habitat, which is expected to be vulnerable to climate change.

Physical features such as depth, bathymetry, and rocky substrate are expected to be resilient to climate change and therefore would result in lower sensitivity for those species that rely on those types of habitats. Other physical features that are more vulnerable to climate changes (e.g., beach topography, fronts, eddies, upwelling) will produce greater impacts to species that rely on those types of features. We consider the physical and chemical characteristics of the water column as habitat features, which are more dynamic than persistent geologic features.

Biogenic habitat – habitat created by or consisting of organisms or organism remains – may undergo the greatest changes from a changing climate, as both the ecosystem engineers and underlying physical conditions may be impacted by changing conditions (Nelson, 2009; Doney *et al.*, 2012; Harley *et al.*, 2012). Examples of biogenic habitat include kelp forests, mangroves, salt marshes, coral reefs, and seagrass beds (Teck *et al.*, 2010; Okey *et al.*, 2015). Thus, species that depend on biogenic habitats are likely more vulnerable to climate change.

While the presence of suitable prey plays a key role in defining a species' habitat, we consider the prey and diet specificity of the species in a separate attribute. Similar to the prey/diet specificity attribute, we encourage future iterations of this assessment to interface with vulnerability assessments that score the vulnerability of habitat to climate change.

All aspects of a stock's life history within and outside of US waters should be considered when scoring this attribute.

Relationship to abundance: A stock with greater habitat specificity is more likely to experience declines in abundance due to climate-driven habitat alterations.

Relationship to distribution: A stock with greater habitat specificity is more likely to experience shifts in distribution due to climate-driven habitat alterations.

Relationship to phenology: A stock with greater habitat specificity is more likely to experience shifts in phenology due to climate-driven habitat alterations.

How to use expert opinion: This attribute will be scored using a combination of the three criteria described above: habitat specialist or generalist; whether or not the stock depends on biological habitats (i.e., live coral reefs, deep water corals, mangroves, salt marshes, sea grass beds); and habitat availability (limited vs. abundant). It is understood that these criteria are not dichotomous but are a continuum. Stocks that are dependent on "disturbed" habitats should do fine or increase with climate change, so put these species in the “low” bin. If you think that a stock fits in multiple scoring bins, weight your 5 tallies between the appropriate bins. Using your expert opinion, account for any lifespan or ontogenetic shifts in diet; however, limit your response to the juvenile and adult life stages as larvae are considered under the attribute “early life history survival and settlement requirements.”

Habitat Specificity Scoring:

- **Bin 1 (Low):** Stock exclusively utilizes physical features resilient to climate conditions
- **Bin 2 (Moderate):** Stock utilizes a variety of features, but is not reliant on physical features vulnerable to climate conditions and/or biogenic habitat for specific life stages
- **Bin 3 (High):** Stock relies on biogenic habitat or physical features vulnerable to climate conditions for one life stage or event
- **Bin 4 (Very High):** Stock relies on biogenic habitat or physical features vulnerable to climate conditions for multiple life stages or events, or for any one particularly critical life stage or event

Relevant Species Narrative Categories: Habitat Specificity

2. Prey/Diet Specificity

Goal: To estimate the breadth of a stock's diet and the ability of individuals to shift foraging strategy and/or diet under changing conditions.

Background:

Generalists stocks should be more resilient to changing resource availability (habitat and food) than specialists (Wilson *et al.*, 2008; Clavel *et al.*, 2011; Graham *et al.*, 2011; Pecl *et al.*, 2014). Understanding how reliant a stock is on specific prey species could predict its ability to persist as the climate changes. Specialists (who have specific prey requirements) are likely to be more vulnerable to climate change because their persistence is dependent on not only their own response to climate change, but also the response of their prey. During mass extinction events of the past, diet specialists were more prone to extinction than diet generalists (Clavel *et al.*, 2011).

Background: Climate change impacts extend beyond the stock in question to include species within its food web (e.g., prey, predators and competitors).

How to use expert opinion: The scoring bins below estimate the stocks' relative distribution along a continuum that runs between prey specialists and prey generalists. Using your expert opinion, account for any lifespan or ontogenetic shifts in diet; however, limit your response to the juvenile and adult life stages as larvae are considered under the attribute "early life history survival and settlement requirements." For this attribute, prey type refers to groups of similar species; copepods, krill, forage fish, etc., for example, are each categorized as a prey type.

Prey/Diet Specificity Scoring:

- **Bin 1 (Low)**: Generalist; feeds on a wide range of prey types and sizes
- **Bin 2 (Moderate)**: Generalist; feeds on a limited number of prey types or sizes, but a wide variety of species within those types
- **Bin 3 (High)**: Specialist; exhibits strong preference for one prey type for the majority of its caloric intake, but is capable of switching prey types
- **Bin 4 (Very High)**: Specialist; reliant on one prey type, often a single genus or family, for the majority of its caloric intake, and is unable to switch to other prey types

Relevant Species Narrative Categories: Prey Specificity

3. Adult Mobility

Goal: To estimate the ability of the stock to move to a new location if their current location changes and is no longer favorable for growth and/or survival.

Relationship to climate change: Site-dependent species that are unable to move to better habitat when a location becomes unfavorable are less able to adapt to environmental change than highly mobile species (Foden *et al.*, 2013).

Background: As climate change occurs, habitats that were once suitable may change and no longer be able to sustain a given stock of fish. Similarly, what was once unsuitable habitat may become suitable. A stock can survive changes in habitat as long as they have the ability to disperse from unsuitable habitat and find new, suitable habitat; and dispersal ability can be used as a proxy for the capacity to change distribution (Pecl *et al.*, 2014). This can occur through larval dispersal and settlement (covered under the "Dispersal of Early Life Stages" attribute) or through adult mobility. Species can be limited in their mobility by physical or behavioral (e.g., won't swim across open ocean) barriers.

How to use expert opinion: This attribute represents a continuum from sessile to highly migratory organisms. Use your expert opinion to place the stock in question in the appropriate bin according to its physical and behavioral ability to move. Homing behavior for spawning should not be considered here as it is accounted for in the "Complexity in Reproductive Strategy" attribute. For this attribute, we define site-dependent stocks as those whose adults are site-attached (i.e., spend their entire adult phase in one limited location).

<u>Adult Mobility Scoring</u>:
- **Bin 1 (Low):** Non-site dependent. The stock is highly mobile and non-site dependent.
- **Bin 2 (Moderate):** Site dependent but highly mobile. The stock has site-dependent adults capable of moving from one site to another if necessary.
- **Bin 3 (High):** Site dependent with limited mobility. The stock has site-dependent adults that are restricted in their movement by environmental or behavioral barriers.
- **Bin 4 (Very High):** Non-mobile. The stock has sessile adults.

<u>Relevant Species Narrative Categories:</u> Adult Mobility

4. Dispersal of Early Life Stages

Goal: To estimate the ability of the stock to colonize new habitats when/if their current habitat becomes less suitable.

Relationship to climate change: In general, the greater the dispersal of larvae, the better its ability to respond to climate change. Wide distribution of eggs and larvae can lead to greater ability to colonize new habitats in areas that are suitable for survival. Conversely, if a stock has limited larval distribution and the habitat in the localized area becomes unsuitable, then the stock is more likely to be negatively affected.

Background: For marine species, extended larval dispersal is an important strategy for colonizing new areas. Duration of the larval stage may impact dispersal distance and stock persistence. Jablonski and Lutz (1983) found that marine invertebrates with relatively long planktonic larval stages were more persistent in the fossil record than those species with non-planktonic larvae and had lower extinction rates. Early life stage dispersal is affected by a number of factors including spawning, advection, diffusion, larval behavior, planktonic duration, planktonic survival, and settlement habitat (Pineda *et al.*, 2007). In general, studies have found that spawning time and place and planktonic duration are key factors, but the other factors can be important in specific situations.

How to use expert opinion: The main point of this attribute is to estimate dispersal ability. If no information is known about actual dispersal distances, capacity for larval dispersal can be estimated by a stock's larval duration (hatching to settlement in benthic species and hatching to yolk-sac re-absorption in pelagic species) (Pecl *et al.*, 2014). However, if information about actual dispersal distances are known, use that information. If a stock has a relatively short larval duration, but is known to disperse large distances, or if the larvae are able to influence dispersal through selective tidal stream transport, adjust your tallies accordingly. Keep in mind that long-distance dispersal of only a small fraction of the larvae could still be adequate for colonization of new areas in a changing climate.

Dispersal of Early Life Stages Scoring:
Larval durations utilized in Bins are adapted from Pecl *et al*. (2014); distances are provided on a log-scale to show general/large changes in magnitude.

- **Bin 1 (Low):** Highly dispersed eggs and larvae. Duration of planktonic eggs and larvae greater than 8 weeks and/or larvae are dispersed >100 km from spawning locations.
- **Bin 2 (Moderate):** Moderately dispersed eggs and larvae. Duration of planktonic eggs and larvae less than 8 but greater than 2 weeks and/or larvae are dispersed 10-100 km from spawning locations.
- **Bin 3 (High):** Low larval dispersal. Duration of planktonic eggs and larvae less than 2 weeks and/or larvae typically found over the same location as parents.
- **Bin 4 (Very High):** Minimal larval dispersal. Benthic eggs and larvae or little to no planktonic early life stages.

Relevant Species Narrative Categories: Mobility and Dispersal of Early Life Stages (i.e., Early Mobility & Dispersal).

5. Early Life History Survival and Settlement Requirements

Goal: To determine the relative importance of early life history requirements for a stock.

Relationship to climate change: In general, the early life stages (eggs and larvae) of marine fish are characterized by high mortality rates, via predation, starvation, advection, or unsuitable conditions. Small changes in the environment can lead to large changes in early life survival, which can affect recruitment and year-class strength. Large scale climate change could have a greater impact on species that have more specific early life history and settlement requirements.

Background: Close to 100 years ago, fisheries scientists recognized the importance of recruitment variability in fish populations (Hjort, 1914). Despite considerable research devoted to fisheries recruitment, there is still considerable uncertainty about how environmental variability impacts recruitment (Punt *et al.*, 2014). Scientists now understand that multiple processes are important during the egg and larval stages. Conditions that can lead to decreased or negligible recruitment include:

Larvae that are dependent on specific biological conditions in the water column during their larval stage. For example, if the larvae are dependent on the presence of food at a specific point in development, different emergence of the larvae and the food (due to dependence on different cues) could result in a mismatch in availability. Alternatively, if the larvae have evolved to survive in low predator (and low food) conditions, a change in predation pressure could impact survival (Bakun, 2010).

Larvae or eggs that are dependent on specific physical conditions to survive (e.g., specific temperature requirements for eggs, temporary gyres that provide food and retention for larvae, calm conditions that allow for concentration of larval prey, specific transport pathways to nursery habitats, etc.) (Houde 2008).

Larvae that are dependent on a cue for settlement or metamorphosis that could be impacted by a changing climate (Pecl et al. 2014).

For the purpose of this assessment, early life history requirements include the environmental conditions necessary for larval survival, and encompass the eggs, pelagic larvae stages, and settlement. The more specific the early life history requirements, the more precise the environmental conditions may need to be, and thus the more vulnerable the stock may be in a changing environment. *Note: fishes that evolved life history traits which minimize or eliminate early life stages either by birthing well-developed young or by laying egg cases that allows embryos to fully develop before hatching should be ranked as "Low."*

How to use expert opinion: Marine species are largely dependent on both physical and biological conditions during their larval stage. However, the reliance on specific conditions varies between stocks. For the bins below, recruitment can be characterized as low variability when there is relatively constant recruitment events every 1-2 years, and high variability when the stock experiences highly episodic recruitment events (Pecl *et al.*, 2014). If no citable reference is available on a stock's early life history survival and settlement, the score may be based on expert opinion.

Early Life History Survival and Settlement Scoring:

- **Bin 1 (Low):** Larval requirements are minimal. Stock has general requirements for the larval stage that are relatively resilient to environmental change.
- **Bin 2 (Moderate):** Larval requirements are minimal or unknown. Stock requirements are not well understood, and recruitment is relatively constant, suggesting limited environmental influence.
- **Bin 3 (High):** Larvae have some specific requirements. Stock requirements are not well understood, but recruitment is highly variable and appears to have a strong dependence on environmental conditions.
- **Bin 4 (Very High):** Larvae have multiple specific requirements. Stock has specific known biological and physical requirements for larval survival.

Relevant Species Narrative Categories: Specificity in Early Life History Requirements

6. Complexity in Reproductive Strategy

Goal: To determine how complex the stock's reproductive strategy is and how dependent reproductive success is on specific environmental conditions.

Relationship to climate change: Species that have complex reproductive strategies (that require a series of events or special conditions) are more likely to have these conditions disrupted by changes in the environment.

Background: There is great diversity in reproductive strategies in marine fishes. The more complex the reproductive strategy, the more precise the conditions may need to be, and thus the more vulnerable the stock may be to environmental change. For our purposes, complexity in reproductive strategy is defined as reproductive behaviors, characteristics or cues that create specific requirements that must be met in order for reproduction to be successful. Species with reproductive events that are dependent on temperature (vs. day-length) cues will be more sensitive to climate change (Pecl *et al*. 2014).

How to use expert opinion: A list of common reproductive characteristics that may affect the reproductive capacity of a stock in a changing climate is provided below. To score, determine if any of these examples apply to the stock. Note: this is not intended to be an exhaustive list. If other characteristics exist that may affect a stock's reproduction capacity in a changing climate, incorporate that information and adjust your score appropriately.

Example reproductive characteristics that create "complexity":

a) The stock has known temperature effects on reproduction. Examples include temperature-dependent sex changes, and temperature cues that impact spawning, gonad development, etc.
b) The stock uses large spawning aggregations. Large spawning aggregations can contribute to a high sensitivity because a large number of individuals must get to the spawning area simultaneously (i.e., migration or cues to migrate may be impeded by a change in the environment), the spawning area has to retain the environmental conditions that made it successful in the past, and the reproductive success for that year is dependent on the conditions present at one time period.
c) The stock experiences decreased recruitment per spawner, or a weakening in the strength of density dependence, at low stock sizes, potentially because of depensation/Allee effects. If unknown, does the stock share life history characteristics that would predict depensation effects (e.g., significant changes in the relative abundance of the stock's predators/prey at low stock densities, decreased fertilization success at low stock sizes)?
d) The reproductive success of the stock requires the use of vulnerable habitats (freshwater, estuaries, mangroves, salt marshes, corals) for spawning or rearing of young. Vulnerable habitats are likely to experience larger climate change impacts (such as changes in salinity, dissolved oxygen, pollution, sedimentation, or water depth), and stocks that require these habitats for successful reproduction will likely be impacted.

Complexity in Reproductive Strategy Scoring Bins:
If a particular characteristic is suspected to have a large impact on the stock, adjust the score appropriately.

- **Bin 1 (Low):** Simple reproductive strategy. The stock contains no more than one characteristic that suggest complexity in reproductive strategy.
- **Bin 2 (Moderate):** Slight complexity. The stock has two characteristics that suggest complexity in reproductive strategy.
- **Bin 3 (High):** Complex reproductive strategy. The stock has three characteristics that suggest complexity in reproductive strategy.
- **Bin 4 (Very High):** Very complex reproductive strategy. The stock has four or more characteristics that suggest complexity in reproductive strategy.

Relevant Species Narrative Categories: Complexity in Reproductive Strategy (labeled as Sensitivity to Temperature in Spawning & Habitat in the individual species narratives),

7. Spawning Cycle

Goal: To determine if the duration of the spawning cycle for the stock could limit the ability of the stock to successfully reproduce if necessary conditions are disrupted by climate change.

Relationship to climate change: It is assumed that stocks that spawn throughout the year will be more likely to be successful in a changing environment: “Protracted spawning is believed to enhance offspring survival by allowing the stock to “hedge its bet” against adverse environmental conditions” (Marteinsdottir and Thorarinsson, 1998). Conversely, stocks that spawn all at once in major events are more likely to experience recruitment failure with potential changes in environmental conditions.

Background: Spawning characteristics describe the spawning activity of a stock (in aggregate, not individually) over a particular time frame. If a stock spawns several times per year across a variety of seasons, then they will likely be less susceptible to climate change because their reproductive events are not dependent on just one set of very specific conditions (e.g., phenological events). Increased spawning events, also help to protect against vulnerabilities associated with single spawning aggregations (see the “Complexity in Reproductive Strategy” attribute). Similarly, stocks that reproduce seasonally are also less likely to adapt to climate change as they are dependent on environmental conditions historically present during a given season that may not persist through time. For example, spring-like conditions and related activities have occurred progressively earlier since the 1960s (Walther *et al.*, 2002) and changes in spawning season and location have already been observed and predicted to continue (Rijnsdorp *et al.*, 2009; Shoji *et al.*, 2011). Note: We are describing the spawning activity of the entire stock, not the individual. In other words, we are interested in the time from when spawning commences until when it ends, not how long a single individual spawns.

How to use expert opinion: It is impossible to distill every potential spawning cycle into 4 scoring bins. The below bins are rough breaks in a continuum of possibilities. If a species does not fit the below bins, use your expert judgment to best score the species based on the above discussion. For stocks (such as elasmobranchs) that are born as fully developed juveniles capable of long-distance movements, there is less concern over a short hatching/mating period, and these stocks should be ranked low to moderate.

<u>Spawning Cycle Characteristics Scoring:</u>

- **Bin 1 (Low):** Consistent throughout the year. Stocks that spawn continuously throughout the year without a defined “spawning season” are less likely to suffer spawning failure. Example: a stock that spawns daily or monthly.
- **Bin 2 (Moderate):** Several spawning events throughout the year. Stocks that spawn several times per year and spawn across more than one season have a moderate likelihood of spawning success to be impacted by climate change. Example: a stock that spawns in both the spring and summer.
- **Bin 3 (High):** Several spawning events per year within a confined time frame. Stocks that may spawn several times per year but all spawning events in that year take place in one season have a higher likelihood of being affected by climate change. Example: the spawning season occurs once a year and lasts over a period of less than 3 months.

- **Bin 4 (Very High):** One spawning event per year. Stocks that require very specific environmental/social cues to initiate spawning and that only spawn once per year have the highest likelihood of being affected by climate change. Example: the spawning season occurs once a year over a brief period of time.

Relevant Species Narrative Categories: Spawning Cycle

8. Sensitivity to Temperature

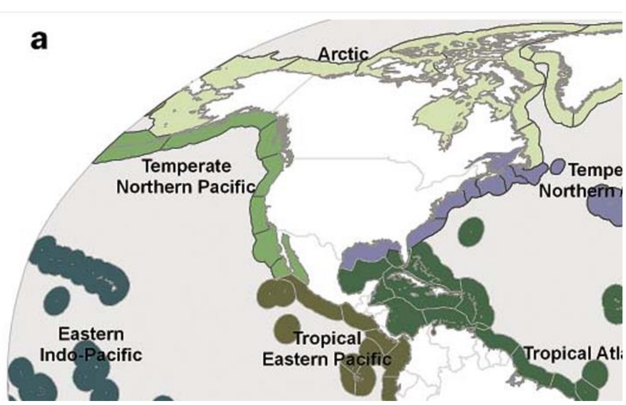
Goal: To use information regarding temperature of occurrence or the distribution of the species as a proxy for its sensitivity to temperature.

Relationship to climate change: Species that experience a wide range of temperature regimes are more likely to persist in a warming ocean.

Background: A species temperature requirements can be a good predictor of how it will respond to climate change. For species that lack specifics on temperature requirements, the latitudinal coverage of the species can be a proxy for temperature tolerance (Pecl *et al*. 2014). Since species can cover a wide tropical latitude but still have a limited temperature tolerance, distribution of a species within or across provinces can be used instead. Spalding *et al*. (2007) (Figure A1) divides coastal waters of the world into 62 provinces and 232 ecoregions. Even though Spalding's provinces are not specifically based on temperature (they also consider upwelling, currents, salinity, nutrients, etc.), they can be used to delineate areas with similar thermal conditions.

In addition, a species' distribution in the water column and seasonal movements can indicate its sensitivity to temperature. Species that make large diurnal migrations across the thermocline have lower sensitivities to changing temperatures than species that have limited depth distributions. Additionally, species that make large seasonal migrations and track seasonally changing water temperatures may have more sensitivity to temperature than indicated by range alone.

How to use expert opinion: Use known temperature requirements to score this attribute when available. When temperature information is not known, use the species distribution, along with Figure 2A to determine if a species is found across >1 province. Also use knowledge of seasonal and diurnal movements to adjust the tallies. Keep in mind that you can adjust your tallies depending on the distribution of the species relative to the area of interest (i.e., if the area of interest is at the edge of the distribution of the species, consider if the species is expected to move out of or expand into the area of interest).



Spalding *et al*. (2007) only characterize coastal environments; therefore, use your expert opinion for open ocean species. If information about temperature requirements or depth distributions is available, use this to modify your response.
For example, if a species is found across 2 provinces, but it has a limited depth distribution, the expert could distribute the 5 tallies between bins 2 and 3. If a species' sensitivity changes with ontogeny, consider the most limited stage when determining the most appropriate bin(s). Given that a stock range will always be less than a species range, if scoring temperature dependence for

a stock, consider not only the stock range, but also the species range as the species range may predict the stock's ability to adapt. Consideration of the species distribution relative to the study area is also important. Stocks at the cold edge of the species range would be expected to fare well, while stocks at the warm edge of its species range may not (Planque and Frédou, 1999; Drinkwater, 2005). With the California Current System, tropical and semi-tropical species are expected to have lower sensitivity to projected increases in ocean temperature as compared to temperate species.

In addition, across the California Current system the distribution and abundance of many marine species are acutely impacted by oceanic oscillations (i.e., the Pacific Decadal Oscillation and the El Niño–Southern Oscillation*)* characterized by pronounced swings in ocean temperatures. These variable environmental conditions play a critical role in reproductive patterns and distribution of marine organisms and consequently, the fisheries that they support (Radovich 1961; Parrish et al. 1981). Water temperature directly affects metabolic functions, preferred food availability, and the distribution of predators. Changing in ocean current flows and water temperatures associated with these oscillations that have historically led to displacing or shifting species within faunal groups may help us anticipate future changes to ecosystem structure

Temperature Sensitivity Scoring:

- **Bin 1 (Low):** Large temperature range. Species occurs in a wide range of temperatures (>15^{o}C), or is found across 3 or more provinces. Species are minimally or favorably impacted by warm water PDO and/or ENSO phases.
- **Bin 2 (Moderate):** Moderate temperature range. Species occurs in a moderately wide range of temperatures (10-15^{o}C), or is found across 2 provinces. Moderate and/or inconsistent impacts are observed in association with warm water PDO and/or ENSO phases.
- **Bin 3 (High):** Somewhat limited temperature range. Species occurs in a moderately narrow range of temperatures (5-10^{o}C), or is found within one province but has a variable depth distribution. Substantial (though short-lived) constriction of species range and/or reductions in abundance have been observed in regional waters in association with warm water PDO and/or ENSO phases.
- **Bin 4 (Very High):** Very limited temperature range. Species occurs in a narrow range of temperatures (<5^{o}C) or is found within one province and has a limited depth distribution (i.e., depth range is <100 m). Pronounced (an enduring) constriction of species range and/or reductions in abundance have been observed in regional waters in association with warm water PDO and/or ENSO phases.

Relevant Species Narrative Categories: Sensitivity to Temperature, Distribution Maps, information about ENSO impacts spread across other categories (do this last after you've already reviewed them)

9. Sensitivity to Ocean Acidification

Goal: To estimate a stock's sensitivity to ocean acidification (OA) based on its relationship with "sensitive taxa."

Relationship to climate change: Impacts of OA on marine organisms can be highly variable, with considerable variability between taxa and species. Therefore, we are estimating the impact of OA by examining the dependence of the stock on sensitive taxa. For example, current research shows a consistent negative impact of OA on mollusks, corals, calcified algae and echinoderms (Kroeker *et al.*, 2013), so species in these classes or dependent on species in these classes should be considered more sensitive to changes in ocean pH.

Background: Ocean acidification is often called "the other carbon dioxide problem," and is the term given to the chemical changes in the ocean as a result of carbon dioxide emissions (Wicks and Roberts, 2012). While initial research suggested that the majority of species that have calcium carbonate or chitin shells or those that lay down calcium carbonate skeletons (corals) will be negatively impacted by ocean acidification (Orr *et al.*, 2005; Hoegh-Guldberg *et al.*, 2007; Kawaguchi *et al.*, 2010), recent studies have highlighted a high variability in response between different shelled organisms and suggest that not all shelled species will be impacted to the same degree and not all impacts will be negative (i.e., Ries *et al.*, 2009; Kroeker *et al.*, 2013). For example, Kroeker *et al*. (2013) in a meta- analysis of 228 studies found significant and consistent negative impacts of OA on the larval stages of mollusks and corals. However, recent research suggests soft corals may not be as sensitive as stony corals (Gabay *et al.*, 2014). In contrast, high variability in the responses of crustaceans suggests impacts may be species specific within this group, with brachyuran crustaceans showing a higher resistance (Kroeker *et al*. 2013).

The direct effect of ocean acidification on finfish is not well understood. Recent research suggests impacts on finfish stocks will be most prevalent at the egg and early larval stages (Franke and Clemmesen, 2011; Baumann *et al.*, 2012; Frommel *et al.*, 2012). Despite these studies, not enough is known to be able to predict which finfish stocks will be more sensitive.

How to use expert opinion: Use current information on a species' reliance on sensitive taxa (e.g. corals, mollusks, echinoderms, or calcified algae; see Kroeker et al. 2013) to bin species. When scoring, base your score on the most sensitive life stage, if appropriate. In cases where research has shown that the effects of OA may be positive or mitigated by biological processes (e.g., reduced OA by plant absorption of CO_2), use your expert judgment to inform the score. We have binned sensitive taxa which are directly impacted by changes in OA as "very high" and those dependent on sensitive taxa as "high" due to the indirect impact. However, use your expert opinion to place your tallies between these groups depending on your perception of the species' adaptability.

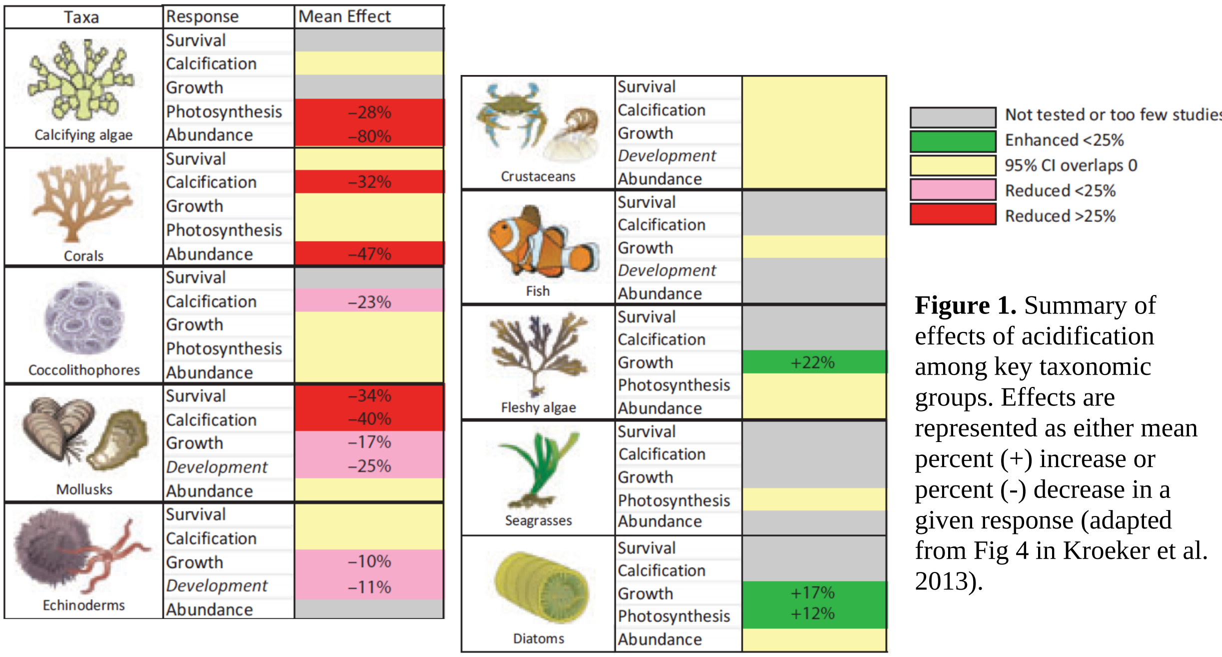


Figure 1. Summary of effects of acidification among key taxonomic groups. Effects are represented as either mean percent (+) increase or percent (-) decrease in a given response (adapted from Fig 4 in Kroeker et al. 2013).

Sensitivity to Ocean Acidification Scoring:
Sensitive taxa are taxa that consistently show negative effects from OA, such as hard corals, mollusks, calcified algae, and echinoderms (Kroeker *et al*. 2013).

- **Bin 1 (Low):** Stock either does not use sensitive taxa, or is expected to respond positively to ocean acidification. The stock does not utilize sensitive taxa for food or habitat. Species expected to respond positively to ocean acidification should be scored as low.
- **Bin 2 (Moderate)**: Stock is somewhat reliant on sensitive taxa. The stock utilizes sensitive taxa as either food or habitat but can switch to non-sensitive taxa when necessary. This can include omnivores and species that prefer coral habitats but can utilize any rigid structure.
- **Bin 3 (High):** Stock is reliant on sensitive taxa. The stock is dependent on sensitive taxa for either food or habitat (i.e., cannot switch to a non-sensitive alternative).
- **Bin 4 (Very High):** Stock is a sensitive taxa. The stock is a sensitive taxa (such as hard corals, mollusks, calcified algae, and echinoderms) that have been shown to have a consistent negative impact of OA on survival.

Relevant Species Narrative Categories: Sensitivity to OA, Habitat Specificity, Prey Specificity

10. Population Growth Rate

Goal: To estimate the relative productivity of the stock.

Relationship to climate change: More productive stocks are, in general, more resilient to long term changes in the environment, such as climate change (Lande 1993; Pecl et al. 2014).

Background: Productivity is a measure of the capacity of the stock to reproduce and recover if the population is reduced. In general, it is thought that highly productive stocks are more resilient to change because they are quicker to respond to impacts, such as fishing, or catastrophic events (Lande 1993; Pecl et al. 2014). In fisheries, productivity can be measured as the maximum intrinsic rate of increase (r_{max}). We are interested in the maximum intrinsic rate of increase as it describes how fast a population is able to recover from a disturbance. Given density dependence, the classic model of population growth can be given by: $\partial N/\partial t = r_{max}N(1 - {}^{N})$, where K is carrying capacity and for which population growth rate is maximized at 0.5K.

If a direct measurement of the maximum intrinsic rate of increase (r_{max}) is unavailable, other biological reference points that are correlated with population growth rate can be used: von Bertalanffy growth rate (k), age at maturity, maximum age, natural mortality and maximum length (Patrick *et al.*, 2010; Hutchings *et al.*, 2012). Scoring bins for these proxies were developed from an analysis of 141 marine fish species that were considered to be representative of U.S. fisheries (Patrick *et al*. 2010).

How to use expert opinion: Multiple proxies may be used to inform the final score, but the accuracy and precision of the different proxies should be considered. For example, a stock with a “good” estimate of age at maturity is in the range for a “High” score, and a “fair” estimate of maximum age is in the range for the “High” scoring bin. In that case, the scorer should use their expert opinion to weigh their response according to their confidence in the estimates. If no estimates are available, estimate a relative score for the stock across a continuum of r-selected (low) vs. k-selected (high) species.

Population Growth Rate Bins:

Parameter	**Bin 1 (Low)**	**Bin 2 (Moderate)**	**Bin 3 (High)**	**Bin 4 (Very High)**
Maximum growth rate (r_{max})	> 0.50	0.16 - 0.50	0.05 - 0.15	< 0.05
von Bertalanffy K	> 0.25	0.16 - 0.25	0.11 - 0.15	<= 0.10
Age at maturity	< 2 yrs	2 - 3 yrs	4 - 5 yrs	> 5 yrs
Maximum age	< 10 yrs	11 - 15 yrs	15 - 25 yrs	> 25 yrs
Natural mortality (M)	> 0.50	0.31 - 0.50	0.21 - 0.30	< 0.2
Maximum length	< 55cm	55 – 85cm	85 – 150cm	> 150cm

<u>Relevant Species Narrative Categories</u>: Population Growth Rate

11. Stock Size/Status

Goal: To estimate stock status to clarify how much stress from fishing the stock is experiencing and to determine if the stock's resilience or adaptive capacity are compromised due to low abundance.

Relationship to climate change: It is assumed that a stock that has a large biomass is more resilient to changes in climate. Conversely, stocks with very low biomass are likely to be in a compromised ecological position and therefore may have a diminished capability to respond to climate change (Rose, 2004). The genetic diversity, as well as the abundance, of a stock can impact its susceptibility. The assumption is that species with a limited genetic diversity could be more negatively impacted by climate change as their offspring would be less variable and thus less likely to have the combination of genes needed to adapt to changes in the environment. Note: stocks that are at historical high biomass levels may be an indication of a net positive effect to an environmental change.

Background: Fish stocks that are already being affected by other stressors are likely to have faster and more acute reactions to climate change. Fishing is the largest stressor currently impacting fish stocks (Jackson *et al.*, 2001), and the magnitude of the stress can be estimated through the status of the stock. Stock size/status can be measured as a ratio of the current stock size (B) over the biomass at maximum sustainable yield (B_{MSY}) and is a commonly used biological reference point for U.S. federally managed stocks. For other areas, B_{max} may be available and can also be used. Use the following link for information on current estimates of B/B_{MSY} in U.S. species: http://www.nmfs.noaa.gov/sfa/statusoffisheries/SOSmain.htm.

Low genetic variation can decrease a species' ability to adapt to climate change. Large variation in reproductive success between individuals, large fluctuations in population size, and frequent local extinctions can all decrease genetic diversity (Grosberg and Cunningham, 2001). Presence of these characteristics could suggest a decreased ability to adapt to changes in the environment. Beyond stock status and genetic diversity, there are additional concerns for stocks that are particularly rare. The IUCN classifies stocks with a population <10,000 mature individuals as vulnerable (IUCN 2015). Therefore, for the purposes of this attribute, stocks with population sizes less than 10,000 individuals are considered to have significantly reduced ability to adapt to climate change and should be scored as "Very High."

How to use expert opinion: If a direct measure of biomass is not available, biomass proxies (such as survey indices or spawning stock biomass) may be used. For data-poor stocks with an unknown status, or stocks that are analyzed as part of a species group, use your expert opinion to estimate the stock size and rate the data quality accordingly. We note that B_{MSY} can change which will affect B/B_{MSY} ratio and thus vulnerability scores. In situations where B_{MSY} has been recently updated, use your expert opinion to adjust your scores appropriately. Also, if a stock has known low genetic diversity, adjust your ranks accordingly.

<u>Stock Size/Status Scoring</u>:

- **Bin 1 (Low):** $B/B_{MSY} \geq 1.2$ (or proxy)

- **Bin 2 (Moderate):** $B/B_{MSY} \geq 0.8$ but < 1.2 (or proxy)
- **Bin 3 (High):** $B/B_{MSY} \geq 0.5$ but < 0.8 (or proxy)
- **Bin 4 (Very High):** $B/B_{MSY} < 0.5$ (or any stock below <10,000 mature individuals)

Relevant Species Narrative Categories: Stock Size Status

12. Other Stressors

Goal: To account for conditions that could increase the stress on a stock and thus decrease its ability to respond to changes.

Relationship to climate change: In most cases but not all, climate change is predicted to exacerbate the effects of other stressors. Fish stocks that are already being affected by other stressors are likely to have faster and more acute reactions to climate change.

Background: Scientists theorize that species experiencing additional stressors are more likely to have faster and more acute reactions to climate change (Stein et al. 2013, Sumaila et al. 2011). A stress is an activity that induces an adverse effect and therefore degrades the condition and viability of a natural system (Groves *et al*. 2000; EPA 2008). This attribute attempts to take into account interactions between climate change and other stressors already impacting fish stocks. Some examples of other stressors include: habitat degradation, invasive species, disease, pollution, and hypoxia. Although climate change is not currently the biggest threat to many natural systems, its effects are projected to be an increasingly important source of stress in the future (Mooney *et al*. 2009). Consideration of observed and projected impacts of climate change in the context of other environmental stressors is essential for effective planning and management (Tingley et al. 2014).

How to use expert opinion: For the purpose of this assessment, we are looking for detrimental impacts from other stressors. We have provided examples of other stressors that may be impacting stocks, but the list is not exhaustive. If the stock being scored is suffering from a known or suspected stressor that is not listed below, adjust the score appropriately. The magnitude of the stressors should also be considered. If a single stressor is suspected of a large impact on the stock, adjust the score appropriately. It is expected that in some cases, impacts of climate change could create positive impacts (e.g., reduction in predators). If you suspect positive impacts, adjust tallies toward the lower bins as appropriate. We are not including fishing pressure as a stressor here as it is covered under the “stock size/status” attribute.

Example of stressors the stock may be experiencing:

a) The habitat on which the stock depends is degraded. Examples include anthropogenic effects or changes to freshwater input, stratification, storm intensity, and hypoxia.
b) The stock is currently exposed to detrimental levels of pollution (chemical and/or nutrient).
c) The stock has experienced a known increase in parasites, disease, or harmful algal bloom exposure.
d) The stock has experienced a detrimental impact due to a change in the food web. Examples include increases in the abundance of predators or competitors, or the introduction of an invasive species that negatively impacts the stock. Do not include changes to prey here as they are covered under the “prey specificity” attribute.

<u>Other Stressors Scoring</u>:
If a single stressor is suspected of a large impact on the stock, adjust the score appropriately.

- **Bin 1 (Low):** Stock is experiencing no known stress other than fishing. Stock is experiencing no more than one known stressor.
- **Bin 2 (Moderate):** Stock is experiencing limited stress other than fishing. Stock is experiencing no more than two known stressors.
- **Bin 3 (High):** Stock is experiencing moderate stress other than fishing. Stock is experiencing no more than three known stressors.
- **Bin 4 (Very High):** Stock is experiencing high stress other than fishing. Stock is experiencing four or more known stressors.

Relevant Species Narrative Categories: Other Stressors

Table 2. Exposure Factors

Table 2. List of eight climate change exposure factors. Descriptions and background literature review adapted from (Lettrich et al., 2019).

Exposure factor	Goal	Low Score	High Score
1. Mean sea surface temperature	Determine if there are changes in mean ocean surface temperature comparing 1990-2020, 2030-2060, 2070-2100 periods	Low magnitude of change	High magnitude of change
2. Mean sea surface salinity	Determine if there are changes in mean ocean surface salinity comparing 1990-2020, 2030-2060, 2070-2100 periods	Low magnitude of change	High magnitude of change
3. Ocean acidification (surface pH)	Determine if there are changes in mean ocean pH comparing 1990-2020, 2030-2060, 2070-2100 periods	Low magnitude of change	High magnitude of change
4. Air temperature (a proxy for nearshore ocean temperature)	Determine if there are changes in mean air temperature (a proxy for nearshore ocean temperature) comparing 1990-2020, 2030-2060, 2070-2100 periods	Low magnitude of change	High magnitude of change
5. Mean precipitation	Determine if there are changes in mean precipitation comparing 1990-2020, 2030-2060, 2070-2100 periods	Low magnitude of change	High magnitude of change
6. Phenology of upwelling (winds)	Determine if there are changes in the timing of upwelling comparing 1990-2020, 2030-2060, 2070-2100 periods	Low magnitude of change	High magnitude of change
7. Subsurface oxygen	Determine if there are changes in mean dissolved oxygen the comparing 1990-2020, 2030-2060, 2070-2100 periods	Low magnitude of change	High magnitude of change
8. Sea level rise	Evaluate the magnitude of sea level rise relative to the change in habitat of the stock comparing 1990-2020, 2030-2060, 2070-2100 periods	Low magnitude of change	High magnitude of change

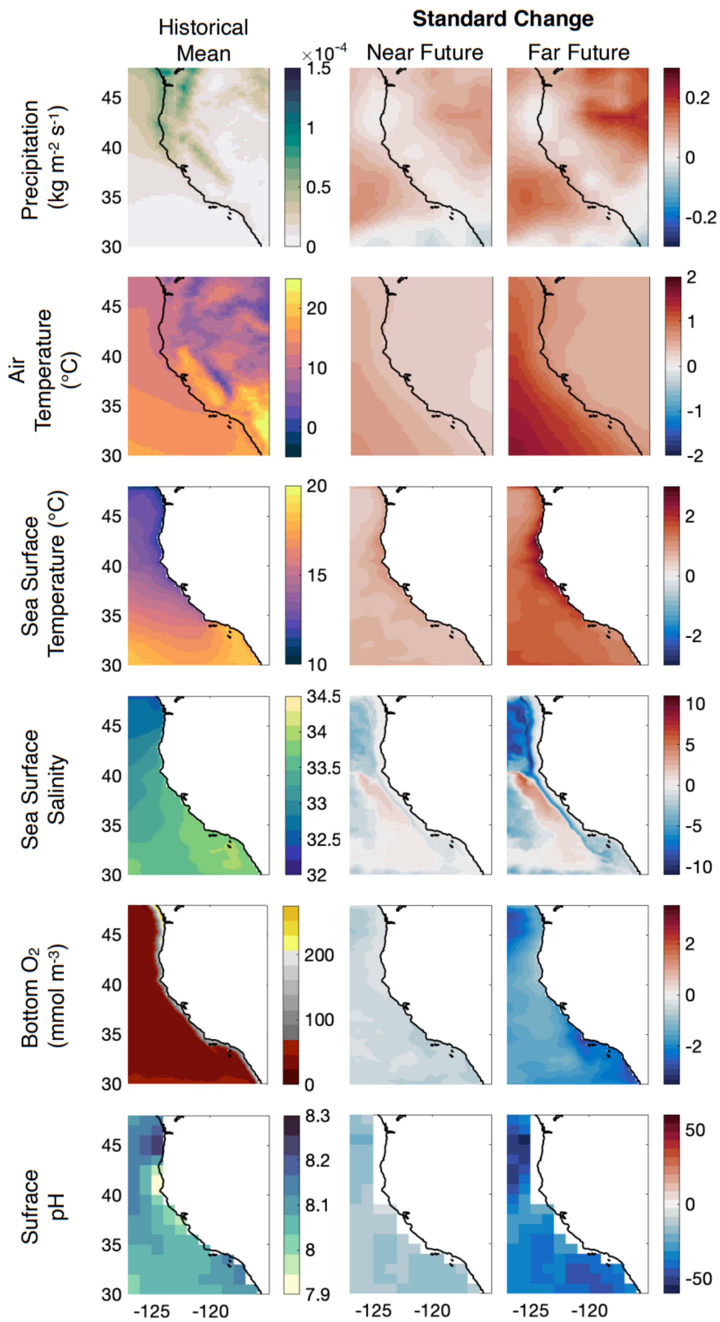
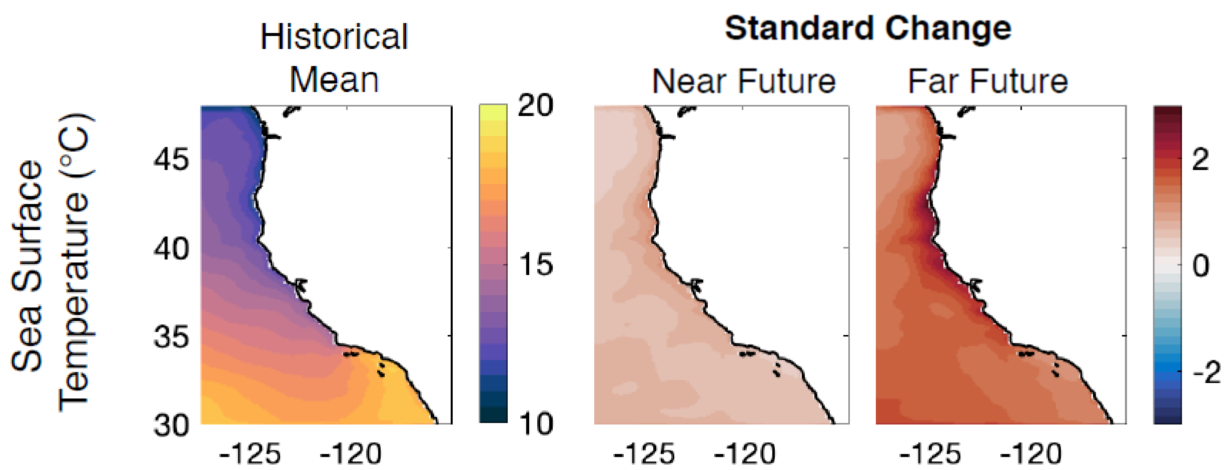


Figure 2. Historical mean (1990-2020, left) and standardized change in the near (2030–2060 relative to historical, center) and far (2070–2100 relative to historical, right) future for the climate change exposure factors: precipitation (top), air temperature at 2m (second row), sea surface Temperature (third row), sea surface Salinity (fourth row), bottom dissolved oxygen (fifth row), and surface pH (bottom row). Historical means for precipitation and air temperature are from the European Centre for Medium-Range Weather Forecasts version 5 (ERA-5; Hersbach et al., 2020) at ~25km. Historical mean for pH is from the GLODAPv2 mapped product (1972-2013, Lauvset et al., 2016) at ~100km. Standardized changes for pH are from GFDL-ESM2M, IPSL-CM5A-MR ,and Had2GEM-ES (near future: 2006-2055 relative to 2006-2055, and far future: 2055-2099 relative to 2006-2055) at ~100km (from https://psl.noaa.gov/ipcc/ocn/). The rest of the variables are from an ensemble of three downscaled projections at 10km described in Pozo Buil et al., 2021.

1. Sea Surface Temperature

Background: Sea surface temperature (SST) is measured using a variety of methods and at corresponding depths. For the purpose of this assessment, SST refers to the temperature of the upper water column, or the mixed layer. Many species exist in this depth zone for at least some of their life cycle and for some species prefer a relatively narrow range of temperatures. In assessing exposure to projected changes in SST, scorers should consider species biotic (i.e., kelp forests are acutely sensitive to SST increases) and abiotic (i.e., bays and estuaries have high exposure) habitat associations, and depth distributions (i.e., shallow and narrow depth distributions used during one or multiple life history stages have high exposure).



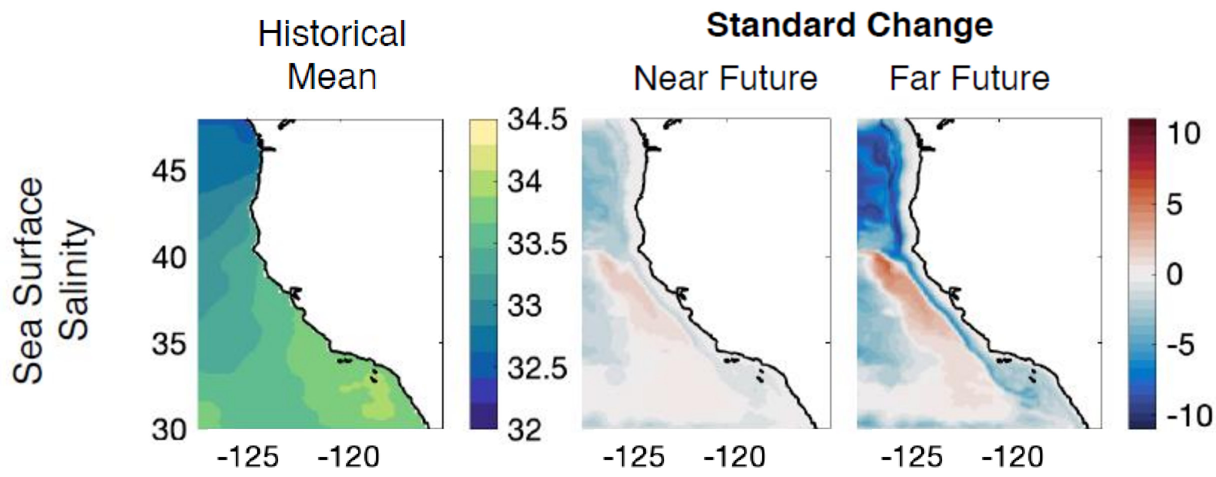
Scoring:

	Projected mean vs historical variance
Bin 1 (Low):	$\|x\| < 0.5$ std dev
Bin 2 (Moderate):	0.5 std dev $\leq \|x\| < 1.5$ std dev
Bin 3 (High):	1.5 std dev $\leq \|x\| < 2.0$ std dev
Bin 4 (Very High):	$\|x\| \geq 2.0$ std dev

<u>Relevant Species Narrative Categories:</u> Distribution Maps, Habitat Specificity, Sensitivity to Temperature (i.e., water column utilization)

2. Sea surface salinity

Background: Surface salinity is a dynamic property that affects ocean circulation and has been shown to affect spawning success (e.g., Griffin et al. 1998; Cook et al. 2005) and larval survival (e.g., Alderdice and Forrester 1968; Stick and Lindquist 2009) in some species while have substantial impacts on smaller aquatic organisms (i.e., cyanobacteria, plankton, and zooplakton) that may serve as prey. Salinity may also be an important habitat characteristic in bays and estuaries which are important nursery habitats for some species, though estuarine species are often euryhaline, adapted to tolerate fluctuating salinity, whereas many marine species are stenohaline and limited by their narrow range of physiological tolerance.



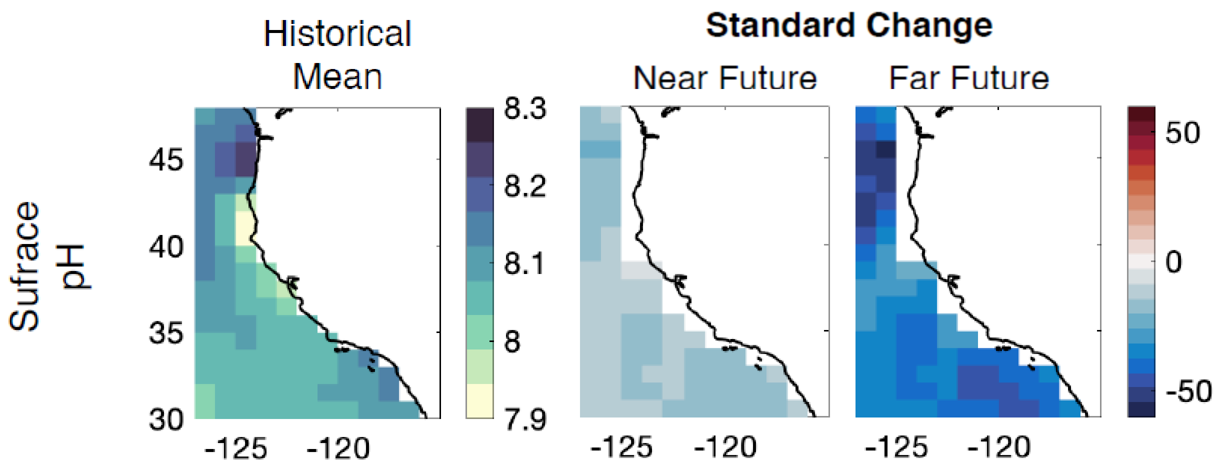
Scoring:

	Projected mean vs historical variance
Bin 1 (Low):	|x| < 0.5 std dev
Bin 2 (Moderate):	0.5 std dev ≤ |x| < 1.5 std dev
Bin 3 (High):	1.5 std dev ≤ |x| < 2.0 std dev
Bin 4 (Very High):	|x| ≥ 2.0 std dev

<u>Relevant Species Narrative Categories:</u> Distribution Maps, Habitat Specificity

3. Ocean Acidification

Background: Ocean acidification refers to the decreasing of the ocean's pH through chemical reactions resulting from increased atmospheric carbon dioxide. Changes in pH have been shown to impact habitats (e.g., coral reefs) and calcifying organisms (Kroeker et al. 2010). Although it would be best to examine changes in the ocean's pH at depths corresponding to where calcifying organisms inhabit, model projections were only available for pH levels at the ocean's surface at 1 degree grid cells. As ocean acidification is believed to be comparatively more pronounced at depth, demersal species and benthic species may have a comparatively higher exposure to projected changes in pH in the near-future, but in the far future exposure (given the magnitude of projected changes) is likely to be uniformly very high.



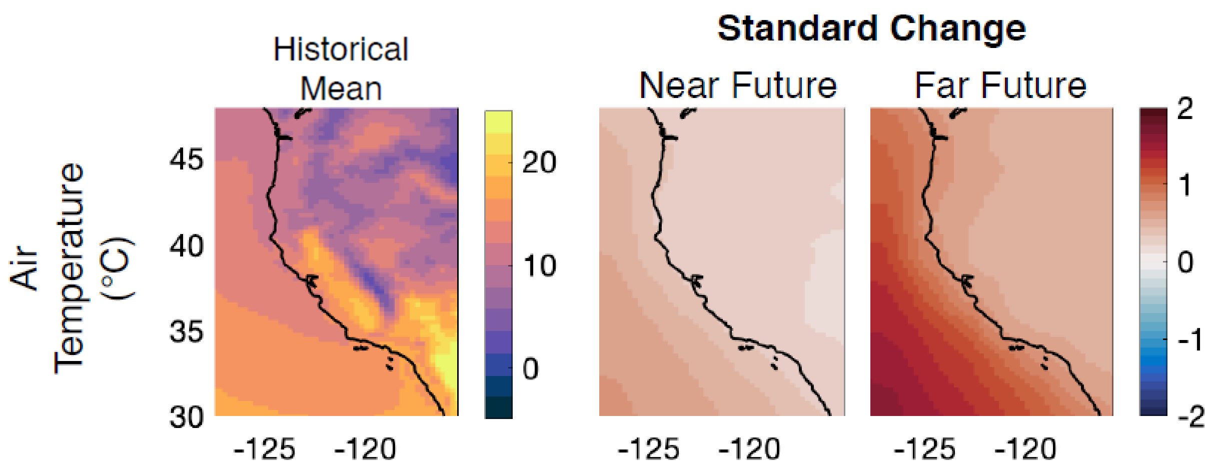
Scoring:

	Projected mean vs historical variance
Bin 1 (Low):	|x| < 0.5 std dev
Bin 2 (Moderate):	0.5 std dev ≤ |x| < 1.5 std dev
Bin 3 (High):	1.5 std dev ≤ |x| < 2.0 std dev
Bin 4 (Very High):	|x| ≥ 2.0 std dev

<u>Relevant Species Narrative Categories:</u> Distribution Maps, Sensitivity to Temperature (i.e., water column utilization).

4. Air Temperature

Background: Air temperature can serve as a valuable proxy for water temperature in estuaries and shallow coastal areas that are typically not resolved by projections of sea surface temperature (Roelofs and Bumpus 1953, Hare and Able 2007, Hare et al. 2010, Galbraith et al. 2012, Pilgrim et al. 1998). Air temperature and surface ocean temperature are likely correlated, but the two factors are distinct in terms of their impact on the biology of some species (e.g., estuaries serve as important nursery habitat for CA halibut whereas sardines inhabit surface pelagic waters). Across species, intertidal organisms may be most exposed to projected changes in air temperature.



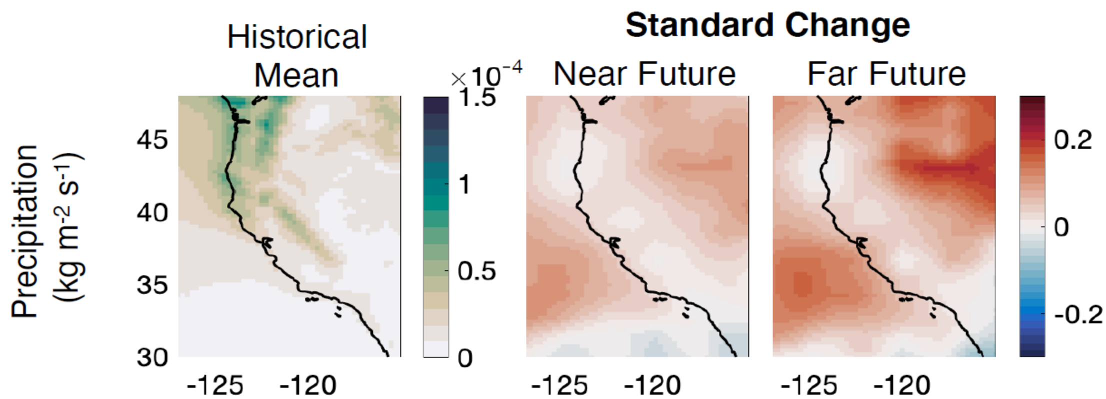
Scoring:

	Projected mean vs historical variance
Bin 1 (Low):	|x| < 0.5 std dev
Bin 2 (Moderate):	0.5 std dev ≤ |x| < 1.5 std dev
Bin 3 (High):	1.5 std dev ≤ |x| < 2.0 std dev
Bin 4 (Very High):	|x| ≥ 2.0 std dev

<u>Relevant Species Narrative Categories:</u> Distribution Maps, Habitat Specificity

5. Precipitation

Background: Precipitation affects surface salinity in the open ocean and streamflow in coastal areas. High streamflow serves as a delivery mechanism for pollutants and debris from land-based sources into estuaries, bays, and nearshore marine environments (Kuivila and Foe 1995). Most climate models do not simulate streamflow, precipitation is therefore used here as a proxy for pollutants entering in estuarine ecosystems. Anadromous organisms and sessile, benthic organisms that inhabit coastal areas near stream beds and river mouths may be comparatively more exposed (though also potentially more tolerant) to increases in stream outflow and freshwater discharge as compared to open ocean species (where standard change is projected to be minimal).



Scoring:

	Projected mean vs historical variance
Bin 1 (Low):	|x| < 0.5 std dev
Bin 2 (Moderate):	0.5 std dev ≤ |x| < 1.5 std dev
Bin 3 (High):	1.5 std dev ≤ |x| < 2.0 std dev
Bin 4 (Very High):	|x| ≥ 2.0 std dev

Relevant Species Narrative Categories: Distribution Maps, Habitat Specificity

6. Phenology of Upwelling

Background: Upwelling occurs when equatorward alongshore winds drive offshore Ekman transport, and surface waters are replaced with nutrient-rich deep waters. The input of nutrient-rich waters to the euphotic zone promotes high levels of primary productivity and Eastern Boundary Upwelling Systems (EBUS) such as the California Current System (CCS) support nearly 20% of the global fish catch despite occupying less than 1% of the global ocean (Mote et al., 2002; Pauly and Christensen, 1995). Many organisms in the CCS have life history traits (foraging, reproduction, migration) adapted to the present timing of annual upwelling events (Bograd et al. 2009). Thus, a delayed or early start to spring-summer upwelling may result in a temporal mismatch between predator needs and prey availability (Bograd et al. 2009, Bakun et al. 2015).

Upwelling intensity is affected by basin-scale modes of climate variability in the north Pacific (e.g., ENSO, PDO and NPGO). Positive Pacific Decadal Oscillation (PDO) and El Niño Southern Oscillation (ENSO) tend to be correlated with weaker nearshore upwelling (<50 km from shore) and stronger offshore upwelling (>50 km from shore), while the North Pacific Gyre Oscillation (NPGO) is associated with the opposite (Chhak and Di Lorenzo 2007; Di Lorenzo et al., 2008; Macias et al., 2012; Jacox et al., 2014). The PDO influence is stronger in the northern CCS, while the NPGO influence is stronger in the southern CCS. Basin-scale climate variability (ENSO, PDO, and NPGO) in the CCS may dominate on 30-50 year time scales, making it difficult to distinguish climate change driven upwelling from natural variability (Jacox et al., 2015). Yet, delayed and weakened upwelling in the central CCS during El Niño years (Bograd et al. 2009), along with the frequency of extreme El Niño events, are predicted to double with climate change (Cai et al. 2014). If species abundance has been negatively impacted by changes in upwelling timing and magnitude associated with past ENSO events, they may be comparatively more exposed to corresponding changes in the future.

Overall, recent studies suggest that changes in climate driven upwelling will be season, region, and latitude dependent, with the CCS experiencing increased upwelling to the north during the spring, decreased summer upwelling to the south, and a decrease in upwelling in the winter (Figure 1; Wang et al., 2015; Rykaczewski et al., 2015). Rykaczewski et al. 2015 predicted an average decrease of 8% (+/- 10% SD) in upwelling favorable winds across the CCS. The Wang et al. 2015 and Rykaczewski et al. 2015 studies are the first to use an ensemble of over 20 coupled atmosphere-ocean general circulation models (AOGCMs), developed in association with the Intergovernmental Panel on Climate Change; therefore, they are currently the most reliable predictions of climate change impacts on upwelling favorable winds in the CCS. However, uncertainty in the predictions still exists because the models included in the ensemble are global models, making it difficult to resolve local dynamics in the CCS.

Impacts of upwelling on the ecosystem will depend on their interaction with other changes in the water column. If upwelling intensifies, increased nutrient input could stimulate added productivity to a point, however too much wind will increase turbulence and offshore transport of surface waters and reduce productivity nearshore. Conversely, either reduced upwelling or upper ocean warming (and resultant increased water column stratification) would reduce the efficacy of coastal upwelling for delivering nutrients to the euphotic zone. Such a scenario has been invoked to explain ecosystem changes in the latter half of the 20th century, where an abrupt increase in sea surface temperature and water column stratification around 1977 reduced the input of nutrients to the surface layer and was linked to widespread changes in the zooplankton community, decreased abundance of larval fish and seabirds, and reduced commercial fish landings.(Roemmich and McGowan 1995; Palacios et al. 2004; Di Lorenzo et al., 2005). Finally, changes in basin-scale circulation may result in dramatic increases in the nutrient content of upwelling source waters (Rykaczewski and Dunne, 2010), in which case the coastal zone is likely to be highly productive regardless of how the wind changes.

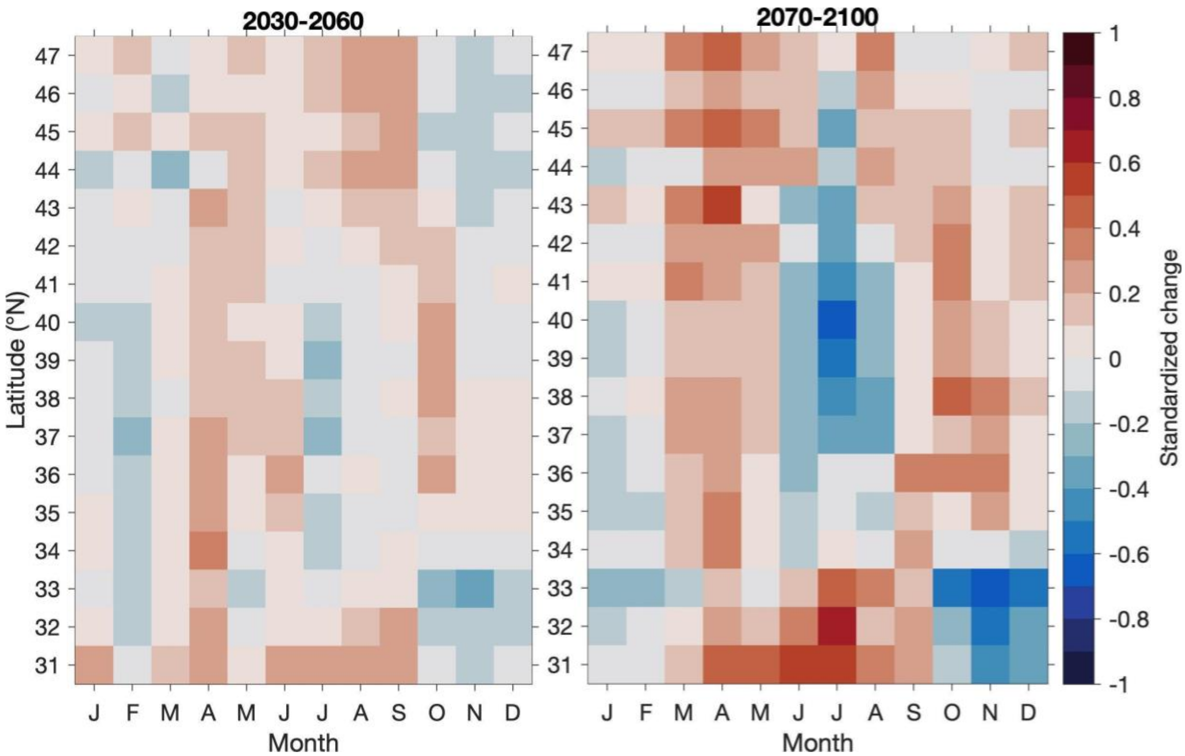


Figure 3. Projected change in coastal upwelling magnitude (CUTI). Change is relative to a 1990-2020 reference period, and is standardized by the standard deviation during the reference period. See Jacox et al., 2024 for source data.

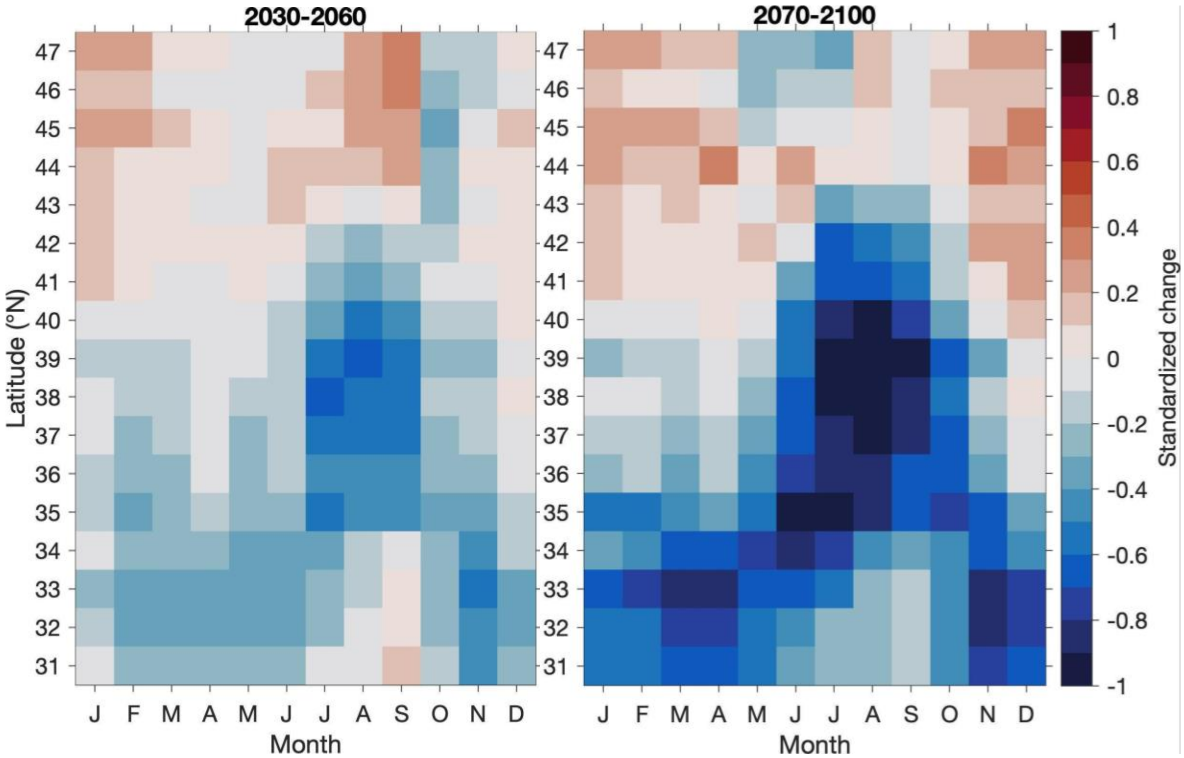


Figure 4. As in Figure 3, but for vertical nitrate flux (BEUTI). See Jacox et al., 2024 for source data.

Scoring:

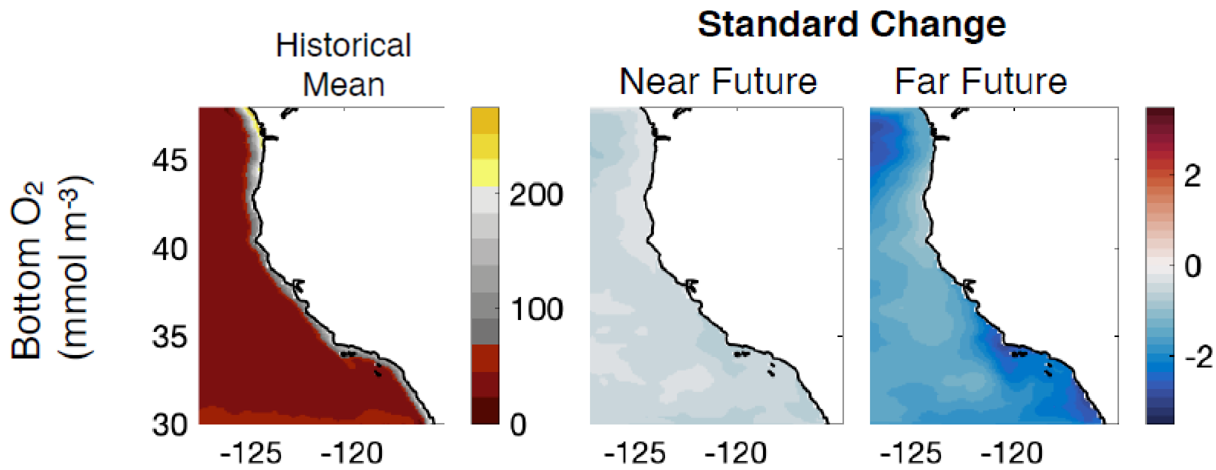
	Projected mean vs historical variance
Bin 1 (Low):	|x| < 0.5 std dev; relatively low exposure to projected changes in CUTI & BEUTI.
Bin 2 (Moderate):	0.5 std dev ≤ |x| < 1.5 std dev; moderate exposure to projected changes in CUTI & BEUTI
Bin 3 (High):	1.5 std dev ≤ |x| < 2.0 std dev; high exposure to projected changes in CUTI & BEUTI
Bin 4 (Very High):	|x| ≥ 2.0 std dev; high exposure to projected changes in CUTI and & BEUTI with severe effects of the species are expected.

<u>Relevant Species Narrative Categories:</u> Distribution Maps, Complexity in Reproductive Strategy (only if upwelling mentioned), Spawning Cycle (only if upwelling mentioned), Other Stressors (only if upwelling mentioned), Specificity in Early Life History (only if upwelling mentioned)

7. Subsurface Dissolved Oxygen

Background: Dissolved oxygen (DO) is fundamental for all aerobic life and it plays a direct role in biogeochemical cycling of nutrients in the ocean (Keeling et al., 2010). Once DO concentrations drop below a certain level organisms suffer from a variety of stresses; this oxygen deficiency is termed hypoxia. Waters are considered hypoxic when O2 concentrations are below 60 μmol kg^{-1} and the depth of hypoxia is the shallowest depth at which waters become hypoxic (Bograd et al, 2008). DO concentrations are influenced by air-sea oxygen exchange, circulation, ventilation, production, and respiration (Bograd et al., 2008). DO levels are predicted to decline with climate change because oxygen is less soluble in warm water and because increased stratification reduces the exchange of surface oxygen into the ocean interior (Keeling et al., 2010).

Hypoxic conditions occur at mid-depths (250-400 m) across the North Pacific. In fact, the CCS has an acute and extensive oxygen minimum zone (OMZ), the zone in which oxygen saturation is at its lowest (Keeling et al., 2010; Moffitt et al., 2015). Over the past 50 years there has been an expansion in the area and volume of OMZs in the open North Pacific (Keeling et al, 2010). Similar declines have been observed in the CCS, with studies focusing on the central Oregon coast and the Southern California Bight. In the North Pacific the depth of hypoxia has shoaled from 400 to 300m from the 1950s to present (Whitney et al. 2007). The hypoxic boundary in Southern California shoaled by 45 (offshore) to 90 (inshore) m from 1985 to 2007 (McClatchie et al. 2010; Bograd et al., 2008). Species that have high metabolic oxygen demands; live on the benthos in coastal areas where algal organic material accumulates (i.e., freshwater discharge associated w/ rivers) or prospective deep water hypoxic zones, and/or undertake extended vertical migrations may be most exposed to projected changes in subsurface dissolved oxygen. Even in the absence of direct physiological effects, changes in DO may impact prey species.



Scoring:

	Projected mean vs historical variance
Bin 1 (Low):	$\lvert x \rvert < 0.5$ std dev
Bin 2 (Moderate):	0.5 std dev $\leq \lvert x \rvert < 1.5$ std dev
Bin 3 (High):	1.5 std dev $\leq \lvert x \rvert < 2.0$ std dev
Bin 4 (Very High):	$\lvert x \rvert \geq 2.0$ std dev

Relevant Species Narrative Categories: Distribution Maps, Habitat Specificity, Sensitivity to Temperature (i.e., water column utilization).

8. Sea level rise

Background: Sea level rise refers to the relative change in sea level and has both a local and a global component. Sea level rise comprises thermal expansion of sea water, addition of water volume from melting of land-based glaciers, and local changes in land elevation due to processes such as subsidence and isostatic rebound. Sea level rise can effectively eliminate some shoreline habitat over time and has the potential to exacerbate coastal flooding during storms and spring tides. Stocks located offshore that are trophically linked to estuary, wetland, seagrass, or beach habitat may also experience indirect effects from sea level rise.

Projections of sea level rise along the West Coast of the United States have also been estimated. In 2012 the National Research Council (NRC) predicted future sea level rise in California, Oregon, and Washington for the years 2030, 2050, and 2100 (NRC 2012). The NRC included in their models how sea level rise is affected by regional factors including: 1) ENSO events (El Niño leads to higher sea levels and La Niña to lower), 2) the rising and sinking of land along the coast, and 3) the proximity of Alaska's glaciers which exert a gravitational pull on sea water. The results are listed in Table 1. Sea level rise south of Cape Mendocino are similar to global projections, where the coast is sinking 1 mm/yr; while north of Cape Mendocino the projections are lower because much of the coast is rising (around 1.5-3.0 mm/yr), causing seismic strain. If there was a large earthquake north of Cape Mendocino to reduce the strain, sea level could rise an additional 1-2m above these projections.

	2030	**2050**	**2100**
South of Cape Mendocino	.04 – .3 meters	.12 – .61 meters	.42 – 1.67 meters
North of Cape Mendocino	-.04 – .23 meters	-.03 – .48 meters	.10 – 1.43 meters

Table 1: Sea level rise projections for the West Coast of the U.S. relative to the year 2000.

An increasing rate of sea level rise will worsen the impacts of high tides, storms, and floods (Cayan et al. 2008). Furthermore, intense storms are expected to become more frequent with climate change, leading to more frequent sea level extremes (Cayan et al., 2008; Hansen et al.; 2015). For example, the incidence of extreme water heights in San Francisco Bay is predicted to increase from 9 hours per decade to hundreds of hours per decade by 2050 (NRC 2012). Sea level rise will result in salinity intrusion into delta areas and will damage marginal ecosystems (e.g., seagrass beds and salt marshes) that many juvenile fish rely on (Cayan et al., 2008).

To score this exposure factor, first consider whether the stock will experience sea level rise in a relevant manner. Stocks that use wetlands, seagrass beds, beaches, and/or estuaries are expected to experience direct effects of sea level rise and should be scored in Bin 3 or Bin 4 based on the degree of projected sea level rise within their range. Stocks with coastal distributions and in waters over the continental shelf are expected to experience diluted direct effects of sea level rise that decrease with depth. However, these coastal stocks may be trophically linked to wetland, seagrass, or estuarine habitat and may experience shifts in available habitat from a changing coastline. Generally, coastal stocks will align with Bin 2. Offshore and open ocean stocks are not expected to directly experience the effects of sea level rise, though they may have trophic linkages to wetland, seagrass, or estuarine habitat. Generally, offshore stocks will align with Bin 1.

Scoring:

Bin 1 (Low):	Stock is found generally in deeper water beyond the continental shelf
Bin 2 (Moderate):	Stock is generally coastal or found in continental shelf waters
Bin 3 (High):	Stock relies on wetland, seagrass, beach, or estuary habitat for one or more life stage and the change in regional sea level within their range is expected to increase less than 7 mm yr^{-1} by 2050
Bin 4 (Very High):	Stock relies on wetland, seagrass, beach, or estuary habitat for one or more life stage and regional sea level within their range is expected to increase greater than or equal to 7 mm yr^{-1} by 2050

Relevant Species Narrative Categories: Distribution Maps, Habitat Specificity

References

Bakun, A. 2010. Linking climate to population variability in marine ecosystems characterized by non-simple dynamics: Conceptual templates and schematic constructs. Journal of Marine Systems, 79: 361–373.

Baumann, H., Talmage, S. C., and Gobler, C. J. 2012. Reduced early life growth and survival in a fish in direct response to increased carbon dioxide. Nature Climate Change, 2: 38–41. Nature Publishing Group.

Clavel, J., Julliard, R., and Devictor, V. 2011. Worldwide decline of specialist species: toward a global functional homogenization? Frontiers in Ecology and the Environment, 9: 222–228.

Doney, S. C., Ruckelshaus, M., Emmett Duffy, J., Barry, J. P., Chan, F., English, C. A., Galindo, H. M., *et al.* 2012. Climate Change Impacts on Marine Ecosystems. Annual Review of Marine Science, 4: 11–37.

Drinkwater, K. F. 2005. The response of Atlantic cod (Gadus morhua) to future climate change. ICES Journal of Marine Science, 62: 1327–1337.

Foden, W. B., Butchart, S. H. M., Stuart, S. N., Vié, J.-C., Akçakaya, H. R., Angulo, A., DeVantier, L. M., *et al.* 2013. Identifying the World's Most Climate Change Vulnerable Species: A Systematic Trait-Based Assessment of all Birds, Amphibians and Corals. PLOS ONE, 8: e65427. Public Library of Science.

Franke, A., and Clemmesen, C. 2011. Effect of ocean acidification on early life stages of Atlantic herring (*Clupea harengus* L.). Biogeosciences, 8: 3697–3707. Copernicus GmbH.

Frommel, A. Y., Maneja, R., Lowe, D., Malzahn, A. M., Geffen, A. J., Folkvord, A., Piatkowski, U., *et al.* 2012. Severe tissue damage in Atlantic cod larvae under increasing ocean acidification. Nature Climate Change, 2: 42–46. Nature Publishing Group.

Gabay, Y., Fine, M., Barkay, Z., and Benayahu, Y. 2014. Octocoral Tissue Provides Protection from Declining Oceanic pH. PLOS ONE, 9: e91553. Public Library of Science.

Graham, N. A. J., Chabanet, P., Evans, R. D., Jennings, S., Letourneur, Y., Aaron MacNeil, M., McClanahan, T. R., *et al.* 2011. Extinction vulnerability of coral reef fishes. Ecology Letters, 14: 341–348.

Grosberg, R., and Cunningham. 2001. Genetic structure in the sea : from populations communities. Marine Community Ecology. Sinauer Associates. https://cir.nii.ac.jp/crid/1573387450011251584 (Accessed 10 February 2023).

Harley, C. D. G., Anderson, K. M., Demes, K. W., Jorve, J. P., Kordas, R. L., Coyle, T. A., and Graham, M. H. 2012. Effects of Climate Change on Global Seaweed Communities. Journal of Phycology, 48: 1064–1078.

Hjort, J. 1914. Fluctuations in the great fisheries of northern Europe viewed in the light of biological research. ICES.

Hoegh-Guldberg, O., Mumby, P. J., Hooten, A. J., Steneck, R. S., Greenfield, P., Gomez, E., Harvell, C. D., *et al.* 2007. Coral Reefs Under Rapid Climate Change and Ocean Acidification. Science, 318: 1737–1742. American Association for the Advancement of Science.

Hutchings, J. A., Myers, R. A., García, V. B., Lucifora, L. O., and Kuparinen, A. 2012. Life-history correlates of extinction risk and recovery potential. Ecological Applications, 22: 1061–1067.

Jablonski, D., and Lutz, R. A. 1983. Larval Ecology of Marine Benthic Invertebrates: Paleobiological Implications. Biological Reviews, 58: 21–89.

Jackson, J. B. C., Kirby, M. X., Berger, W. H., Bjorndal, K. A., Botsford, L. W., Bourque, B. J., Bradbury, R. H., *et al.* 2001. Historical Overfishing and the Recent Collapse of Coastal Ecosystems. Science, 293: 629–637.

Jacox, M.G., Bograd, S.J., Fiechter, J., Pozo Buil, M., Alexander, M., Amaya, D., Cordero Quiros, N., Ding, H. and Rykaczewski, R.R., 2024. Linking upwelling dynamics and subsurface nutrients to

projected productivity changes in the California Current System. Geophysical Research Letters, *51*(10), p.e2023GL108096.
Kawaguchi, S., Kurihara, H., King, R., Hale, L., Berli, T., Robinson, J. P., Ishida, A., *et al.* 2010. Will krill fare well under Southern Ocean acidification? Biology Letters, 7: 288–291. Royal Society.
Kroeker, K. J., Kordas, R. L., Crim, R., Hendriks, I. E., Ramajo, L., Singh, G. S., Duarte, C. M., *et al.* 2013. Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming. Global Change Biology, 19: 1884–1896.
Marteinsdottir, G., and Thorarinsson, K. 1998. Improving the stock-recruitment relationship in Icelandic cod (Gadus morhua) by including age diversity of spawners. Canadian Journal of Fisheries and Aquatic Sciences, 55: 1372–1377. NRC Research Press.
Nelson, W. A. 2009. Calcified macroalgae – critical to coastal ecosystems and vulnerable to change: a review. Marine and Freshwater Research, 60: 787–801. CSIRO PUBLISHING.
Okey, T. A., Agbayani, S., and Alidina, H. M. 2015. Mapping ecological vulnerability to recent climate change in Canada's Pacific marine ecosystems. Ocean & Coastal Management, 106: 35–48.
Orr, J. C., Fabry, V. J., Aumont, O., Bopp, L., Doney, S. C., Feely, R. A., Gnanadesikan, A., *et al.* 2005. Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms. Nature, 437: 681–686. Nature Publishing Group.
Patrick, W. S., Spencer, P., Link, J., Cope, J., Field, J., Kobayashi, D., Lawson, P., *et al.* 2010. Using productivity and susceptibility indices to assess the vulnerability of United States fish stocks to overfishing. Fishery Bulletin, 108: 305–322.
Pecl, G. T., Ward, T. M., Doubleday, Z. A., Clarke, S., Day, J., Dixon, C., Frusher, S., *et al.* 2014. Rapid assessment of fisheries species sensitivity to climate change. Climatic Change, 127: 505–520.
Pineda, J., Hare, J. A., and Sponaugle, S. 2007. Larval Transport and Dispersal in the Coastal Ocean and Consequences for Population Connectivity. Oceanography, 20: 22–39. Oceanography Society.
Planque, B., and Frédou, T. 1999. Temperature and the recruitment of Atlantic cod (Gadus morhua). Canadian Journal of Fisheries and Aquatic Sciences, 56: 2069–2077. NRC Research Press.
Punt, A. E., A'mar, T., Bond, N. A., Butterworth, D. S., de Moor, C. L., De Oliveira, J. A. A., Haltuch, M. A., *et al.* 2014. Fisheries management under climate and environmental uncertainty: control rules and performance simulation. ICES Journal of Marine Science, 71: 2208–2220.
Ries, J. B., Cohen, A. L., and McCorkle, D. C. 2009. Marine calcifiers exhibit mixed responses to CO2-induced ocean acidification. Geology, 37: 1131–1134.
Rijnsdorp, A. D., Peck, M. A., Engelhard, G. H., Möllmann, C., and Pinnegar, J. K. 2009. Resolving the effect of climate change on fish populations. ICES Journal of Marine Science, 66: 1570–1583.
Rose, G. A. 2004. Reconciling overfishing and climate change with stock dynamics of Atlantic cod (Gadus morhua) over 500 years. Canadian Journal of Fisheries and Aquatic Sciences, 61: 1553–1557. NRC Research Press.
Shoji, J., Toshito, S., Mizuno, K., Kamimura, Y., Hori, M., and Hirakawa, K. 2011. Possible effects of global warming on fish recruitment: shifts in spawning season and latitudinal distribution can alter growth of fish early life stages through changes in daylength. ICES Journal of Marine Science, 68: 1165–1169.
Spalding, M. D., Fox, H. E., Allen, G. R., Davidson, N., Ferdaña, Z. A., Finlayson, M., Halpern, B. S., *et al.* 2007. Marine Ecoregions of the World: A Bioregionalization of Coastal and Shelf Areas. BioScience, 57: 573–583.
Teck, S. J., Halpern, B. S., Kappel, C. V., Micheli, F., Selkoe, K. A., Crain, C. M., Martone, R., *et al.* 2010. Using expert judgment to estimate marine ecosystem vulnerability in the California Current. Ecological Applications, 20: 1402–1416.
Walther, G.-R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J. C., Fromentin, J.-M., *et al.* 2002. Ecological responses to recent climate change. Nature, 416: 389–395. Nature Publishing Group.
Wicks, L. C., and Roberts, J. M. 2012. Benthic invertebrates in a high- CO2 world. *In* Oceanography and Marine Biology. CRC Press. 62 pp.

Wilson, S. K., Burgess, S. C., Cheal, A. J., Emslie, M., Fisher, R., Miller, I., Polunin, N. V. C., *et al*. 2008. Habitat Utilization by Coral Reef Fish: Implications for Specialists vs. Generalists in a Changing Environment. Journal of Animal Ecology, 77: 220–228. [Wiley, British Ecological Society].