Vulnerability of fishery resources to climate change in the Tropical Eastern Pacific Ecosystem off Peru

(Supplementary information)

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Table of contents

Methods S1. Species profiles

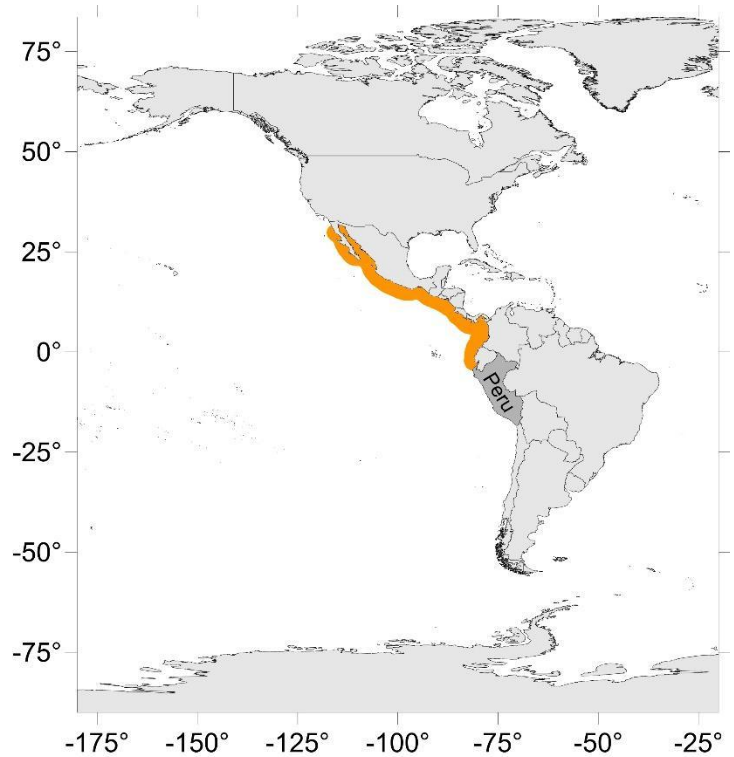
Benthic

1.1 Black ark - *Anadara tuberculosa*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	In Tanzania, *A. antiquata* has an approximate fecundity of 1,652,000 ± 562,000 eggs (Mzighani 2005); similar fecundity is assumed for *A. tuberculosa*.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Recruitment events are considered consistent every 1–2 years.
Average age at maturity	In the Colombian Caribbean, the mean length at sexual maturity is 46.7 ± 9.3 mm, and the length at first maturity is 43.5 mm (Lucero-Rincón et al. 2013), at approximately 12 months of age (Borda & Cruz 2004). However, smaller mature individuals have also been observed in Peru (Marín 2013) and along the Mexican coast, where the minimum and maximum sizes at maturity are 36.5 mm and 59 mm, respectively (Pérez 2005).
Generalist vs. specialist – food and habitat	Filters plankton (Mora 1990; Mora & Moreno 2010); inhabits muddy bottoms, buried at 1–30 cm deep between the roots of mangroves (Ordinola et al. 2010a).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Has a planktonic larval phase which development lasts between 23 and 31 days in oceanic waters (Borda & Cruz 2004).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Movement at adult/juvenile phase is probably limited.

Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance

Distributed from Baja California, Mexico to Punta Malpelo, Peru, near the Tumbes river in Peru (Mora 1990; Mora & Moreno 2010). Approximately 35° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range

Currently there are no reports of habitat availability further south of its geographic distribution within Peruvian waters. However, there is habitat availability (~ 30°) to the north of Peru.

Phenology

Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows

Not available.

Environmental variable as a phenological cue for settlement or metamorphosis

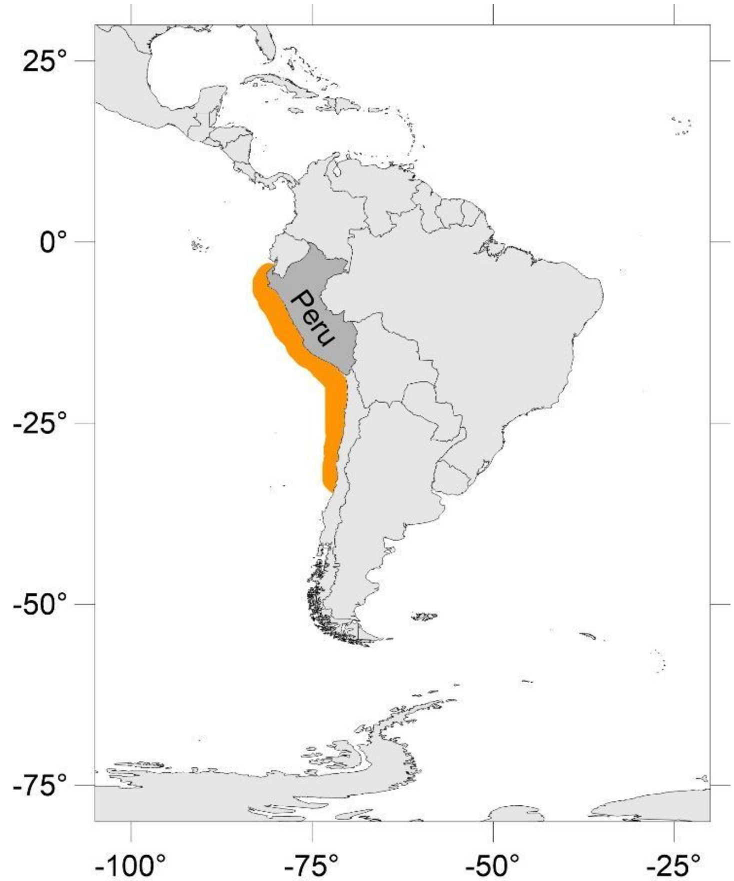
Not available.

Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Summer (January-March) is the most critical breeding season. The period of greatest reproductive intensity of *A. tuberculosa* in the tropical region (northern Peru, Ecuador and Colombia) seems to occur between the first days of December and the end of March (Espinosa et al. 2010), with a lower reproductive peak between June and August. Therefore, it is considered that the duration of the spawning or breeding season is > 4 months.
Migration (seasonal and spawning)	Unlikely.
Exposure	
Response to environmental variability	Changes in the size of the local population are likely with climate change. Temperature, turbidity and salinity can affect *Anadara* spp population growth. The black ark can be affected by El Niño events (Díaz & Orlieb 1993; Llanos et al. 2010) due to various changes in the environment, from changes in food availability to habitat modification. Other species of the genus *Anadara*, for example *A. granosa*, show anomalous growth that tends to decrease in relation to the increase in temperature (Broom 1982). Ocean acidification is a threat to this species due to the dissolution of the shell; an effect that has been observed in other calciferous species.

1.2 Changos octopus - *Octopus mimus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Up to 20,000 eggs (Cortez et al. 1995); 432,000 eggs (Baltazar et al. 2000).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Due to its annual life cycle, recruitment to the fishery must occur before one year of life.
Average age at maturity	First maturity occurs at 12.5 cm of body dorsal length (Ishiyama et al. 1999). Octopuses generally have an annual life cycle, therefore it is assumed that this species reaches sexual maturity in maximum one year.

Generalist vs. specialist – food and habitat	In Pucusana, Peru it feeds on crustaceans, brachyurians, barnacles, gastropods and bivalve molluscs, echinoderms and fishes; canibalism also occurs (Cardoso et al. 2004). Inhabits rocky and intertidal reefs at 0–30 m depth (Norman et al. 2013).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	It is assumed that paralarvae may spend 35–60 days in the plankton, as per *O. vulgaris* (Villanueva 1995; Carrasco et al. 2006).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Not available.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Distributed from Tumbes, Peru to San Vicente, Chile. The distribution is also suggested from northern Peru to Valparaiso, Chile (Norman et al. 2013); approximately 35° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 17° of latitude may be available to the south of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Spawning peaks appear to occur at higher temperatures (Cortez et al. 1995). Highest values of gonadosomatic index, from September to December, show that the period of sexual maturity and spawning coincides with the increase in sea surface temperature (Ishiyama et al. 1999).
Environmental variable as a phenological cue for settlement or metamorphosis	Cephalopods tend to have marked growth responses due to temperature changes (Forsythe & Van Heukelem 1987), with growth rates increasing at higher temperatures.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Highest values of gonadosomatic index are from September to December (Ishiyama et al. 1999). Therefore, it is considered that the duration of the spawning or breeding season is approximately 4 months.

Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Low temperatures do not favor the sexual maturity of *O. mimus*, whereas the higher spawning peaks appear to occur at higher temperatures (Cortez et al. 1995). The highest values of the gonadosomatic index from September to December show that the period of sexual maturity and spawning of *O. mimus* coincides with the gradual increase in sea surface temperature (Ishiyama et al. 1999). In addition, cephalopods have marked growth responses due to temperature changes (Forsythe & Van Heukelem 1987). During warm events, i.e., during El Niño, catches of *O. mimus* increased in Peru (Cardoso et al. 2004).

1.3 Green spiny lobster - *Panulirus gracilis*

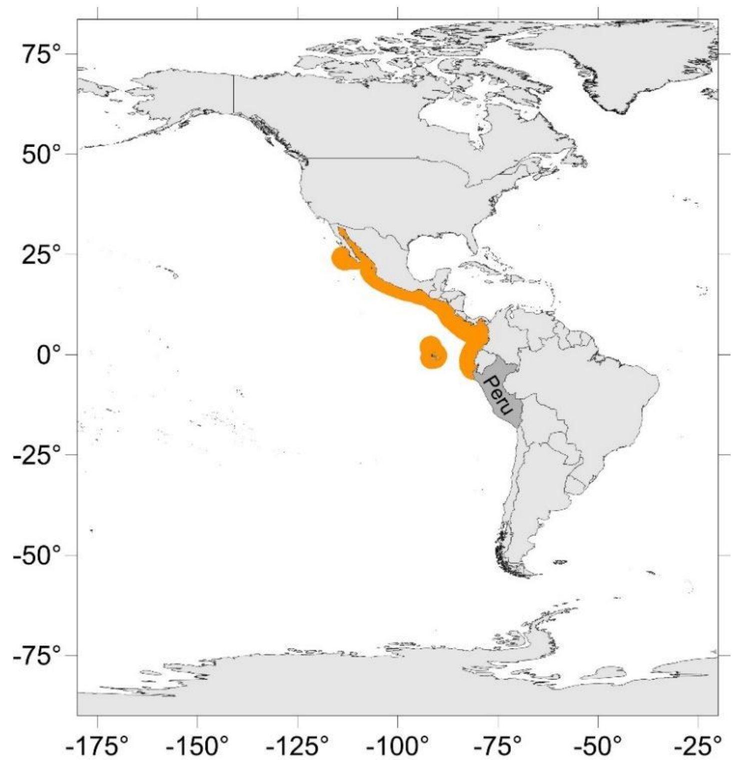
Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Not available.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Episodic recruitment events.
Average age at maturity	Age at first maturity is 2.1 years in Central American waters (Naranjo-Madrigal 2011).
Generalist vs. specialist – food and habitat	Lives up to 18 m deep in rocky bottoms (Holthius 1991; Butler et al. 2011; Naranjo-Madrigal 2011).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	The planktonic larval phase is assumed to last over 1 or 2 years.

Capacity for adult/juvenile movement – lifetime range post-larval stage

Assumed to be limited.

Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance

This species is distributed from Baja California, Mexico to northern Peru; this is a latitudinal coverage of approximately 35° (Holthius 1991; Butler et al. 2011; Naranjo-Madrigal 2011).



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range

Currently there are no reports of habitat availability further south of its geographic distribution within Peruvian waters. However, there is habitat availability (~ 30°) to the north of Peru.

Phenology

Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows

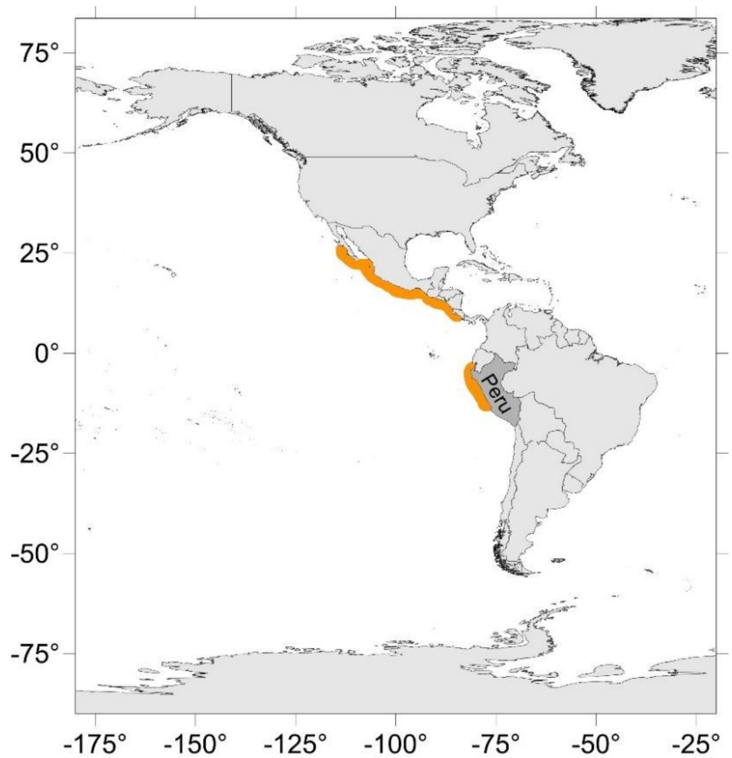
Not available.

Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Spawns multiple times throughout the year (Vega et al. 2013). Therefore, it is considered that the duration of the spawning or breeding season is > 4 months.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Limited available information. Observations by IMARPE (unpublished data) indicate that this species may be affected by drastic changes in local oceanographic conditions, such as those produced by El Niño events.

1.4 Pacific goose barnacle - *Pollicipes elegans*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	The fertility of *P. elegans* has been estimated between 122,000 and 538,000 embryos (Villena 1995).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Two annual biological recruitment pulses (i.e., cypress settlements on adult peduncles) were observed in Paita, the most intense from July to September (Oliva 1995). For a similar species in Portugal (*P. pollicipes*), interannual variations have been observed in the recruitment season and its duration (Cruz et al. 2010).
Average age at maturity	Length at sexual maturity was estimated at 22.8 mm length of captitulum (Villena 1995); age at maturity may be estimated from length at maturity.
Generalist vs. specialist – food and habitat	Feed on copepod and diatom larvae (Kameya & Zeballos 1988). Associated with hard substrates in the areas of Punta Mero and Cancas, with patches on the side of the rocks that is exposed to intense waves (Ordinola et al. 2010b).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement	Members of the family Pollicipedidae present several nauplii-like larval stages, followed by a last cypress-like

(benthic species), hatching to yolk sac re-adsorption (pelagic species)	stage, which finally settles on the peduncle of a conspecific adult, metamorphosing to the juvenile stage (Seoane 2015). The larval life span has been estimated at one month (Molares 1994).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Juveniles move through the adult peduncle towards the rocky substrate where it becomes completely sessile (Seoane 2015).
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Has distribution patches from northern Mexico to Peru (Ordinola et al. 2010b; Marchant et al. 2015); approximately 40° of latitude.

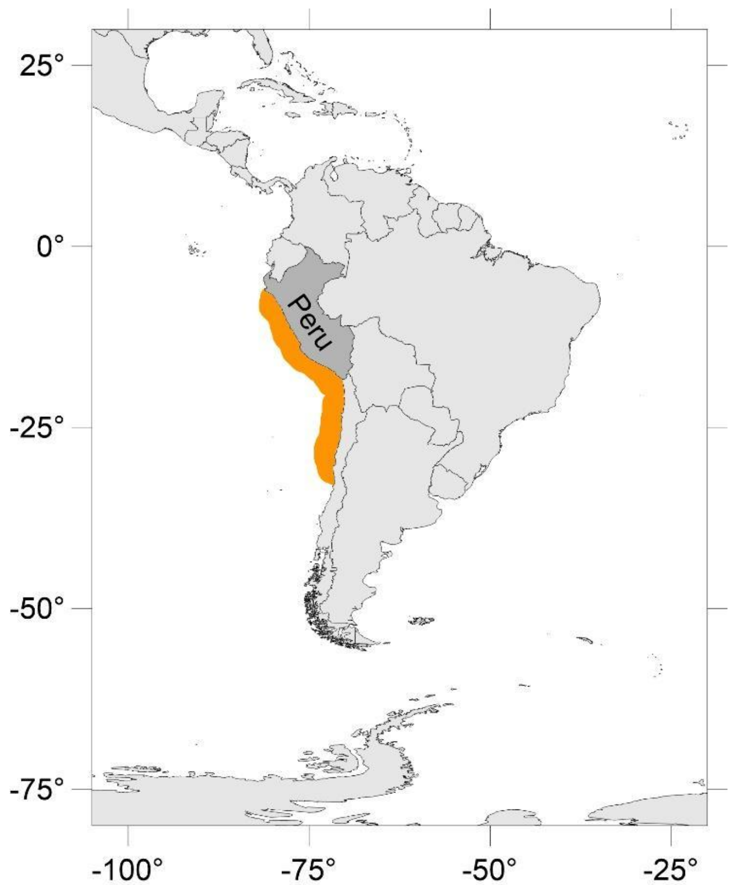


Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Potential habitat available (nearly 5° of latitude) further south in Peruvian waters.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Not available.

Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	The reproductive period of *P. pollicipes* in Portugal is from March to September, and includes two periods of larval release, one from March to April and another more important from July to October (Molares 1994). Therefore, it is considered that the duration of the spawning or breeding season is > 4 months.
Migration (seasonal and spawning)	None.
Exposure	
Response to environmental variability	Larvae have a wide optimum temperature range (Walther et al. 2013). Sea surface temperature and habitat conditions have an effect on the density of populations in tropical regions (Marchant et al. 2015).

1.5 Peruvian calico scallop - *Argopecten purpuratus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	1–40 million eggs (Bermudez-Corcuera et al. 2004).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Spawning occurs throughout the year with the highest spawning peaks in spring and summer (IMARPE 2014). It takes from 1 to 1.5 years to reach the commercial size (65 mm) (Mendo et al. 2008); hence it is assumed that recruitment events are consistent and occur every 1–2 years.
Average age at maturity	Reaches sexual maturity at 10–12 months of age (Bermudez-Corcuera et al. 2004; IMARPE 2008)
Generalist vs. specialist – food and habitat	Filters phytoplankton (Bermudez-Corcuera et al. 2004). Inhabits protected areas with shells, rocky, sandy, sandy-muddy, and silty bottoms, or with algae. It is distributed from 3 to 60 m depth; the natural banks occur mainly

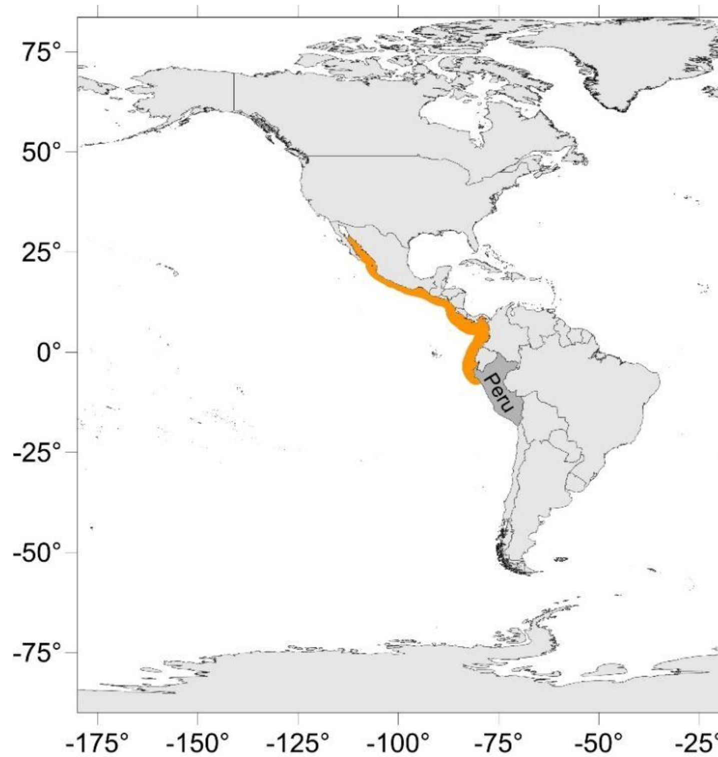
	between 10 and 20 m depth (Bermudez-Corcuera et al. 2004).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	The planktonic larval stage lasts approximately 15 days (IMARPE 2008).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Adult bivalves do not appear to move great distances, for instance adult *Pecten novaezealandiae* in New Zealand move approximately 2 meters per month (Twist et al. 2016).
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Occurs from Paita, Peru to Valparaiso, Chile (IMARPE 2008); approximately 28° of latitudinal coverage. 
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 15° of latitude may be available to the south of Peru.

Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Low temperatures have negative effects on spawning and recruitment (Mendo et al. 2008). Mature and spawning individuals appear to be more vulnerable than juveniles to thermal stress and hypoxia (Brokordt et al. 2015). The decline in salinity due to river discharges may have caused massive mortality in the scallop bank at Tortugas Bay in 1998 (Mendo et al. 2008). Temperature, dissolved oxygen, currents, and turbidity were found to affect the gonadosomatic index (Cueto et al. 2014). Temperature and current velocity were highly associated with gonad weight variability (Cabrera & Mendo 2011).
Environmental variable as a phenological cue for settlement or metamorphosis	The peruvian calico scallop takes 1 to 1.5 years to reach commercial size; however, during El Niño events it only takes 6 to 8 months to reach commercial size (Mendo et al. 2008).
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Spawning occurs throughout the year with the highest spawning peaks in spring and summer (IMARPE 2014), this is between 2 and 6 months of duration.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	The abundance of *A. purpuratus* in Peru has increased in some sites after El Niño events (Mendo et al. 2008). Oceanic warming and improvement of oxygen conditions near the bottom result in increasing growth rates and recruitment of this species in Pisco, as well as in the increase of carrying capacity of the bays. Low temperatures have negative effects on spawning and recruitment (Mendo et al. 2008). In Chile, this species showed a better physiological condition (based on fecundity, egg size, biochemical composition, and larval survival) at 15°C, and at decreasing temperatures starting at 19°C down to 15°C under controlled conditions (Martínez & Pérez 2003). Mature and spawning individuals appear to be more vulnerable than juveniles to thermal stress and hypoxia (Brokordt et al. 2015). The decline in salinity due to river discharges may have caused massive mortality in the scallop bank at Bahía de Tortugas in 1998 (Mendo et al. 2008). Temperature, dissolved oxygen,

	currents, and turbidity were found to affect the gonadosomatic index (Cueto et al. 2014), whereas temperature and current velocity were highly associated to gonad weight variability (Cabrera & Mendo 2011). Scallops take 1–1.5 years to reach commercial size; however, during El Niño events it only takes 6–8 months to reach commercial size (Mendo et al. 2008).

1.6 Stone oyster - *Striostrea prismatica*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Oysters release thousands of gametes, of which only a small number form larvae (Cariño & Monteforte 2007).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Not available.
Average age at maturity	Not available.
Generalist vs. specialist – food and habitat	Inhabits the rocky intertidal and subtidal zone, up to 7 m deep (Fournier 1992; Coan & Valentich 2012), as well as rocky coasts of the open sea where it forms dense banks (Mora 1990). From Caleta La Cruz to Punta Sal Grande, *S. prismatica* lives between 1.9 m and 9 m deep, cemented to hard substrates (rocks) or submerged metal structures.
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Larvae are dispersed for 20–35 days (Cariño & Monteforte 2007).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Limited.

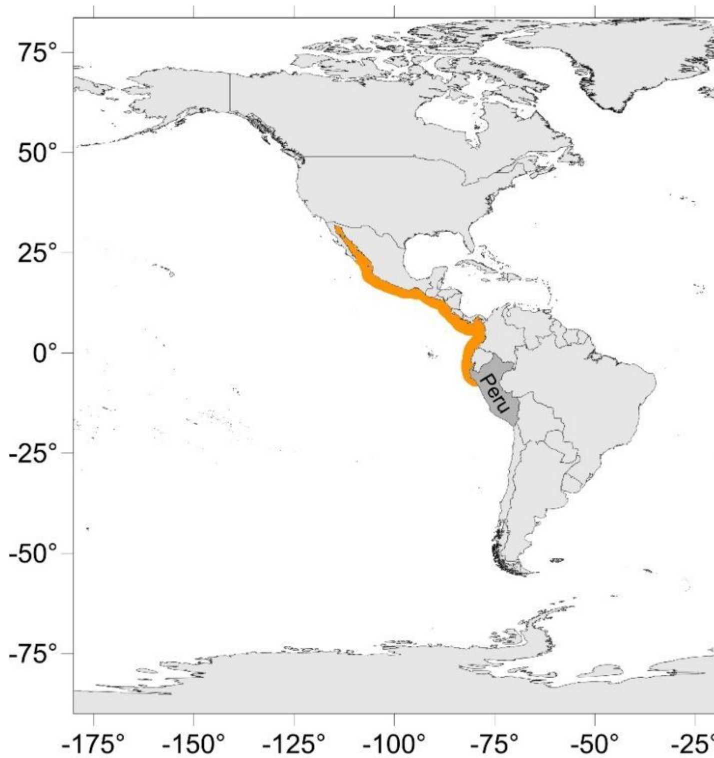
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	This species is distributed from the central zone of Baja California, Mexico to Peru (Ríos-Gonzáles et al. 2018); approximately 35° of latitudinal coverage. 
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	There may be spatial availibity of unoccupied habitat further south of its current distribution, of approximately 12° of latitude in Peruvian waters.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	The spawning season occurs from August to September and is stimulated by high temperatures ranging between 29°C and 34°C (Páez-Osuna et al. 1993).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.

Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season.	The spawning season occurs from August to September (Páez-Osuna et al. 1993). Therefore, it is considered that the duration of the spawning season is approximately 2 months.
Migration (seasonal and spawning)	Unlikely.
Exposure	
Response to environmental variability	Juvenile oysters are affected by sudden changes in temperature, salinity and water composition (Cariño & Monteforte 2007). During the transition between winter and spring, when low-temperature water masses predominate, population growth rates decrease. However, this is associated with a decrease in natural mortality. During summer-autumn, population growth and natural mortality increase (Melchor-Aragón et al. 2002). Small oysters are mostly found in the dry season; small and medium sizes occure during the transition between the dry and the rainy seasons, whereas small, medium, and large size oysters occur during the rainy season (Gonzabay-Rodríguez 2018). Temperature plays an important role in the reproductive biology of oysters. The spawning season occurs from August to September and is stimulated by high temperatures ranging between 29°C and 34°C (Páez-Osuna et al. 1993). The highest concentrations of *S. prismatica* were associated with isotherms of 23.7°C to 26.9°C, and oxygen concentrations of 4.45 mL/L to 5.11 mL/L (Ordinola et al. 2010c). Movements of the sea caused by winds and tides affect the circulation and sedimentation of particles, the renewal of the water and its oxygenation, therefore also affect the turbidity factor. Tides and currents affect the development of oyster processes (Ledesma 2001). The speeds and directions of water currents influence gene flow (Ordinola et al. 2010b). The areas along the Tumbes coast where the main banks of *S. prismatica* are located are characterized by current speeds that fluctuate between 1 and 38 cm/s, which represents a transport of between 800 m/day to 32 km/day. These speeds allow adequate flow of larvae, however the directions of the currents do not follow

a single direction, but are oriented in such a way that they can impede the free flow of larvae (Loor 2012).

1.7 Western wing oyster - *Pteria sterna*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Not available.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	The size structure indicates the presence of continuous recruitments with maximums in April and August; young specimens were recorded in most months, with the highest recruitments during April and August (Ordinola et al. 2013).
Average age at maturity	Not available.
Generalist vs. specialist – food and habitat	It is distributed bathymetrically between 7 m and 18 m deep, with higher densities from 10 m to 15 m (Luque et al. 2001). Also it has been reported up to 25–35 m deep (Carbajal & Santamaría 2015; Paredes et al. 2016). In the sub-coastline of Canoas, Cancas and Punta Sal it was recorded in sandy-rocky substrate at depths of 3 m to 5.4 m (Ordinola et al. 2010b). It is also associated with rocky bottoms or is attached to gorgonid corals and submerged metal structures; it has not been found in muddy or silty bottoms (Ordinola et al. 2010d). In the areas of Zorritos, La Cruz and Punta Sal, important populations of *P. sterna* have been reported between depths of 3 and 45 m on the structure of oil platforms (Robles & Mendez 1989).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	The veliger larva of *Pteria sterna* settles between 31 and 38 days after hatching (Araya et al. 1991). Dispersion from north to south of its known range has been reported, settling in the intertidal zone as far south as Ancon, Pisco and Mejillones (Chile) after El Niño 1982–1983 (Diaz & Ortlieb 1993; Tarazona et al. 1985, Tomicic 1985).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Limited.

Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	It is distributed from the Gulf of California, Mexico to Pimentel, Peru (Luque et al. 2001), although it has also been reported in mangrove areas and in the sub-littoral to Ancon, Lima, Peru (Paredes et al. 2016); approximately 35° of latitudinal coverage. 
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 10° to the south of its known geographic distribution.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Not available.
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.

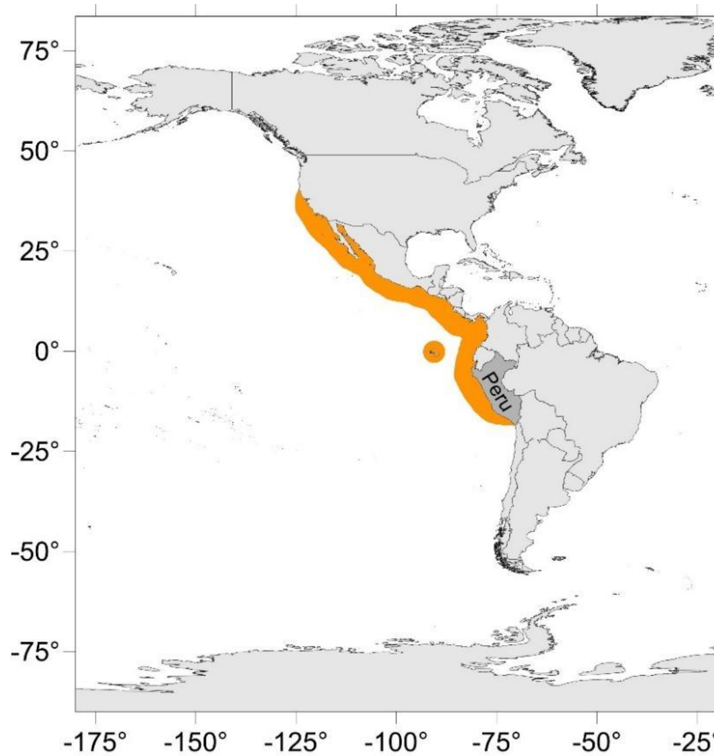
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Spawning was recorded during six of the seven months studied in a given year (Ordinola et al. 2013).
Migration (seasonal and spawning)	Unlikely.
Exposure	
Response to environmental variability	This species has been found in areas where sea surface temperature ranges between 14.9°C and 20.9°C, with an average of 16.8°C, and where sea bottom temperature ranges between 14.2°C and 18.5°C, with an average of 15.4°C. Salinity profiles suggest the presence of Equatorial Surface Waters in the northern zone, and the presence of a nucleus of Subtropical Surface Waters in the southern zone. High densities of the resource were found in the 10 to 20 m depth stratum, between the isotherms of 16.5°C and 17°C, preferring salinities of 35.10 UPS to 35.15 UPS; in relation high densities occurred between 1.5 and 3.5 mL/L of dissolved oxygen, with the highest density at 2 mL/L (Ordinola et al. 2010d). Juveniles appeared in Ancón Bay during El Niño 1982–1983, colonizing artificial tile substrates placed at a depth of 5 m (Tarazona et al. 1985).

Demersal

1.8 Bighead tilefish - *Caulolatilus affinis*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Not available.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Not available.
Average age at maturity	Not available.

Generalist vs. specialist – food and habitat	It is a passive predator that feeds mainly during the day; the most intense feeding season occurs between reproductive seasons (Elorduy-Garay & Caraveo-Patiño 1994). It is a demersal species that lives from 30 m to 200 m deep on rocky and sandy bottoms, near isolated reefs (Froese & Pauly 2019).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Not available.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Juveniles of *C. affinis* have a behavior similar to that of *C. princes* (demersal in character); juveniles remain in shallow areas and may be part of the shrimp companion fauna. Probably remain in low-lying areas until reaching sexual maturity, later migrating to deep areas and joining the reproductively active population (Ceballos 1993).
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	It is distributed from California, United States of America, to southern Peru (Acero et al. 2010); this is approximately 66° of latitudinal coverage.



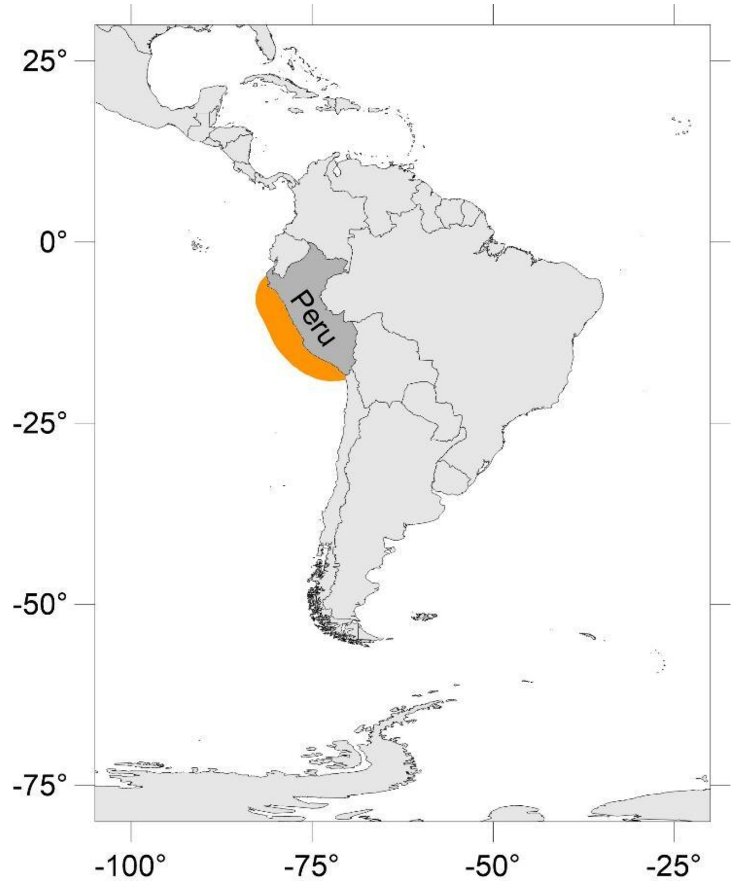
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Uncertain beyond the southern limit of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	The frequency of spawning individuals decreases as temperature increases (Ceballos 1993).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Spawning occurs in late fall, winter, and early spring, while resting ovaries occur in spring, summer, and part of fall. Spawning females are found from January to April, and from June to August (Ceballos 1993). Therefore, it is considered

	that the duration of the spawning or breeding season is > 4 months.
Migration (seasonal and spawning)	Juveniles of *C. affinis* have a behavior similar to that of *C. princes* (demersal in character); juveniles remain in shallow areas and may be part of the shrimp companion fauna. Probably remain in low-lying areas until reaching sexual maturity, later migrating to deep areas and joining the reproductively active population (Ceballos 1993).
Exposure	
Response to environmental variability	The frequency of spawning individuals decreases as temperature increases (Ceballos 1993). Demersal fish inhabit the continental shelf and are associated with Cronwell's Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of demersal species also varies in size. In summer, the habitat expands and in winter it shrinks, resulting in lower or higher densities, respectively. During El Niño, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast towards greater depths and from the pelagic system towards the bottom (Velez et al. 1988; Espino 1990). Changes in distribution due to El Niño have also resulted in changes in size structure (Samamé et al. 1985). With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).

1.9 Black cusk-eel - *Genypterus maculatus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	*Genypterus chilensis* spawns floating gelatinous egg masses; average fecundity is 80,000 eggs and the maximum reported fecundity is 285,000 eggs per mass. *Genypterus chilensis*

	spawns at night; the incubation period is 4 to 5 days and a 5 mm plantonic larva hatches (Vega et al. 2012).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Recruitment events are considered occasional and variable.
Average age at maturity	Average sexual maturity was estimated at 86 cm in total length, which corresponds to approximately 8–12 years of age (Tascheri et al. 2003; García 2016).
Generalist vs. specialist – food and habitat	It is an opportunistic predator, depending on the relative abundance of prey (Mitchell 1984). However, its most important preys are the *Pleuroncodes monodon* shrimp, as well as *Pterigosquila armata* (Chong & González 2009; Bahamonde & Zavala 1981). Occurs in rocky areas and on sandy-muddy bottoms between 20 and 300 m deep (Chirichigno & Cornejo 2001).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Not available.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Not available.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Distributed in the Southeast Pacific in Peru and northern Chile (Froese & Pauly 2019); this is approximately 13° of latitudinal coverage.



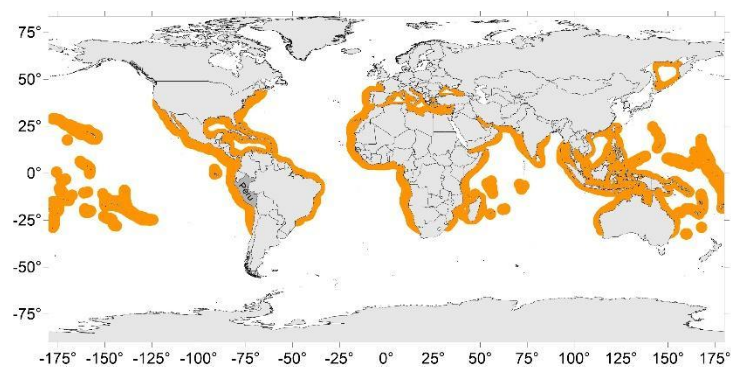
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Not available.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Hatching occurs in a temperature range of 12°C to 13°C (Vega et al. 2012).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Asynchronous or partial spawners with long reproductive periods. Females and males present mature gonads between January and March, June, August and December

	(De Lucio et al. 2013). Therefore, it is considered that the duration of the spawning or breeding season is > 4 months.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Hatching occurs in a temperature range of 12°C to 13°C (Vega et al. 2012).

1.10 Flathead grey mullet - *Mugil cephalus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	0.8 to 2.6 million eggs (Froese & Pauly 2021).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Recruitment may be consistent every 1–2 years given that spawning occurs every year (Llanos et al. 2009) and sexual maturity is reached at 2–4 years (Culquichicón et al. 2011). However, when recruitment is affected it may be occasional and variable.
Average age at maturity	Sexual maturity between 2 and 4 years of life (Culquichicón et al. 2011; Froese & Pauly 2021). Length at first maturity is 25 cm approximately (Llanos et al. 2009).
Generalist vs. specialist – food and habitat	Juveniles feed on zooplankton; in general, the flathead grey mullet feeds on detritus, microalgae, small invertebrates and other benthic organisms (Kottelat & Freyhof 2012). In Callao, central Peru, it feeds on diatoms, dinoflagellates, tintinids, silicoflagellates, copepods, among other species of zooplankton (Blaskovic' et al. 2008). It's a pelagic species, occurs in coastal waters, in estuaries and rivers, occasionally upstream, in hypersaline lagoons and environments on sandy or muddy bottoms, between 0 and 10 m depth in tropical, subtropical and temperate waters (Froese & Pauly 2021).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement	Not available.

(benthic species), hatching to yolk sac re-adsorption (pelagic species)	
Capacity for adult/juvenile movement – lifetime range post-larval stage	Not available.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Cosmopolitan species that is distributed in California, the Mexican Pacific, Central America, the coasts of Peru and northern Chile (Kottelat & Freyhof 2012); approximately 35° of latitudinal coverage to the south of Peru and also to the north of Peru.



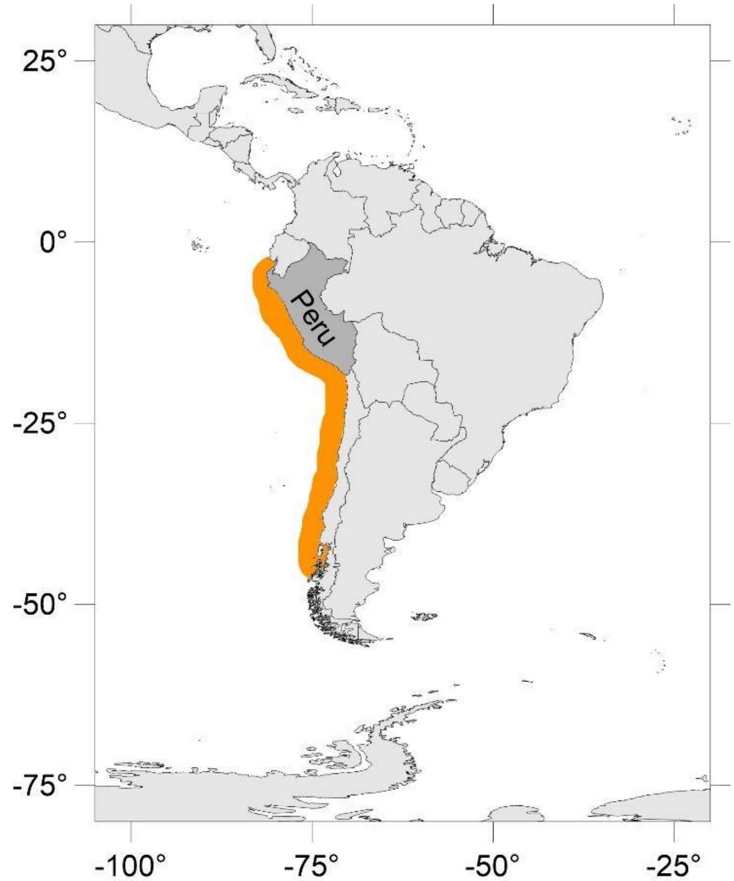
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range.	Approximately 17° of latitude may be available to the south of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Positive thermal anomalies appear to have a negative effect in the main spawning peak. For instance, in 2009 the main spawning peak was less intense and it was surpassed by the secondary spawning peak (Llanos et al. 2009).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season.	Main spawning peak lasts approximately 3 months, between December and February. A secondary spawning peak lasts 2 months, between May and June (Llanos et al. 2009).

	Therefore, it is considered that the duration of the spawning or breeding season is > 4 months.
Migration (seasonal and spawning)	Spawning occurs at sea; juveniles approach the coast in December and remain in estuaries and coastal marine waters until they are approximately three years old (Oliver 1943).
Exposure	
Response to environmental variability	The largest catches of the flathead gray mullet were reported after the warm episode El Niño 1997–1998, whereas the presence of La Niña appears to be associated with the significant decline in landings (González-Ynope 2001). Warm waters during El Niño events along the Peruvian coast causes reduction of phytoplankton blooms and primary production. As a consequence, the typical species of the area move to other areas due to the lack of food, which may explain the landing fluctuations of coastal species such as the flathead gray mullet in the period 1996–1999 (González-Ynope 2001). In 2009 when positive thermal anomalies occurred, the main spawning peak was less intense and it was surpassed by the secondary spawnings peaks (Llanos et al. 2009).

1.11 Humpback smooth-hound - *Mustelus whitneyi*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Produces on average 9.5 offsprings (Samamé et al. 1985).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	The recruitment to the fishery is assumed to be annual as for *M. antarcticus* (Walker 2010).
Average age at maturity	Sexual maturity is reached at approximately 74–87 cm (González-Pestana 2016), possibly at 9–10 years as in the

	case of *M. henlei* in the Gulf of California, Mexico (Méndez-Loeza 2008).
Generalist vs. specialist – food and habitat	Feeds on fish, crustaceans and molluscs (Llanos et al. 2009). Inhabits rocky, sandy and sandy-muddy bottoms around islands and is generally found at depths between 15 m and 200 m (Chirichigno & Cornejo 2001; Romero 2007).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	*Mustelus whitneyi* has no pelagic larval stage (Encyclopedia of Life 2021).
Capacity for adult/juvenile movement – lifetime range post-larval stage	The migratory capacity of this species is unknown; however juvenile *M. lenticulatus* in New Zealand were found to remain in areas of 2 to 7 km^2 (Francis 2013).
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Reported from Costa Rica, along the Peruvian coast and further south to Corral, Chile (Romero 2007); approximately 45° of latitudinal coverage to the south of Peru.



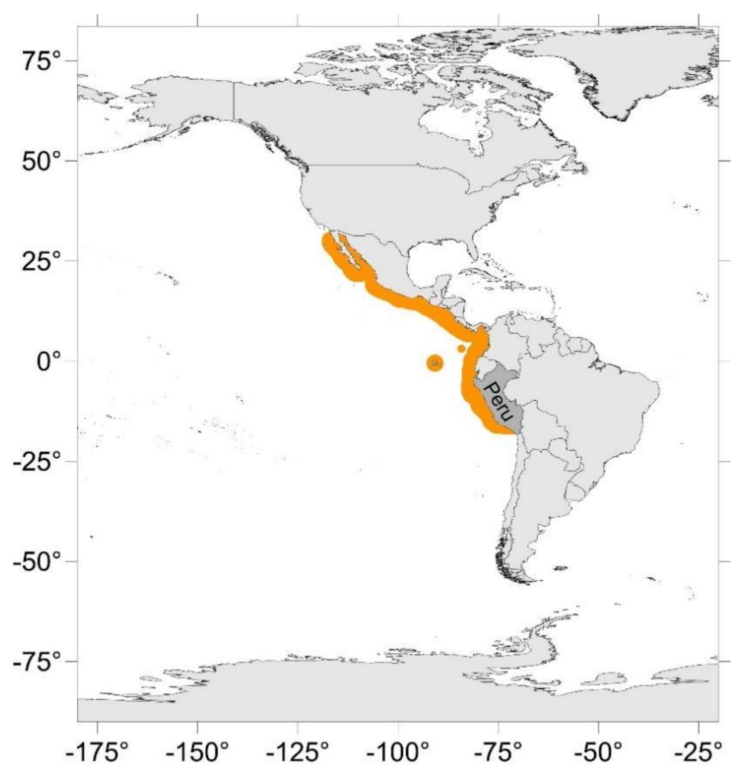
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 30° of latitude may be available to the south of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	The spawning of the humpback smooth-hound decreases during El Niño events (Samamé et al. 1985).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	In the Northeast Atlantic, *M. asterias*, has a gestation period of 12 months and rests 12 months (Farrell et al. 2010). There

	is no detailed information about the duration of the spawning or breeding season.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Demersal fish inhabit the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size intra and interannually. In summer the habitat expands and in winter it is reduced, which results in lower and higher densities respectively. During El Niño events, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño event. With El Niño, the diversity of the demersal system increases due to the incorporation of a larger number of species that move from north to south, from the coast to greater depths and from the pelagic system to the bottom (Velez et al. 1988). Changes in dissolved oxygen concentration in the water can result in changes in distribution and abundance (Espino 1990). During El Niño 1983, the largest sizes were present south of the main distribution area with the mode and average length being greater than in previous years (i.e., 1981) (Samamé et al. 1985). The spawning of the humpback smooth-hound also decreases during El Niño events (Samamé et al. 1985).

1.12 Lumptail searobin - *Prionotus stephanophrys*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	There is no information on fecundity for this species but the partial fecundity of *P. ruscarius* in the Mexican Pacific is 10,400–118,200 eggs (Lucano-Ramírez et al. 2005).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Likely to be consistent every 1–2 years, although it can also be occasional and variable.

Average age at maturity	Size of maturity is reached at 20 cm in length, approximately at 3 years of age (Samamé & Fernández 2000).
Generalist vs. specialist – food and habitat	Feeds mainly on crustaceans, fish and cephalopods (Blaskovic' et al. 2008). Inhabits sandy or sandy-muddy bottoms down to 225 m depth (van der Heiden et al. 2010).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	The duration of the pelagic phase is unknown (Encyclopedia of Life 2021).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Not available.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Distributed in the eastern Pacific from Baja California to southern Peru, including Malpelo and Galapagos Island (van der Heiden et al. 2010). There are records in northern Chile too (Samamé & Fernández 2000); approximately 45° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	No unoccupied habitat availability to the south of Peru. Approximately 30° of latitude may be available to the north of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	With El Niño 1983, the spawning of *P. stephanophrys* occurred earlier in the year (Samamé et al. 1985).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Mature individuals occur mainly in spring and summer; however, sexually mature individuals occur throughout the year except for winter (Samamé & Fernández 2000); the duration of spawning is thus assumed to last between 2 and 6 months.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Demersal species off Peru move latitudinally and longitudinally in response to environmental and biological conditions. In latitudinal movements, oceanographic factors such as the presence of surface sub-tropical waters, oxygen and salinity, as well as feeding and reproduction are crucial (Samamé & Fernández 2000). The lumptail searobin can be considered an indicator of warm waters, associated with movement of the Equatorial Front that occurs regularly every year or irregularly with the presence of El Niño events (Samamé & Fernández 2000). This species frequently occupies the area from the northern border of Peru to 10°S and down to the 220 m isobath. However, its distribution extends to 17°30'S during El Niño, where mainly juvenile and pelagic individuals are found (Samamé & Fernández 2000). Like other demersal species, the lumptail searobin tends to deepen during El Niño events (Espino 1990). The greatest concentrations of this species have been recorded at 14–

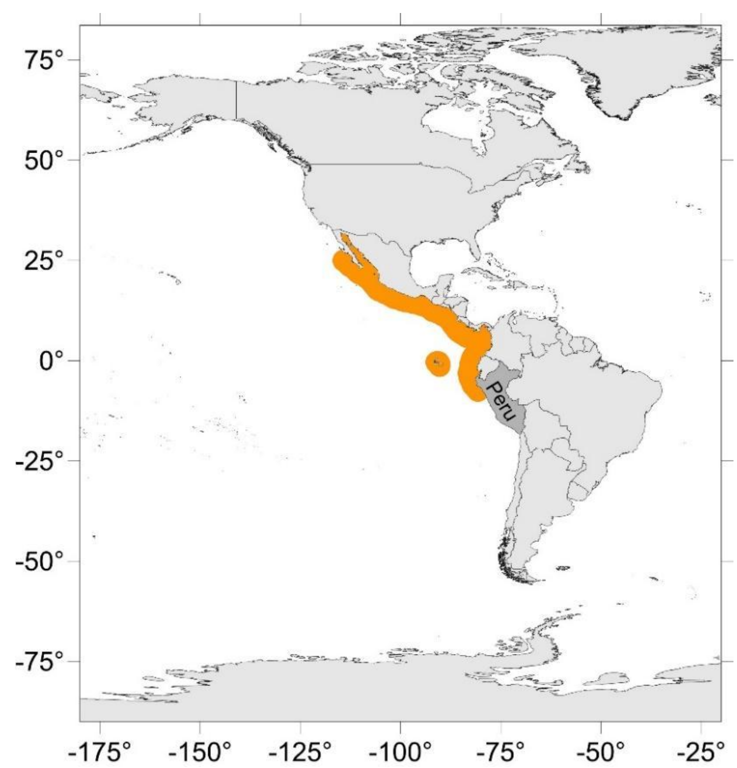
16°C (Samamé & Fernández 2000). In contrast, it occurs at 16–18°C during El Niño events (Espino 1990). This species seems to be persistent to changes in salinity and oxygen (Samamé & Fernández 2000). However, as temperature influences the movement of demersal resources, dissolved oxygen is determinant in the vertical and horizontal distribution, and in the abundance of this species (Samamé & Fernández 2000). *Prionotus stephanophrys* is generally present between 0.5 mL/L and 1.5 mL/L of dissolved oxygen (Espino 1990; Samamé & Fernández 2000), whereas during El Niño it occurs between 1.25 mL/L and 2.5 mL/L of dissolved oxygen (Espino 1990). The deepening of the food from the coast may influence the distribution of the lumptail searobin as well (Samamé & Fernández 2000). The negative effects that changes in temperature have on the Peruvian hake seem to favor the increase in abundance of the lumptail searobin (Samamé et al. 1985).

Changes in size have been recorded probably due to El Niño events and the fishing pressure caused by trawlers (Samamé & Fernández 2000). With El Niño 1983, the spawning of *P. stephanophrys* occurred earlier in the year (Samamé et al. 1985).

1.13 Pacific drum - *Larimus pacificus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Fecundity ranges from 31,088 to 65,038 eggs (Ross 1984).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment every 1–2 years.
Average age at maturity	The sizes of this species in Peru range between 10 cm and 28 cm, of which approximately 60% of the individuals sampled (n = 943) in this size range were sexually mature. They reach sexual maturity from approximately 2 years of age (Samamé et al. 2001).

Generalist vs. specialist – food and habitat	Feeds on planktonic crustaceans (Froese & Pauly 2019). It occurs in coastal waters and up to approximately 100 m depth (Chao et al. 2010; Froese & Pauly 2019). Inhabits shallow sandy and sandy-muddy bottoms (Chirichigno & Cornejo 2001).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Distributed in the Eastern Pacific, from the Baja California peninsula in Mexico to Talara in northern Peru (Chao et al. 2010; Froese & Pauly 2019); approximately 35° of latitudinal coverage.

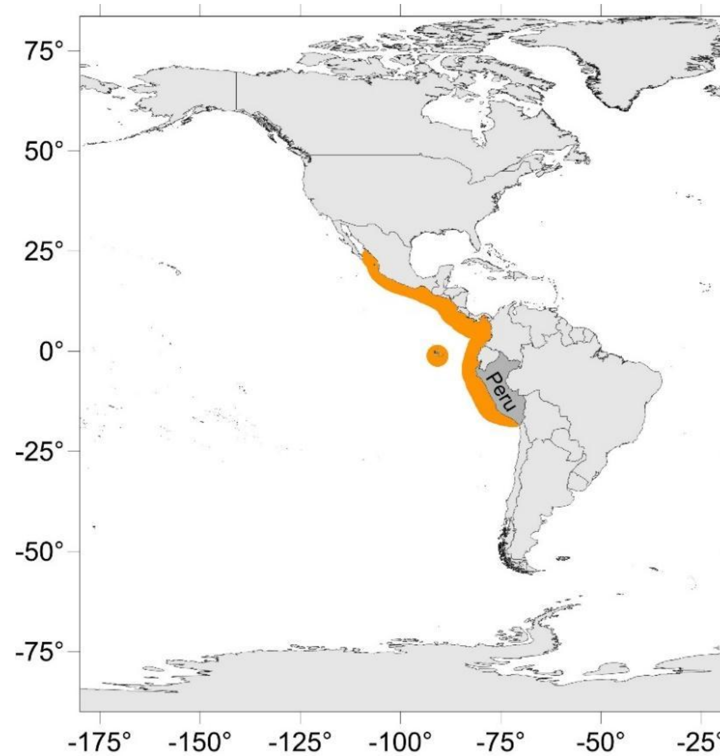


Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Uncertain, habitat availability further south its current southern limit of distribution is unknown but could potentially be 12° of latitude.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	This species is found around 21°C (Fuentes et al. 1969). With ocean warming, the main spawning peak is delayed and the secondary peaks becomes more intense (Llanos et al. 2009).
Environmental variable as a phenological cue for settlement or metamorphosis	This species is found around 21°C (Fuentes et al. 1969).
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Not available.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	This species is found around 21°C (Fuentes et al. 1969). Demersal fish inhabit the continental shelf and are associated with Cronwell's Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size. In summer, the habitat expands and in winter it shrinks, resulting in lower or higher densities, respectively. During El Niño, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast towards greater depths and from the pelagic system towards the bottom (Velez et al. 1988; Espino 1990). Changes in distribution due to El Niño have also resulted in changes in size structure (Samamé et al. 1985). With ocean warming, the main

	spawning peak is delayed and the secondary peaks becomes more intense (Llanos et al. 2009).

1.14 Pacific harvestfish - *Peprilus medius*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Not available.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Not available.
Average age at maturity	Not available.
Generalist vs. specialist – food and habitat	Occurs near the surface in coastal waters and up to 40 m depth (Iwamoto et al. 2010; Froese & Pauly 2019).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	It is distributed in the Eastern Pacific, from Mexico to southern Peru, including the Galapagos Islands (Iwamoto et al. 2010; Froese & Pauly 2019); approximately 42° of latitudinal coverage.



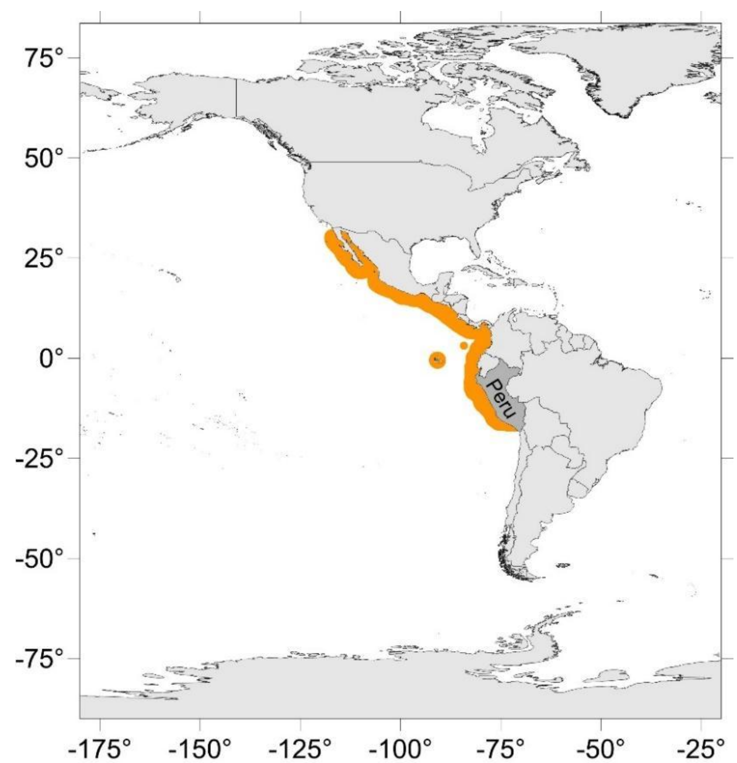
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Currently this species does not occur further south of Peru but there seems to be spatial availability off Chile.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Not available.

Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Demersal fish inhabit the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size. In summer, the habitat expands and in winter it shrinks, resulting in lower or higher densities, respectively. During El Niño, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast towards greater depths and from the pelagic system towards the bottom (Velez et al. 1988; Espino 1990). Changes in distribution due to El Niño have also resulted in changes in size structure (Samamé et al. 1985). With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).

1.15 Paloma pompano - *Trachinotus paitensis*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Not available.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment every 1–2 years.
Average age at maturity	Sexual maturity occurs at approximately 42 cm fork length (Fischer et al. 1995); adult individuals have also been recorded from 31 cm (Morón et al. 1997). A species of the same genus, *T. botla,* matures at 24–25 cm fork length, which corresponds to an age at maturity of 2 years (Parker 2012).

Generalist vs. specialist – food and habitat	It is an opportunistic predator that feeds on mollusks, crustaceans, other invertebrates and small fish (Cruz-Escalona & Abitia-Cárdenas 2004; Smith-Vaniz et al. 2010). Adults are found in coastal waters, generally forming schools in shallow waters (up to 25 m deep) and coastal waters with sandy bottoms.
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	It is distributed in the Eastern Pacific, from southern California in the United States of America to southern Peru, including the Galapagos Islands (Froese & Pauly 2019); approximately 52° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Currently this species does not occur further south of Peru but there may be spatial availability off Chile.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).
Environmental variable as a phenological cue for settlement or metamorphosis	Temperature changes affect the growth of *T. botla*, in particular a decrease in growth has been detected during winter (Parker 2012).
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Not available.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Temperature changes affect the growth of *T. botla*, in particular a decrease in growth has been detected during winter (Parker 2012). Demersal fish inhabit the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size. In summer, the habitat expands and in winter it shrinks, resulting in lower or higher densities, respectively. During El Niño, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast towards greater depths and from the pelagic system towards the bottom (Velez et al. 1988; Espino 1990). Changes in distribution due to El Niño have also resulted in changes in size structure (Samamé et al. 1985). With ocean warming, the main

	spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).

1.16 Peruvian banded croaker - *Paralonchurus peruanus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	There is no information on fecundity but the partial fecundity of a species of the same genus, *P. brasiliensis*, in Brazilian coasts is 18,900 ± 9,500 oocytes (Costa et al. 2015).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment events every 1–2 years.
Average age at maturity	Sexual maturity is reached at 24 cm in length (Froese & Pauly 2021); considering the size-age relationship it is estimated that maturity is reached at 3 years of age (Bringas 2012).
Generalist vs. specialist – food and habitat	It feeds on polychaetes, crustaceans, gastropods, teleosts and ophiuroids (Blaskovic' et al. 2008). Inhabits warm and temperate waters, sandy and muddy bottoms, and estuaries (Chirichigno & Cornejo 2001).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Has a pelagic larval phase (Encyclopedia of Life 2021); unknown duration of the pelagic larval phase.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Not available.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	It is distributed from Puerto Pizarro, Peru to Arica, Chile (Goicochea et al. 2012), although also there are records in Panama (Chao 2010); approximately 26° of latitudinal coverage.

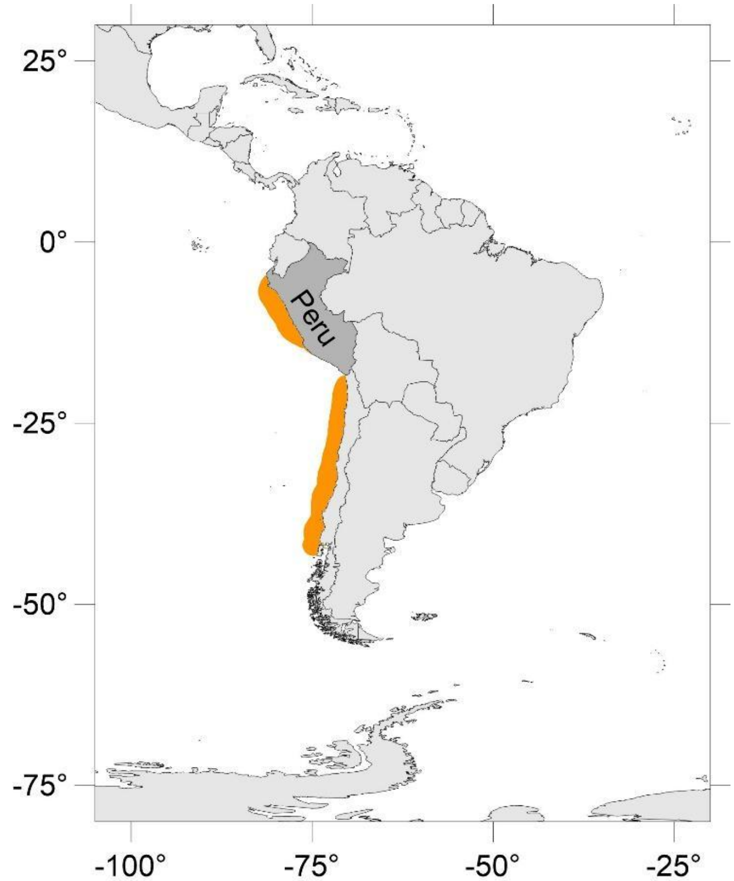
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately < 1° of latitude may be available to the south of Peru; nearly 13° of latitude may be available to the north of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Positive thermal anomalies appear to result in the extension of spawning events (Llanos et al. 2009).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Continuous reproductive activity throughout the year with a late summer-autumn spawning peak (Llanos et al. 2009;

	Bringas et al. 2014); duration of spawning is thus assumed to last > 4 months.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Demersal fish that inhabits the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size intra and interannually. In summer the habitat expands and in winter it is reduced, which results in lower and higher densities respectively. During El Niño events, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño event. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast to greater depths and from the pelagic system to the bottom (Velez et al. 1988; Espino 1990). Changes in temperature, salinity and oxygen may have effects on growth (Bringas et al. 2014) and on the distribution of this species (Espino 1990). Positive thermal anomalies appear to result in the extension of spawning events (Llanos et al. 2009).

1.17 Peruvian hake - *Merluccius peruanus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	The partial fecundity *M. gayi peruanus* is 50,856 oocytes (Perea de la Matta et al. 2005).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Recruitment period is usually consistent every 1–2 years.
Average age at maturity	The size and age at maturity are unknown for this species; however *M. gayi gayi* reaches the age of 50% maturity at 3.5

	years in Chile (http://www.subpesca.cl/institucional/602/articles-9175_documento.pdf).
Generalist vs. specialist – food and habitat	It feeds mainly on crustaceans, fish and cephalopods (Blaskovic' et al. 2008). This is a batidemersal species that inhabits from the coastal zone to a depth range of 50–500 m depth on sandstone or non-muddy clay bottoms (Chirichigno & Cornejo 2001; Iwamoto et al. 2008).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	The yolk sac is likely to be rapidly absorbed, as per *M. australis* at 9 days (Bustos & Landaeta 2005).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Performs migrations that are determined by seasonal (summer-autumn) and interannual changes associated with El Niño events in the Cromwell Current (Wosnitza-Mendo et al. 2009).
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Distributed from the border between Ecuador and Peru to Huarmey, and occasionally it occurs further south to Ilo (Chirichigno & Cornejo 2001); approximately 35° of latitudinal coverage.



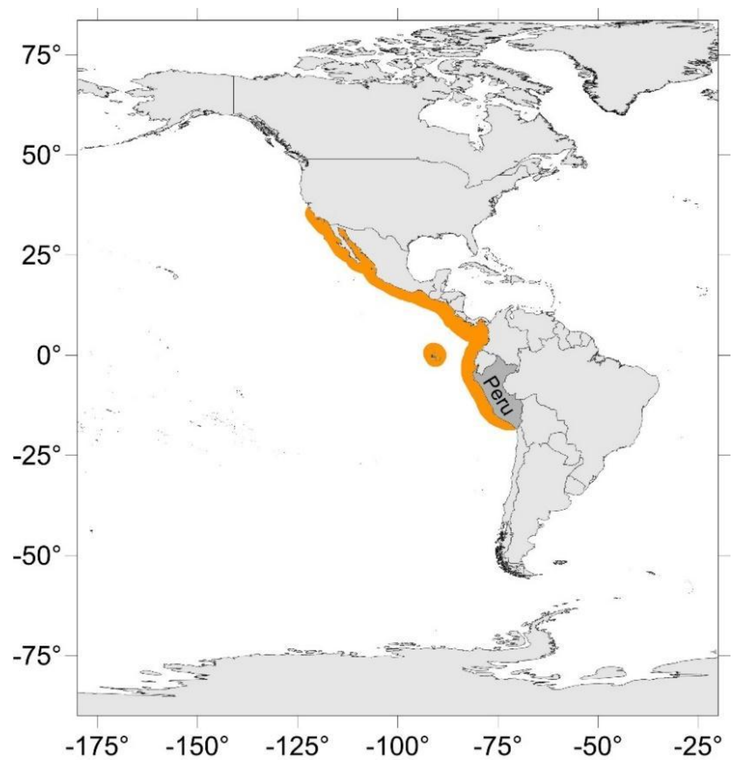
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 22° of latitude may be available to the south of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Not available.
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	The main spawning season is from August to March, with a peak in spring (Iwamoto et al. 2010); duration of spawning is thus assumed to last > 4 months.

Migration (seasonal and spawning)	Performs migrations that are determined by seasonal (summer-autumn) and interannual changes associated with El Niño events in the Cromwell Current (Wosnitza-Mendo et al. 2009).
Exposure	
Response to environmental variability	With the intrusion of oceanic waters, the Peruvian hake tends to become pelagic and coastal mainly in the area of Chimbote-Huarmey. If the species is not able to return to its spawning area then an increase in population size occurs (Samamé et al. 1985). During El Niño events, demersal fishes tend to deepen (Espino 1990). The Peruvian hake usually occurs between 0.75 mL/L and 1.75 mL/L of dissolved oxygen, but during El Niño events it can occur between 1 mL/L and 2 mL/L of dissolved oxygen (Espino 1990).

1.18 Peruvian moonfish - *Selene peruviana*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Not available.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Not available.
Average age at maturity	The maximum recorded fork length is 26.5 cm. *Selene setapinnis* reaches sexual maturity at 21.5 cm total length, approximately at 19 cm fork length (Gonzales et al. 2017).
Generalist vs. specialist – food and habitat	Preys upon small fish and crustaceans (Smith-Vaniz et al. 2010; Froese & Pauly 2019). Inhabits coastal waters and up to 50 m deep; juveniles occur near the surface.
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for

(benthic species), hatching to yolk sac re-adsorption (pelagic species)	dispersal/movement. However, it's not specified at what life stage.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	It is distributed in the Eastern Pacific, from southern California in the United States of America to southern Peru (Froese & Pauly 2019); approximately 52° of latitudinal coverage.



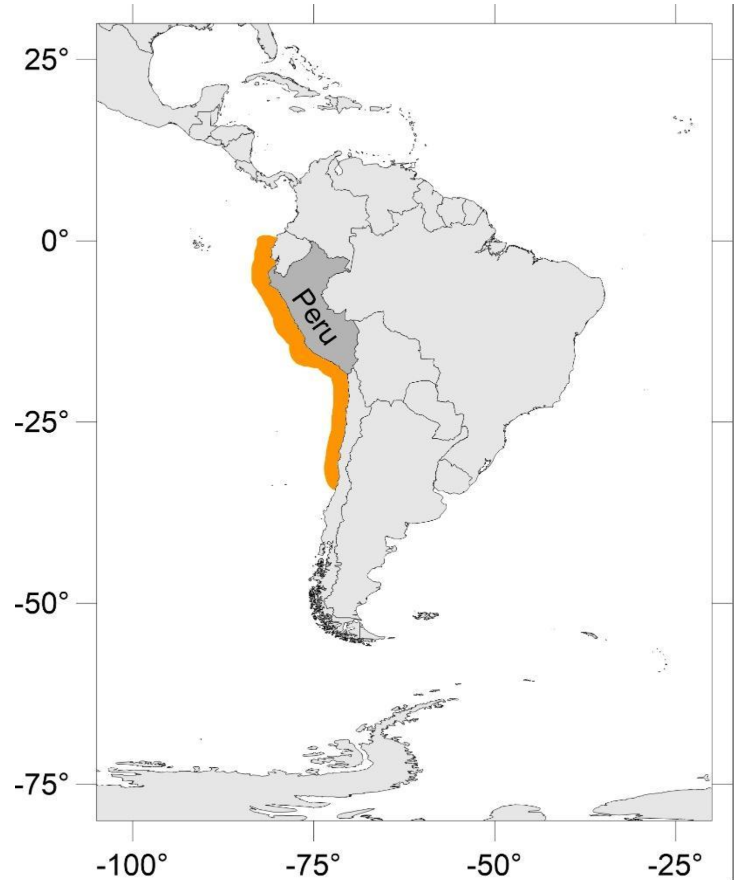
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Currently, this species does not occur further south of Peru but there seems to be spatial availability off Chile.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).

Environmental variable as a phenological cue for settlement or metamorphosis	Changes in distribution due to El Niño have also resulted in changes in size structure (Samamé et al. 1985).
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Not available.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Demersal fish inhabit the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size. In summer, the habitat expands and in winter it shrinks, resulting in lower or higher densities, respectively. During El Niño, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast towards greater depths and from the pelagic system towards the bottom (Velez et al. 1988; Espino 1990). Changes in distribution due to El Niño have also resulted in changes in size structure (Samamé et al. 1985). With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).

1.19 Peruvian rock seabass - *Paralabrax humeralis*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	There is no information on the fecundity of this species, however the fecundity of *P. maculatofasciatus* is 284,000 eggs/kg of female (Avilés 2005).

Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment events every 1–2 years.
Average age at maturity	The size at 50% sexual maturity in females is 24.5 cm of total length (Miñano & Castillo 1971), a size that is reached between 2 years and 3 years of age (Goicochea et al. 2012).
Generalist vs. specialist – food and habitat	Adults feed on crustaceans, fish, cephalopods, polychaetes, euphausiids (Blaskovic' et al. 2008). Generally, inhabits sandy and rocky coastal areas with algae down to 180 m depth (Miñano & Castillo 1971; Smith-Vaniz *et al*., 2010); juveniles are located near the coast (Chirichigno & Cornejo 2001).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Under controlled conditions, larvae of species of the family Serranidae take 2–3 days to consume their yolk sack (Tucker 1998).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Not available.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Distributed from Ecuador to the southern part of Chile and the islands Juan Fernández and Galápagos (Goicochea et al. 2012); approximately 37° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 19° of latitude may be available to the south of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Not available.
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.

Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	The Peruvian rock seabass reproduces from November to August with the main spawning peak in March on the north coast of Peru, i.e., Chimbote (Mejía et al. 1970; Miñano & Castillo 1971); duration of spawning is thus assumed to last > 4 months.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	The Peruvian rock seabass usually occurs at 14–16°C and 0.75–1.75 mL/L of dissolved oxygen but during El Niño it occurs between 17–20°C and 2.25–3.25 mL/L of dissolved oxygen (Espino 1990). In general, demersal fishes tend to deepen during El Niño events (Espino 1990). With El Niño 1983 the larger fish migrated south of the main fishing area, and small fishes were accessible to the fishery (Samamé et al. 1985). The abundance of the Peruvian rock seabass decreased during El Niño (Espino 1990). In contrast, its immediate availability increased during La Niña and CPUE decreased between six months and two years after that event (Adams & Flores 2016). Demersal fish inhabit the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size intra and interannually. In summer the habitat expands and in winter it is reduced, which results in lower and higher densities respectively. During El Niño events, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño event. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast to greater depths and from the pelagic system to the bottom (Velez et al. 1988; Espino 1990). Biomass fluctuates depending on environmental conditions, e.g., the biomass of *P. humeralis* increases as the density of hake decreases during El Niño (Espino 1990).

1.20 Peruvian sea catfish - *Galeichthys peruvianus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Its fecundity is 27 eggs during the spawning season in summer (Castañeda et al. 2007; Bearez et al. 2010).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment events every 1–2 years.
Average age at maturity	Reaches the length of first maturity at 21.7 cm (Llanos et al. 2009), approximately at one year of life.
Generalist vs. specialist – food and habitat	Catfishes prey upon fish, crustaceans, polychaetes, molluscs and algae (Llanos et al. 2009). The anchovy is a common prey mainly in summer and autumn (Castañeda et al. 2007). Inhabits shallow waters with soft bottoms, generally within 50 nautical miles from the coast (Castañeda et al. 2007).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Not available.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Performs seasonal migrations; during winter the main densities occur in the coastal zone at 7–9°S and during spring it moves towards 8–10°S (Castañeda et al. 2007; Bearez et al. 2010), which is approximately a 100–300 km migration.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Distributed from northern Peru to northern Chile (Bearez et al. 2010); approximately 15° of latitudinal coverage.

Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 2° of latitude may be available to the south of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	During 2009, the reproductive pattern of this species was altered due to negative anomalies occurring during the first three months of the year, so spawning was delayed until May and secondary peaks were more intense due to high temperatures in the second half of the year (Llanos et al. 2009). A species of the same genus, *G. caerulescens*, requires low salinities to spawn (Yáñez-Arancibia et al. 1976); therefore, changes in the frequency and intensity of rainfall could have consequences on the spawning events near the coast.
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.

Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Has a major spawning peak that occurs in late summer (Llanos et al. 2009); duration of spawning is thus assumed to last 2–4 months.
Migration (seasonal and spawning)	Performs seasonal migrations; during winter the main densities occur in the coastal zone at 7–9°S and during spring it moves towards 8–10°S (Castañeda et al. 2007; Bearez et al. 2010), which is approximately a 100–300 km migration. After spawning, males bring the fertilized eggs to shallow areas of the coast while the females return to their usual areas of distribution. A species of the same genus, *G. caerulescens*, performs migrations into lagoons during the breeding season (Yáñez-Arancibia et al. 1976). Juveniles become pelagic and eventually move to greater depths (Castañeda et al. 2007; Bearez et al. 2010).
Exposure	
Response to environmental variability	Demersal fish inhabit the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size intra and interannually. In summer the habitat expands and in winter it is reduced, which results in lower and higher densities respectively. During El Niño events, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño event. With El Niño, the diversity of the demersal system increases due to the incorporation of a larger number of species that move from north to south, from the coast to greater depths and from the pelagic system to the bottom (Velez et al. 1988). In fact, the dispersal of the *G. peruvianus* population along the coast during warm events, such as summer or El Niño has been recorded (Bearez et al. 2010). During 2009, the reproductive pattern of this species was altered due to negative anomalies occurring during the first three months of the year, so spawning was delayed until May and secondary peaks were more intense due to the high temperatures recorded in the second half of the year (Llanos et al. 2009). A species of the same genus, *G. caerulescens*, requires low salinities to spawn (Yáñez-Arancibia et al. 1976); therefore, changes in the frequency

	and intensity of rainfall could have consequences on the spawning events near the coast.

1.21 Peruvian weakfish - *Cynoscion analis*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	The fecundity of *C. analis* is unknown; however, *C. leiarchus* off Brazilian coasts has a partial fecundity of 100,000–866,000 oocytes (Carmo-Silva et al. 2016).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Two pulses of recruitment to the fishery have been identified, the main one between June and July and the pulse of lower intensity between January and February (Farroñay et al. 2010). Hence, consistent recruitment events every 1–2 years.
Average age at maturity	The length at first maturity is about 24 cm and the length at 50% of sexual maturity is at 27 cm (Mejía et al. 1970; Llanos et al. 2009).
Generalist vs. specialist – food and habitat	The Peruvian weakfish feeds mainly on crustaceans, fish and cephalopods (Blaskovic' et al. 2008). This is a species of warm and temperate waters that inhabits sandy, muddy and rocky bottoms (Mejía et al. 1970), until approximately 50 m depth (Chao & Espinosa 2010).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	The larvae may consume the yolk sac in only a few days, as observed in larvae of *C. nebulosus*, whose yolk sac is absorbed within 48 h post-hatching (Ibarra-Castro et al. 2015).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Not available.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Endemic to the Eastern Pacific and is distributed from Santa Elena, Ecuador to Coquimbo, Chile (Froese & Pauly 2021). A reduced range of distribution also has been described and comprises from Colombia to the north of Peru (Chao &

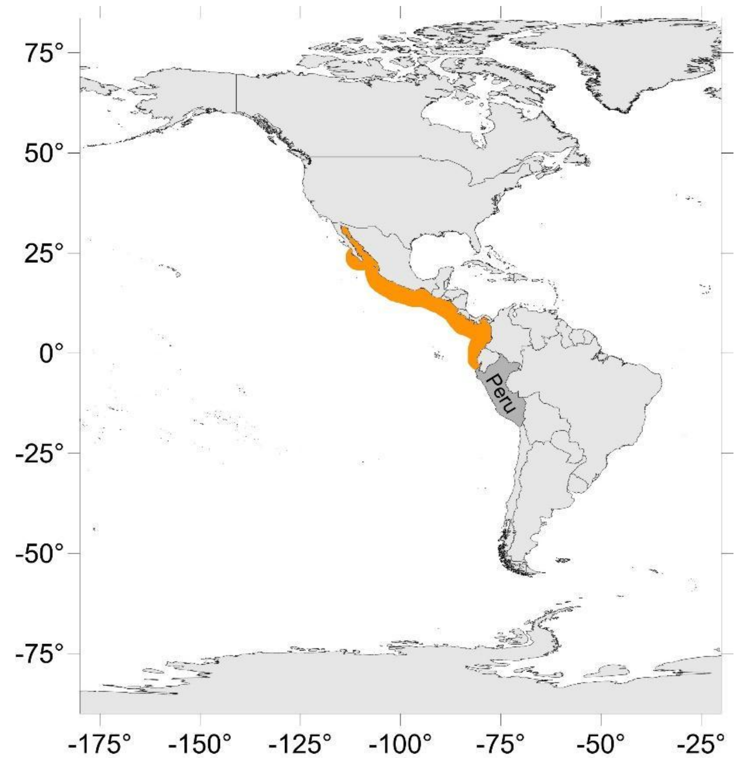
	Espinosa 2010); approximately 28° of latitudinal coverage considering both ranges of distribution.

Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 11° of latitude may be available to the south of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Salinity may have an effect on the spawnings of *C. analis*; for instance, although *C. nubelosus* tolerates a wide range of salinity, spawning is only carried out between salinities of 20 to 40 (Ibarra-Castro et al. 2015).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.

Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	The main spawning peak is in summer, and secondary peaks occur throughout the year (Llanos et al. 2009); duration of spawning is thus assumed to last > 4 months.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	In general, demersal fishes tend to deepen during El Niño (Espino 1990). During normal years the Peruvian weakfish occurs in temperate waters but during El Niño it occurs at higher temperatures (Espino 1990). Demersal fish inhabit the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size intra and interannually. In summer the habitat expands and in winter it is reduced, which results in lower and higher densities respectively. During El Niño events, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño event. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast to greater depths and from the pelagic system to the bottom (Velez et al. 1988; Espino 1990). Changes in distribution due to El Niño events also have resulted in changes in the size structure (Samamé et al. 1985). With oceanic warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009). Salinity may have an effect on the spawnings of *C. analis*; for instance, although *C. nubelosus* tolerates a wide range of salinity, spawning is only carried out between salinities of 20 to 40 (Ibarra-Castro et al. 2015). The Peruvian weakfish generally occurs between 1 mL/L and 1.75 mL/L of dissolved oxygen, whereas during El Niño it occurs between 2 mL/L and 2.25 mL/L of dissolved oxygen (Espino 1990).

1.22 Salema butterfish - *Peprilus snyderi*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Not available.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	The recruitment pattern is continuous and occurs throughout the year with two marked pulses, the most intense in summer and the least intense in spring (Vera et al. 2007). Consistent recruitment events every 1–2 years.
Average age at maturity	The mean length at maturity is 21.3 cm (Inga et al. 2008).
Generalist vs. specialist – food and habitat	Of carnivorous and planktonic habits; their diet is dominated by soft-bodied coelenterates, pelagic crustaceans, stomatopods and euphausiids (IMARPE 2009). This species occurs between 0 and 108 m depth (Iwamoto et al. 2010; Froese & Pauly 2019). It is present in several climatic zones: northern subtropical, northern tropical, equatorial and southern temperate.
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Distributed in the Eastern Central Pacific from the Baja California peninsula in Mexico to northern Peru (Iwamoto et al. 2010; Froese & Pauly 2019); approximately 36° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	There seems to be habitat availability further south of its southern limit off Peru, potentially of 13° of latitude.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	It is a partial spawner whose highest spawning peak occurs in summer, mainly in February (Vera et al. 2007). Therefore, it is considered that the duration of the spawning season is 2–4 months.

Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Demersal fish inhabit the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size. In summer, the habitat expands and in winter it shrinks, resulting in lower or higher densities, respectively. During El Niño, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast towards greater depths and from the pelagic system towards the bottom (Velez et al. 1988; Espino 1990). Changes in distribution due to El Niño have also resulted in changes in length structure (Samamé et al. 1985). With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).

1.23 Sea bass - *Paralabrax callaensis*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	*Paralabrax* spp. have an average fertility of 45,000 oocytes (Lluch-Cota 1995).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment events every 1–2 years.
Average age at maturity	The average length at maturity of females is 40 cm and of males is 42.2 cm total length (Elías 2016).
Generalist vs. specialist – food and habitat	This species lives up to 50 m deep (Bearez et al. 2010; Froese & Pauly 2019).

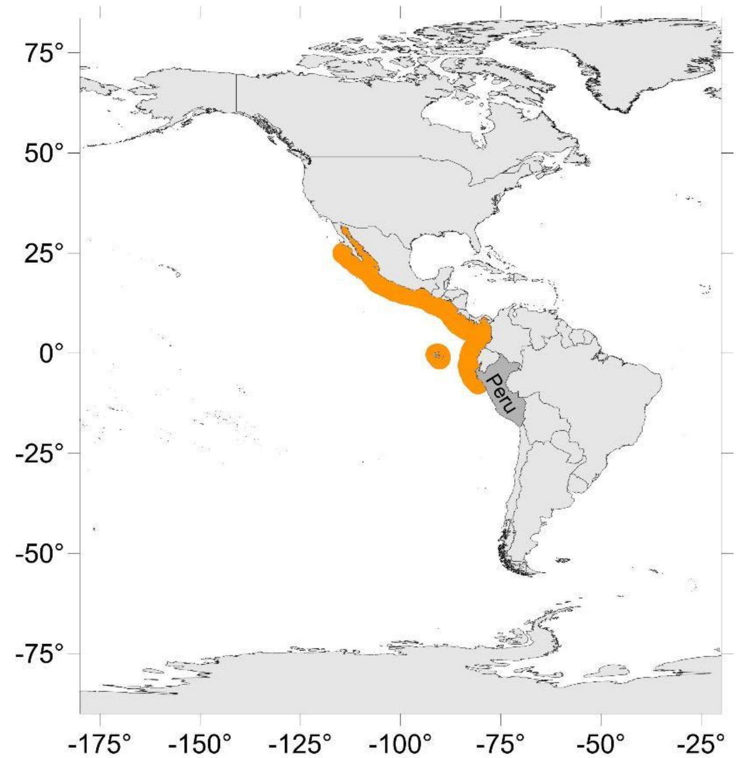
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	It is distributed in the Eastern Pacific, from Colombia to Peru (Bearez et al. 2010; Froese & Pauly 2019); approximately 10° of latitudinal coverage.

Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	There are approximately 6° of potential spatial availability of unoccupied habitat further south of it's southern limit of distribution off Peru.

Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Not available.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Demersal fish inhabit the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size. In summer, the habitat expands and in winter it shrinks, resulting in lower or higher densities, respectively. During El Niño, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast towards greater depths and from the pelagic system towards the bottom (Velez et al. 1988; Espino 1990). Changes in distribution due to El Niño have also resulted in changes in length structure (Samamé et al. 1985). With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).

1.24 Splittail bass - *Hemanthias peruanus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	The fecundity of *H. peruanus* is unknown.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment events every 1–2 years.
Average age at maturity	Other species of the same genus are protogynic or diandric (*H. leptus* and *H. vivanus*) (Richards 1999). The maximum recorded size of the maiden is 45 cm (Gonzales 2017). Mature individuals have been found from 9 cm in standard length (Coleman 1983). Other studies have found the size at first maturity in *H. leptus* females between 5 and 21 cm, and in males between 4 and 45 cm. For *H. vivanus*, the age at first maturity in females has been between 5 and 7 cm, and in males between 11 and 12 cm (Richards 1999).
Generalist vs. specialist – food and habitat	Feeds on plankton (Froese & Pauly 2019). *Hemanthias vivanus* feeds on copepods and foraminifera (Lindquist & Clavijo 1993). Occurs from 20 m to 120 m depth (Froese & Pauly 2019).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	It is distributed in the Eastern Pacific, from the Baja California peninsula in Mexico to northern Peru (Smith-Vaniz et al. 2010); approximately 38° of latitudinal coverage.



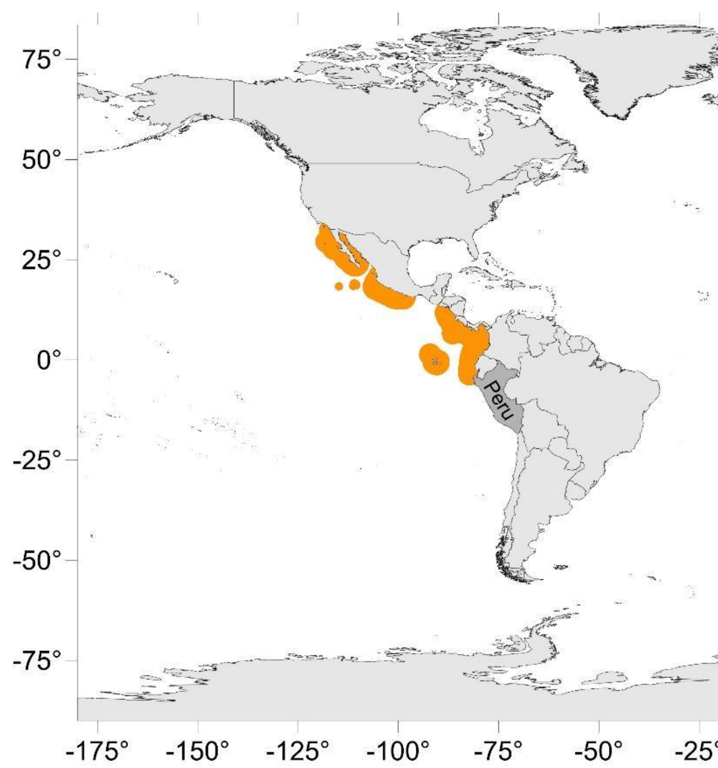
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	There is potential for spatial availability of unoccupied habitat further south of the southern limit of its distribution in Peruvian waters, approximately 11° of latitude.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	*Hemanthias leptus* does not have a specific spawning period; in contrast, *H. vivanus* spawning is more marked in winter-spring in the eastern Gulf of Mexico (Richards 1999). Therefore, it is considered that the duration of the spawning season is 2–4 months.

Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	This species inhabits the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size. In summer, the habitat expands and in winter it shrinks, resulting in lower or higher densities, respectively. During El Niño, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast towards greater depths and from the pelagic system towards the bottom (Velez et al. 1988; Espino 1990). Changes in distribution due to El Niño have also resulted in changes in length structure (Samamé et al. 1985). With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).

1.25 Starry grouper - *Epinephelus labriformis*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Not available.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment events every 1–2 years.
Average age at maturity	The starry grouper is a protogynous hermaphrodite, i.e., it changes gender from female to male upon reaching a standard length of approximately 40 cm (Gimenez-Hurtado et al. 2003).

Generalist vs. specialist – food and habitat	It feeds on small fish and crustaceans (Froese & Pauly 2019); its a demersal species that lives up to 50 m deep in rocky areas (Craig & Erisman 2018; Froese & Pauly 2019).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Changes in distribution have been associated with El Niño (Samamé et al. 1985), suggesting capacity for dispersal/movement. However, it's not specified at what life stage.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	It occurs in the Eastern Pacific, from the Baja California peninsula in Mexico to northern Peru, including the islands of Cocos, Revillagigedo and Galapagos (Froese & Pauly 2019); approximately 36° of latitudinal coverage.

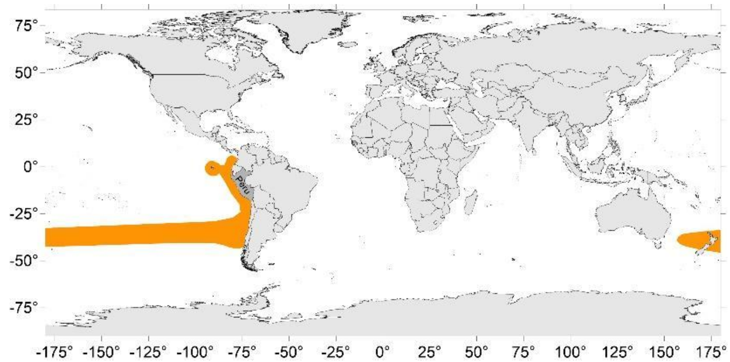


Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	There is potential for 13° of unoccupied habitat further south of the southern limit of its distribution in Peruvian waters.

Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Not available.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Demersal fish inhabit the continental shelf and are associated with the Cronwell Subsurface Countercurrent, which oscillates intra and interannually. As a consequence, the habitat of these species also varies in size. In summer, the habitat expands and in winter it shrinks, resulting in lower or higher densities, respectively. During El Niño, the demersal system would behave as in summer conditions, depending on the intensity and duration of El Niño. With El Niño, the diversity of the demersal system increases due to the incorporation of a greater number of species that move from north to south, from the coast towards greater depths and from the pelagic system towards the bottom (Velez et al. 1988; Espino 1990). Changes in distribution due to El Niño have also resulted in changes in length structure (Samamé et al. 1985). With ocean warming, the main spawning peak is delayed and the secondary peaks become more intense (Llanos et al. 2009).

Pelagic

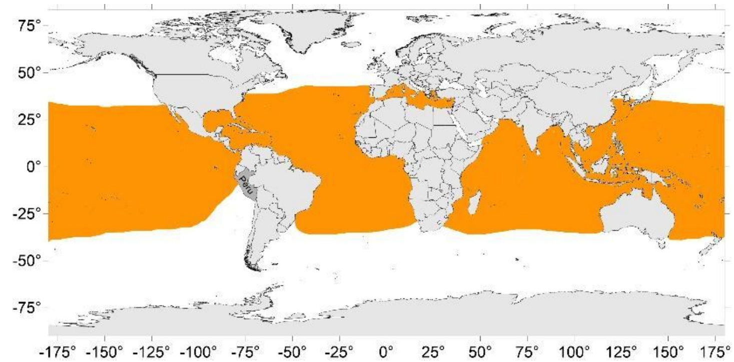
1.26 Chilean jack mackerel - *Trachurus murphyi*	
Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Approximately 78,789 eggs per spawning batch; females larger than 35 cm total length can produce 162,590 eggs per spawning batch (Dioses et al. 1988).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	It is assumed that the recruitment is annual (PRODUCE-IMARPE 2009) with 2–3 years old individuals being recruited (Vásquez et al. 2013).
Average age at maturity	This species reaches sexual maturity at 3 years (Marzloff et al. 2009; Vásquez et al. 2013).
Generalist vs. specialist – food and habitat	Chilean jack mackerel feed on fish, and more commonly on anchovy, as well as on crustaceans (e.g., euphausiids), also prey upon copepods, isopods and cephalopods (Mejía et al. 1970). Found along the coast and in oceanic waters from 10 to 300 m depth (Smith-Vaniz et al. 2010).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	In central Chile, it is estimated that the eggs and larvae are transported up to 1,800 km offshore, between spawning and nursery areas (Smith-Vaniz et al. 2010; Vásquez et al. 2013).
Capacity for adult/juvenile movement – lifetime range post-larval stage.	Not available
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Distributed from Ecuador to the south of Chile (Smith-Vaniz et al. 2010); approximately 45° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 27° of latitude may be available to the south of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Not available.
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	The reproductive season is from August to November and in February, but its greatest reproductive peak occurs at the end of winter (Mejía et al. 1970); duration of spawning is thus assumed to last > 4 months.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	The landing of this species has increased during El Niño events. Possible distributional changes are also anticipated; for example, the horse mackerel was distributed throughout the coast until El Niño 1997–1998, and then it moved to the south (Gutiérrez et al. 2012).

1.27 Common dolphinfish - *Coryphaena hippurus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Fecundity is estimated between 180,000 and 800,000 hydrated oocytes (Solano-Sare et al. 2008).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	The recruitment to the fishery is annual, however good recruitments occurred in 2004, 2007, 2011, i.e., about every 3 years depending on the environmental conditions (Ñiquen 2015).
Average age at maturity	This species reaches sexual maturity at 50–90 cm in length; in Peru it reaches maturity at 90 cm, in the first 2 years of life (Solano-Sare et al. 2008; Florida Museum 2021).
Generalist vs. specialist – food and habitat	Feed on various fishes, as well as on zooplankton, crustaceans and cephalopods (Solano-Sare et al. 2008). Inhabit open waters and coastal areas from the surface to 85 m depth (Collette et al. 2011).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Not available.
Capacity for adult/juvenile movement – lifetime range post-larval stage	This species migrates to the coast due to movements of warm oceanic waters towards the continent and during El Niño (Solano-Sare et al. 2008).
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Cosmopolitan species distributed in the United States, Mexico, throughout Peru (Zorritos, Mancora, Cabo Blanco, Paita, Huacho, Callao, Vila Vila) and as far south as Antofagasta, Chile, as well as in the Galapagos Islands (Collette et al. 2011); approximately 48° of latitudinal coverage.

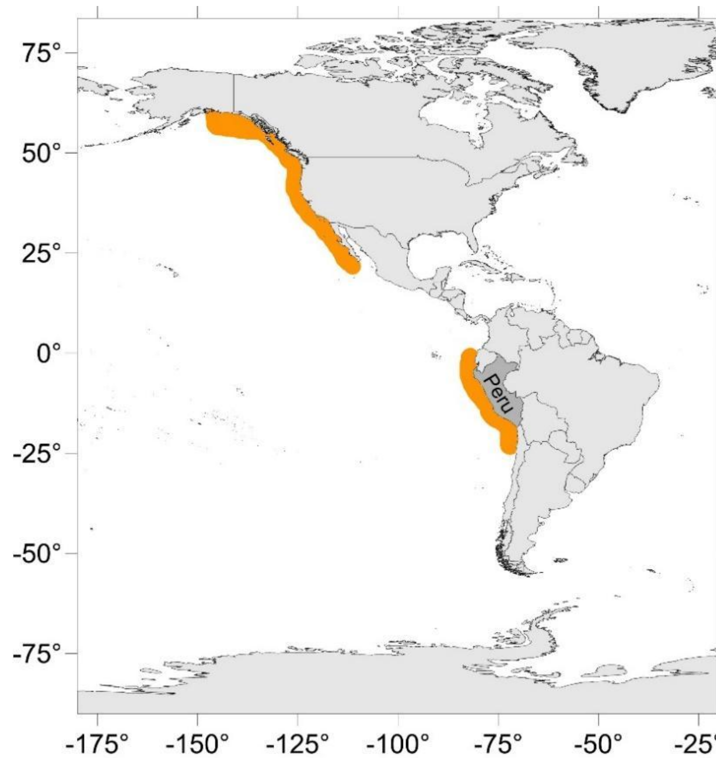


Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 5° of latitude may be available to the south of Peru; approximately 35° of latitude may be available to the north of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	The eggs seem to have a thermal preference around 25°C (Solano-Sare et al. 2008).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	In Peru mature individuals are found throughout the year, and more frequently in the austral summer from December to March (Solano-Sare et al. 2008; Florida Museum 2021); duration of spawning is thus assumed to last > 4 months.
Migration (seasonal and spawning)	This species migrates to the coast due to movements of warm oceanic waters towards the continent and during El Niño (Solano-Sare et al. 2008).
Exposure	
Response to environmental variability	In Peru this species is associated with the intrusion of surface subtropical waters and it is mainly found in waters at 21–28°C (Ñiquen 2014). The eggs seem to have a thermal preference at around 25°C. Catches of this species have increased during El Niño years; after El Niño 1997–1998, catches increased due to the intrusion of warm waters to

	the Peruvian coast (Solano-Sare et al. 2008). This species has high metabolic rates and requires high concentrations of oxygen, therefore, with the shoaling of the minimal oxygen zone its habitat is likely to be reduced vertically (Solano-Sare et al. 2008).

1.28 Eastern Pacific bonito - *Sarda chiliensis*

	Sensitivity
Abundance	
Fecundity – egg production (total fecundity)	Average partial fecundity is around 499,550 oocytes per spawning batch (Yoshida 1980).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Given that major spawning peaks occur annually and sexual maturity is reached at one year of age, it is assumed that recruitment also occurs annually, i.e., consistent recruitment events every 1–2 years.
Average age at maturity	This species reaches maturity at one year of age (Yoshida 1980).
Generalist vs. specialist – food and habitat	In the area of Lambayeque, Peru it feeds mainly on anchovy (Llanos et al. 2009).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Larval growth is slow between 2 and 4 days after hatching, which coincides with the opening of the mouth, the depletion of the yolk sac, and the initiation of external feeding (2.3 days) (Miranda et al. 2014).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Not available.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	In South America this species occurs from Puerto Pizarro, Peru to Talcahuano, Chile (Chirichigno & Cornejo 2001); approximately 33° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range

Approximately 19° of latitude may be available to the south of Peru.

Phenology

Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows

The main spawning peak occurs when positive thermal anomalies are expected (Llanos et al. 2009). In the Northeast Pacific, spawning occurs between 22°C and 26°C (Miranda et al. 2014).

Environmental variable as a phenological cue for settlement or metamorphosis

Not available.

Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season

Its main spawning peak is between December and February (Llanos et al. 2009); duration of spawning is thus assumed to last 2–4 months.

Migration (seasonal and spawning)

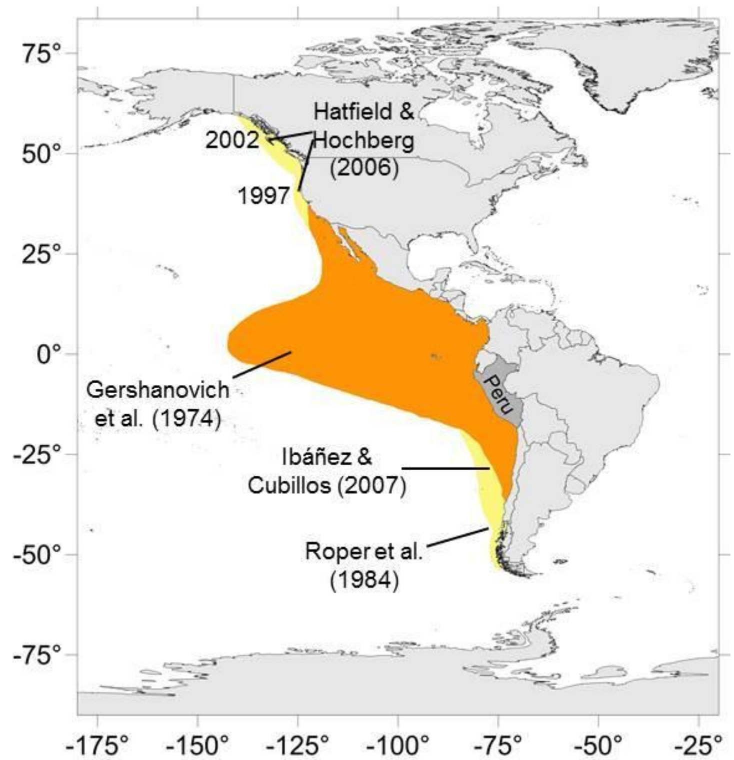
Has seasonal changes in the use of the habitat; it is more common near the coast in summer and at the beginning of

	autumn than during winter. These changes in distribution are attributed to long migrations in search of prey (Allen et al. 2006).
Exposure	
Response to environmental variability	The recurrence of warm conditions in the months of February, June, July and December seem to be associated with the presence of bonito (Llanos et al. 2009). However, the landing of this species has declined during El Niño events. The main spawning peak occurs when positive thermal anomalies are expected (Llanos et al. 2009). In the Northeast Pacific, spawning occurs between 22°C and 26°C (Miranda et al. 2014).

1.29 Jumbo flying squid - *Dosidicus gigas*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	In Peru the potential fecundity has been estimated in up to 25 million eggs in females of 1 m of mantle length (Sanchez 2010, unpublished). Nigmatullin et al. (2001) has reported up to 32 million eggs produced by large females.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment events every 1–2 years.
Average age at maturity	In the Mexican Pacific this species reaches sexual maturity at 205–350 days of age (Mejía-Rebollo et al. 2008).
Generalist vs. specialist – food and habitat	Prey belonging to up to 55 taxa have been found in stomach contents of *D. gigas* but stomachs also can contain only one or two taxa in Peruvian waters (Alegre et al. 2014). Feed mainly on myctophids, squids and crustaceans in the Gulf of California (Markaida et al. 2008); in juvenile stage, up to 9 types of prey have been detected (Camarillo-Coop et al. 2013).

Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Not available.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Adults can perform horizontal movements of ~ 35 km/day (Gilly et al. 2006; Stewart et al. 2012). The jumbo squid is likely to carry out considerable migrations in Peruvian waters (Keyl et al. 2008).
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Oceanic-neritic species that is distributed from California to southern Chile, although its distribution has increased latitudinally in the northern and southern hemispheres (Nigmatullin et al. 2001; Keyl et al. 2008; Ramos et al. 2017); approximately 107° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 32° of latitude may be available to the south of Peru; approximately 62° of latitude may be available to the north of Peru.

Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Temperature is a determinant variable for spawning; paralarvae tolerate a limited range of temperatures, probably between 17°C and 23°C, although embryos and paralarvae may be able to tolerate temperatures as low as 15°C (Staaf et al. 2011). The concentration of nutrients also may favor the recently hatched paralarvae.
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	The main spawning peak of *Dosidicus gigas* is from October to January, and a smaller spawning peak from July to August in Peruvian waters although there are mature females throughout the year (Tafur et al. 2001); duration of spawning is thus assumed to last > 4 months.
Migration (seasonal and spawning)	Spawning occurs on both the continental shelf and adjacent oceanic areas (Nigmatullin et al. 2001), as well as on the slope of the Nazca submarine mountain (Tafur et al. 2001).
Exposure	
Response to environmental variability	The increase in temperature during El Niño has a negative effect on the catches of *D. gigas*, while low temperatures during La Niña have a positive effect (Ibáñez et al. 2016). High temperatures tend to accelerate the rate of growth and decrease the life span, which may be positive as the population turnover would occur more often. However, also there would be negative effects; for instance, the size of the eggs would decrease, the size of sexual maturity would be reached at smaller sizes, and therefore the population structure would change. Individuals would require more food because of increased metabolic demand, and thus would require more oxygen. The increase in temperature also would cause the mismatch of the reproductive cycle and of recruitment (Pecl & Jackson 2008; Hoving et al. 2013). The blood of *D. gigas* has little capacity to carry oxygen; these squids use all the oxygen they carry in their blood, even when resting. The oxygen-blood ratio is highly sensitive

to pH, a property that facilitates the release of oxygen to the muscles but presumably interferes with oxygen extraction in hypoxic or CO_2-rich waters. *Dosidicus gigas* is then vulnerable to ocean acidification, oceanic warming and hypoxia (Rosa & Seibel 2008).

With climate change the oceans are warming and an expansion of the minimal oxygen zone is expected to occur. If *D. gigas* does not adapt or perform horizontal migrations, the synergy between ocean acidification, ocean warming, and the expanding hypoxic conditions will compress the range of habitable depth for this species (Rosa & Seibel 2008).

Temperature is a determinant variable for spawning; paralarvae tolerate a limited range of temperatures, probably between 17°C and 23°C, although embryos and paralarvae may be able to tolerate temperatures as low as 15°C (Staaf et al. 2011). The concentration of nutrients also may favor the recently hatched paralarvae.

1.30 Pacific chub mackerel - *Scomber japonicus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Its partial fecundity has been estimated in 78,174 oocytes per spawning batch (Peña et al. 1986).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment events every 1–2 years.
Average age at maturity	This species reaches sexual maturity at 2 years (Marzloff et al. 2009).
Generalist vs. specialist – food and habitat	Feeds on copepods, euphausiidae, fish eggs; among the teleosts it feeds mainly on anchovy and also has cannibalistic habits (Mejía et al. 1970). This is a pelagic and coastal species that occurs as deep as 300 m depth (Collette et al. 2011).

Distribution

Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)

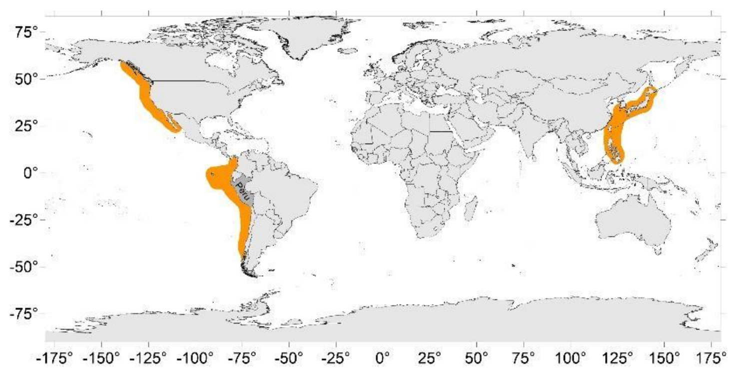
It presents a larval stage that consumes its yolk sac at approximately 46 hours after spawning (Hunter & Kimbrel 1980).

Capacity for adult/juvenile movement – lifetime range post-larval stage

Not available.

Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance

In the Pacific off South America, this species occurs from Costa Rica and along the Peruvian coast to Valparaíso, Chile and the Galapagos Islands (Mejía et al. 1970; Collette et al. 2011); approximately 45° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range

Approximately 27° of latitude may be available to the south of Peru.

Phenology

Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows

Spawning generally occurs between 15°C and 20°C (Collette et al. 2011). The reproductive season appears to occur earlier in the year due to the positive thermal anomalies (Llanos et al. 2009).

Environmental variable as a phenological cue for settlement or metamorphosis

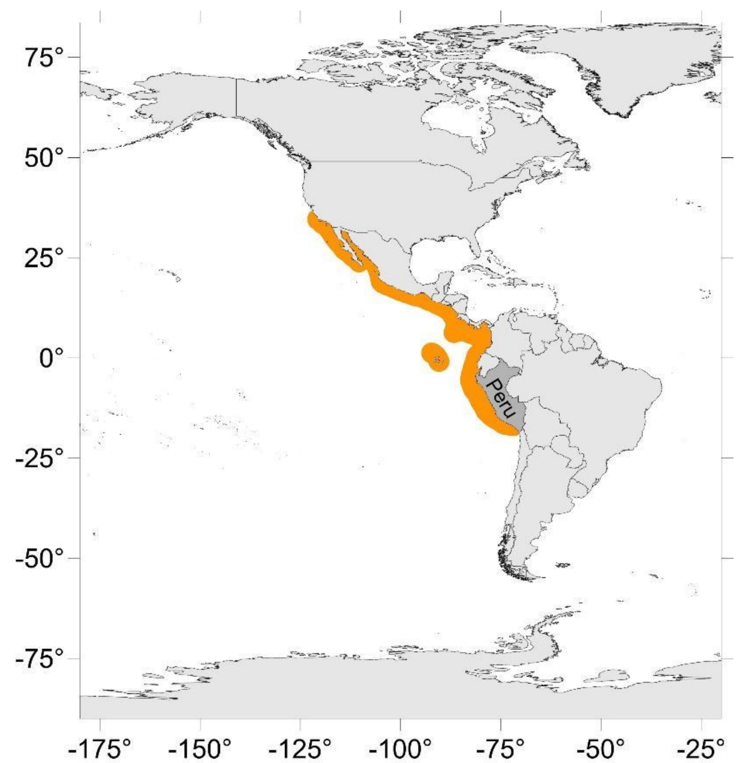
Metamorphosis of larvae appears to be stimulated by the effects of temperature, e.g., metamorphosis occurs in 24 days at 16.8°C or in 16 days at higher temperatures (22.1°C) (Hunter & Kimbrell 1980).

Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	The main spawning peaks occur between April and May, and a secondary peak in November (Llanos et al. 2009); duration of spawning is thus assumed to last 2–4 months.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	This species changed in distribution to the south where juveniles dominated, and there was an increase in the reproductive events, in biomass and in captures in Peru during El Niño 1997–1998 (Ñiquen & Bouchon 2004; Llanos et al. 2009). Spawning generally occurs between 15°C and 20°C (Collette et al. 2011). The metamorphosis of the larva appears to be stimulated by the effects of temperature, e.g., metamorphosis occurs in 24 days at 16.8°C or in 16 days at higher temperatures (22.1°C) (Hunter & Kimbrell 1980). The reproductive season appears to occur earlier in the year due to the positive thermal anomalies (Llanos et al. 2009).

1.31 Pacific sierra - *Scomberomorus sierra*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Not available.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment events every 1–2 years.
Average age at maturity	The Pacific sierra reaches sexual maturity between 26 cm and 32 cm fork length (FL); its maximum recorded length is 99 cm FL and its highest recorded weight is 8.2 kg (Froese & Pauly 2019).
Generalist vs. specialist – food and habitat	Adults feed on small fish, particularly anchovies and clupeids (Collette et al. 2011; Froese & Pauly 2019).

Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Not available.
Capacity for adult/juvenile movement – lifetime range post-larval stage	Not available.
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	It is distributed in the Eastern Central Pacific, from southern California in the United States of America to southern Peru, including the Galapagos Islands; it has recently been reported in Antofagasta, Chile (Collette et al. 2011; Froese & Pauly 2019). This is approximately 55° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Given that recently it has been reported off Antofagasta, Chile (Collette et al. 2011; Froese & Pauly 2019), there seems to be spatial availability of unoccupied habitat further south of its southern limit in Peruvian waters.

Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	Not available.
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Not available.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	Not available.

1.32 Skipjack tuna - *Katsuwonus pelamis*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Average fecundity is 204,000 eggs (Amezcua & Gallardo 2003).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment events every 1–2 years.
Average age at maturity	Not available.
Generalist vs. specialist – food and habitat	This species feeds on fish, crustaceans, cephalopods and mollusks, and there are reports of cannibalism. Occurs in subtropical waters between 0 m and 260 m depth, form

schools near the surface (Collette et al. 2011; Froese & Pauly 2019).

Distribution

Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)

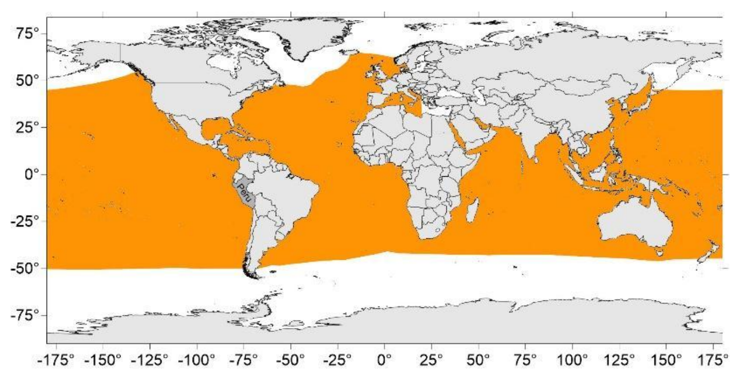
Not available.

Capacity for adult/juvenile movement – lifetime range post-larval stage

It is a highly migratory species (Collette et al. 2011; Froese & Pauly 2019).

Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance

The skipjack tuna is a cosmopolitan and highly migratory species that occurs in subtropical waters (Collette et al. 2011; Froese & Pauly 2019); approximately 100° of latitudinal coverage.



Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range

It occurs further south of Peru, it is therefore assumed to have 32° of latitudinal availability to the south of Peru.

Phenology

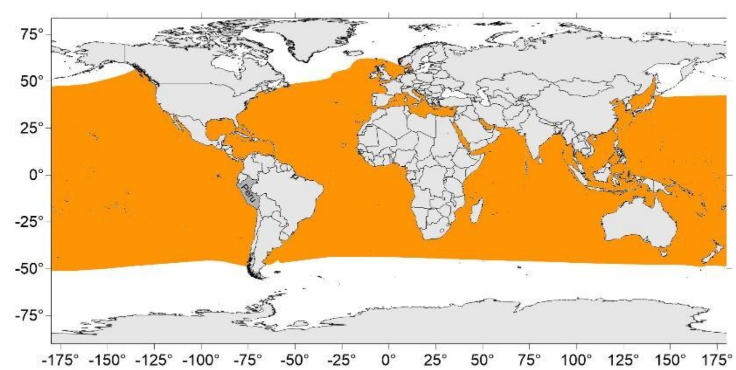
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows

Larvae are generally found at temperatures between 15°C and 30°C (Froese & Pauly 2019); other studies have found this species at temperatures between 18°C and 20°C (Villanueva & Mesía 1965).

Environmental variable as a phenological cue for settlement or metamorphosis	Larvae are generally found at temperatures between 15°C and 30°C (Froese & Pauly 2019); other studies have found this species at temperatures between 18°C and 20°C (Villanueva & Mesía 1965).
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Spawns all year round in equatorial waters and from spring to early autumn in subtropical waters (Fischer et al. 1995); with two peaks in February and October (Amezcua & Gallardo 2003). Therefore, it is considered that the duration of the spawning season is > 4 months.
Migration (seasonal and spawning)	It is a highly migratory species (Collette et al. 2011; Froese & Pauly 2019).
Exposure	
Response to environmental variability	Larvae are generally found at temperatures between 15°C and 30°C (Froese & Pauly 2019); other studies have found this species at temperatures between 18°C and 20°C (Villanueva & Mesía 1965).

1.33 Smooth hammerhead shark - *Sphyrna zygaena*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Not available.
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Off the coast of Kerala in India, the hammerhead shark has two recruitment peaks per year, the highest in July and the lowest in April (Manjusha et al. 2011).
Average age at maturity	In Peruvian waters, the adult size ranges from 152 cm to 258 cm in total length (TL; Elliott et al. 1996). Individuals between 136 cm and 149 cm TL are estimated to be approximately 4 years old (Coelho et al. 2011); considering that length at maturity is about 152 cm TL (Elliott et al. 1996), it is inferred that the smooth hammerhead shark reaches maturity at 5 years of age.
Generalist vs. specialist – food and habitat	Smooth hammerhead sharks feed on small sharks, rays, teleost fish, shrimp, barnacles, and cephalopods (Froese &

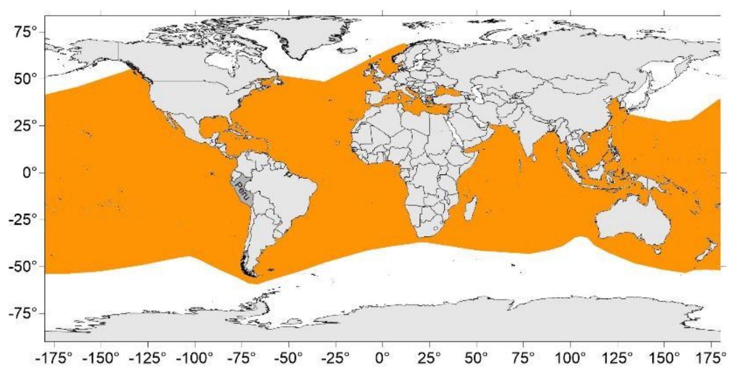
<table>
<tr><td></td><td>Pauly 2019). A more detailed analysis shows the following prey composition of S. zygena: Ommastrephes bartramii (44%; 27–59%), L. argenteus (27%; 14–38%) and D. gigas (17%; 0–34 %) (Loor-Andrade 2013). This species occurs from the surface to 200 m depth in tropical and sub-tropical waters (Froese & Pauly 2019).</td></tr>
<tr><td colspan="2">Distribution</td></tr>
<tr><td>Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)</td><td>Not available.</td></tr>
<tr><td>Capacity for adult/juvenile movement – lifetime range post-larval stage</td><td>It’s a migratory species (Froese & Pauly 2019).</td></tr>
<tr><td>Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance</td><td>Tropical-subtropical pelagic species (Froese & Pauly 2019); approximately 100° of latitude.

</td></tr>
<tr><td>Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range</td><td>There seems to be spatial availability of unoccupied habitat further south of its southern limit of distribution in Peruvian waters, of approximately 32° of latitude.</td></tr>
<tr><td colspan="2">Phenology</td></tr>
<tr><td>Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows</td><td>It breeds in surface waters and its reproductive season is extensive (Manjusha et al. 2011).</td></tr>
</table>

Environmental variable as a phenological cue for settlement or metamorphosis	It's viviparous with a yolk sac placenta (Manjusha et al. 2011).
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	It breeds near the surface and its reproductive season is extensive, with frequent multiple spawning (Manjusha et al. 2011). Therefore, it is considered that the duration of the spawning season is > 4 months.
Migration (seasonal and spawning)	It's a migratory species (Froese & Pauly 2019).
Exposure	
Response to environmental variability	It is found in a range of temperatures from 24°C to 25.3°C (Elliott et al. 1996).

1.34 Thresher shark - *Alopias vulpinus*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	Produces 3 to 4 offspring per year (De Lucio et al. 2013; Gervelis & Natanson 2013; Young et al. 2016).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	The thresher shark has a biennial or triennial reproductive cycle (De Lucio et al. 2013; Gervelis & Natanson 2013; Young et al. 2016). Consistent recruitment events every 1–2 years, although recruitment periods can be occasional and variable.
Average age at maturity	Off southern California, males mature at 3.3 m and females at 2.6–3.2 m (Cailliet & Bedford 1983). The longevity of the common thresher shark is estimated between 15 and 50 years (Gervelis & Natanson 2013).
Generalist vs. specialist – food and habitat	The stomach content of individuals in Peruvian waters suggests that they feed on squid (e.g., *Doryteuthis gahi* and *Dosidicus gigas*; Elliott et al. 1996). In the USA, its main prey are northern anchovy, Pacific sardine, Pacific hake, Pacific mackerel, horse mackerel and market squid (Preti et al. 2001, 2004, 2012). Preys such as mackerels, clupeids, needlefish, lanternfish, among others, as well as squid,

	octopus, pelagic crustaceans, and occasionally seabirds have also been reported (Goldman et al. 2009; Froese & Pauly 2019). It's a pelagic-oceanic species that inhabits between 0 and 650 m of depth, although it is generally found in the first 200 m of depth. The highest concentrations tend to occur in temperate coastal waters (Moreno & Morón 1992; Goldman 2009); it also extends over continental and island shelves, although they are most abundant near land about 40–50 nautical miles offshore (Strasburg 1958; Bedford 1992).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	Not available.
Capacity for adult/juvenile movement – lifetime range post-larval stage	This is a highly migratory species (Young et al. 2016).
Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	The thresher shark is a cosmopolitan subtropical species (Moreno & Morón 1992; Goldman 2009); approximately 100° of latitudinal coverage.



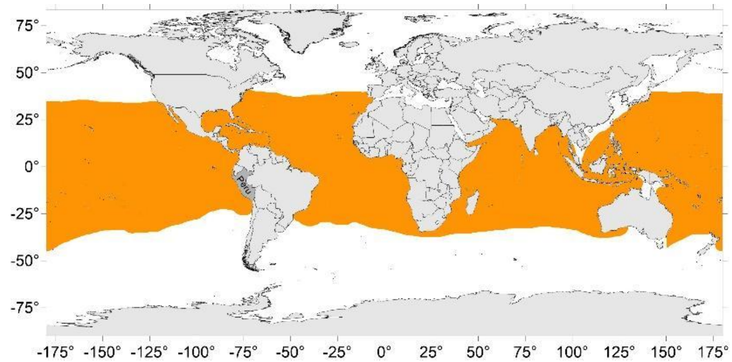
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Potential spatial availability of unoccupied habitat to the south of Peru, of approximately 32° of latitude.
Phenology	
Environmental variable as a phenological cue for spawning or	Thresher sharks are found in temperature ranges between 24°C and 25°C, although they also tolerate lower

breeding – cues include salinity, temperature, currents, and freshwater flows	temperatures (Elliott et al. 1996). In the Marshall Islands, common thresher sharks showed a preference for optimal swimming depth, water temperature, salinity, and dissolved oxygen range of 160–240 m, 18–20°C, 34.5–34.8 PPT, and 1.0–1.5 mL/L respectively, during the day (Cao et al. 2011).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Not available.
Migration (seasonal and spawning)	This is a highly migratory species; for instance, adults migrate through southern California waters in early spring and remain in marine waters for one to two months where they reproduce. Hatchlings appear to move into shallow coastal waters while adults follow warm waters and prey northward, arriving in Oregon and Washington in late summer. Some individuals are able to move to the Columbia River area. It is inferred that subadults move south again in autumn, reaching the area of the Channel Islands, California. Little is known about the suspected southward migration of large adults, which do not appear along the coast until the following spring (Young et al. 2016). This information may suggest seasonal or spawning migrations in the area of study.
Exposure	
Response to environmental variability	No studies have been conducted on the effects of environmental variability in thresher sharks. However, it is possible that climate change could affect this species through changes in ocean temperatures, currents and possibly in the dynamics of the food chain (Young et al. 2016). Thresher sharks are found in temperature ranges between 24°C and 25°C, although they also tolerate lower temperatures (Elliott et al. 1996). In the Marshall Islands, common thresher sharks showed a preference for optimal swimming depth, water temperature, salinity, and dissolved

	oxygen range of 160–240 m, 18–20°C, 34.5–34.8 PPT, and 1.0–1.5 mL/L respectively, during the day (Cao et al. 2011).

1.35 Yellowfin tuna - *Thunnus albacares*

Sensitivity	
Abundance	
Fecundity – egg production (total fecundity)	In Hawaiian waters its fecundity is 2,370,000–8,590,000 eggs, which annually can reach up to 60,000,000 eggs (Joseph 1963; FAO 2021).
Recruitment period – successful recruitment event that sustains the abundance of the fishery	Consistent recruitment events every 1–2 years. However, these can be occasional and variable.
Average age at maturity	Reaches sexual maturity at 2.5–3 years (Joseph 1963; FAO 2021).
Generalist vs. specialist – food and habitat	In general, tunas are opportunistic predator and do not depend on a particular type of prey; the larvae feed on zooplankton. In particular, the yellow fin tuna feeds on mesopelagic fish but a type of prey may be dominant depending on the area and season (FAO 2021). Mesopelagic species that is essentially confined to the upper 100 m of the water column in areas with marked oxyclines (Collette & Nauen 1983; FAO 2021).
Distribution	
Capacity for larval dispersal or larval duration – hatching to settlement (benthic species), hatching to yolk sac re-adsorption (pelagic species)	The passive transport of *T. albacares* probably occurs for 8–10 days, while larvae still have the yolk sack (Wexler et al. 2007).
Capacity for adult/juvenile movement – lifetime range post-larval stage	Tunas move constantly to allow water through their gills and perform long seasonal migrations in search of food and to reproduce (FAO 2021). Its capable of active movementes of around 633 miles (1,019 km) monthly in the Eastern Pacific (Fonteneau & Hallier 2015).

Physiological tolerance – latitudinal coverage of adult species as a proxy of environmental tolerance	Cosmopolitan species that occurs in the Eastern Pacific from Punta Concepcion, U.S.A. to the south of Valdivia, Chile (40°S) (IMARPE); approximately 73° of latitudinal coverage. 
Spatial availability of unoccupied habitat for most critical life stage – ability to shift distributional range	Approximately 11° of latitude may be available to the south of Peru; approximately 39° of latitude may be available to the north of Peru.
Phenology	
Environmental variable as a phenological cue for spawning or breeding – cues include salinity, temperature, currents, and freshwater flows	The temperature window for spawning is narrower and higher than 24°C, and larvae occur in warm surface waters (FAO 2021).
Environmental variable as a phenological cue for settlement or metamorphosis	Not available.
Temporal mismatches of life-cycle events – duration of spawning, breeding or moulting season	Spawns throughout the year but has higher spawning peaks in summer (Joseph 1963; FAO 2021); duration of spawning is thus assumed to last > 4 months.
Migration (seasonal and spawning)	Not available.
Exposure	
Response to environmental variability	This species occurs approximately between 18°C and 31°C (Collette & Nauen 1983). The temperature window for spawning is narrower and higher than 24°C, and larvae occur in warm surface waters (FAO 2021). During El Niño 1997–1998, tuna underwent changes in distribution to the south, from Ecuador to northern Peru, and reproductive events and landings increased in Peru (Ñiquen & Bouchon 2004). Ocean acidification causes damage to the kidneys, liver,

pancreas, eyes and muscles in larvae; and thus it has negative effects on larval growth and survival (Frommel et al. 2016). Concentrations of dissolved oxygen <2 mL/L below the thermocline exclude the presence of this species (Collette & Nauen 1983). The habitat of this species may be reduced due to the increase in temperature and decrease in oxygen concentration likely associated with climate change.

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Methods S2. Climate exposure factors

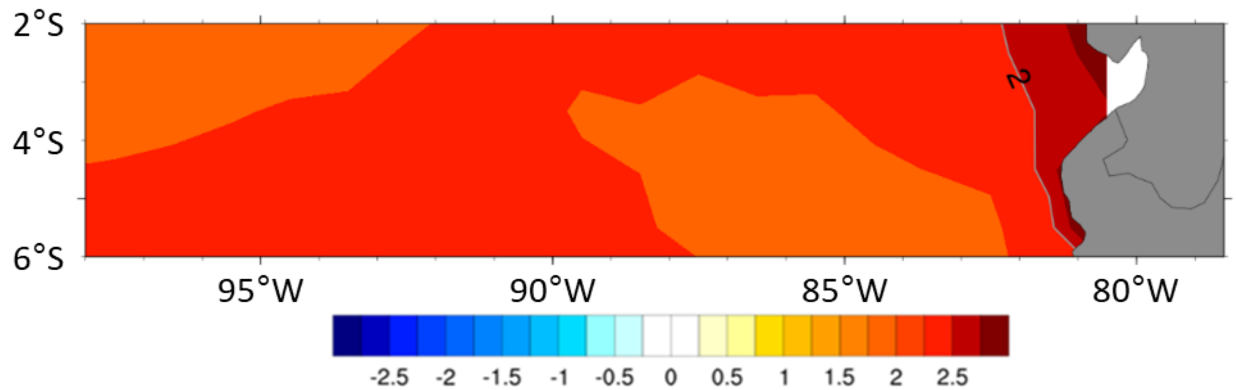
The change in mean climate conditions based on a standard deviate of the modeled future relative to the past was mapped with the NOAA Climate Change Web Portal for the area 3°S–6°S and 80°W–98°W, using the Standard Anom (average historical) statistic following Hare et al. (2016):

$$Z = \frac{\underline{X_f} - \underline{X_p}}{\sigma_p}$$

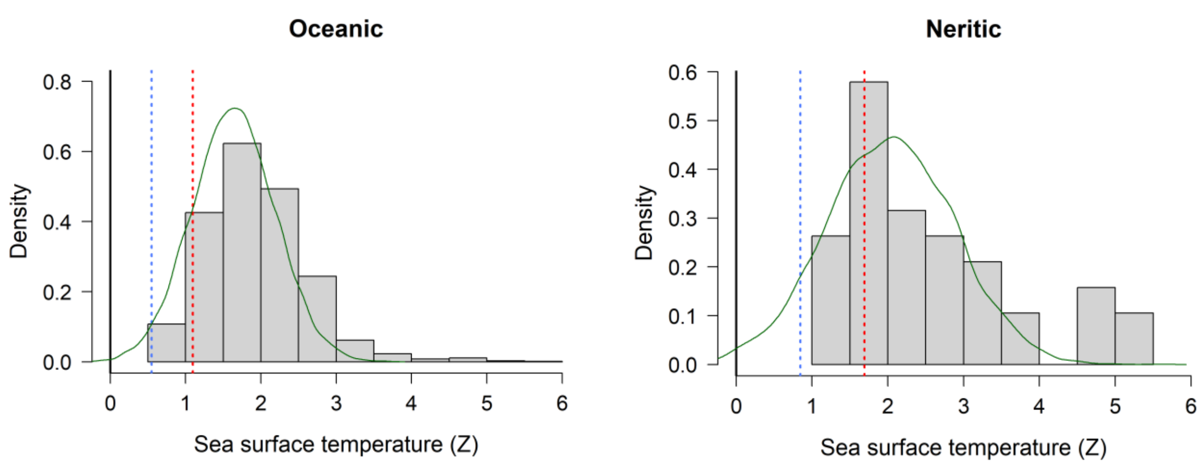
where $\underline{X_f}$ is the mean of the future (2006–2055), $\underline{X_p}$ is the mean of the past (1956–2005), and σ_p is the standard deviation of the past.

The pool of standard anomaly values was taken from 13–37 global climate models. All data is interpolated to a 1 degree by 1 degree grid to facilitate inter-comparison. Atmospheric grids were interpolated bilinearly, while oceanic grids were interpolated by a natural neighbour method. The Generalised Extreme Value (GEV) distribution was fitted to the data to calculate the probability of the magnitude of change in climate conditions. The magnitude of change was defined based on the anomaly values' standard deviation. We assumed a ‘high’ variation if the future climate values were > 2 standard deviations from the historical climate. A ‘medium’ change was considered when the future values were > 1 standard deviation but ≤ 2 standard deviations different from the historical climate. The magnitude of change was assumed ‘low’ if the future climate values were ≤ 1 standard deviation other than the historical climate. These categories were valid for both positive and negative anomaly values. The distribution of probabilities of the change in variables may have heavy tails because of extreme events. The GEV has good properties to describe the behaviour of extreme values (Coles 2001; Rypkema et al. 2019; Tabari 2021). This distribution is characterised by three parameters, the location (μ), the scale (σ), and the shape (ξ), that describe the centre of the distribution, the deviation around the centre, and the behaviour of the distribution’s tail, respectively. Inland, neritic, and oceanic zones were examined separately depending on the availability of data of each exposure factor. Changes in inland precipitation and air temperature were examined to assess the exposure of species located near the shore and in inland bodies of water.

Sea surface temperature



Difference in the mean sea surface temperature in the future (2006–2055) compared with the past (1956–2005) divided by the standard deviation of the past (Z), based on the Representative Concentration Pathway 8.5 (RCP8.5) high-emissions scenario



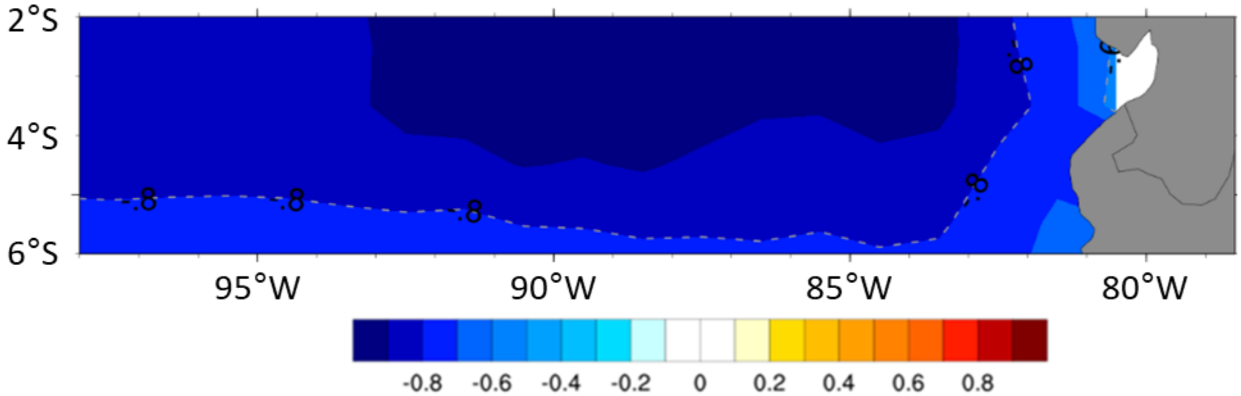
Frequency distribution of the change in mean oceanic and neritic sea surface temperature in the future (2006–2055) compared with the past (1956–2005) (Z). The solid black line indicates no change. The blue dotted line indicates one standard deviation, and the red dotted line indicates two standard deviations, representing the low, medium and high magnitude of change thresholds, respectively

Categories of magnitude of change of mean sea surface temperature (SST) and corresponding estimated probabilities

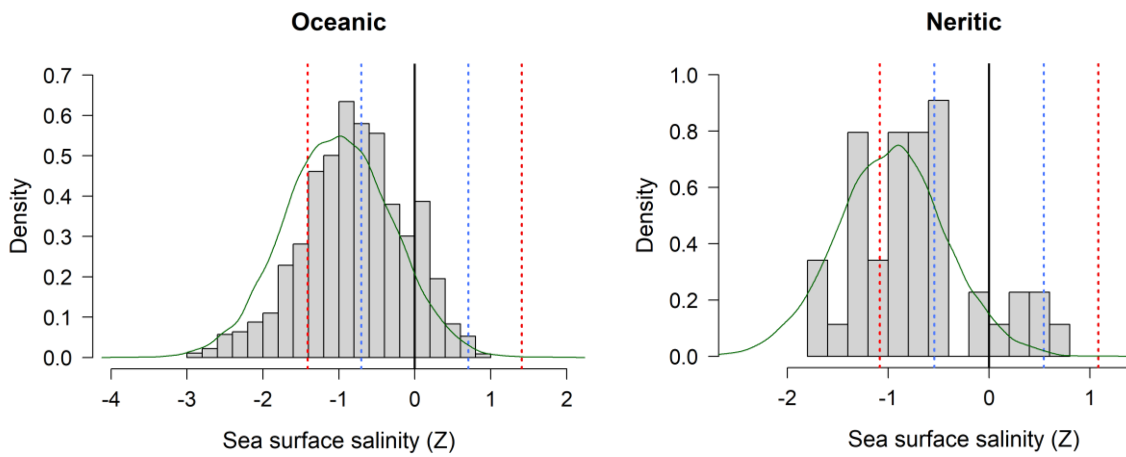
Zone	Change		Thresholds	Estimated probability
	Direction	Magnitude		
Oceanic	Negative	Low	$Z < 0.00$	0.0
	Positive	Low	$0.00 < Z \leq 0.55$	0.1
		Medium	$0.55 < Z \leq 1.10$	7.1
		High	$1.10 < Z$	92.8
Neritic	Negative	Low	$Z < 0.00$	0.0
	Positive	Low	$0.00 < Z \leq 0.85$	0.5
		Medium	$0.85 < Z \leq 1.69$	22.1
		High	$1.69 < Z$	77.4

Z = Difference of the mean SST in the future (2006–2055) compared with the past (1956–2005)

Sea surface salinity



Difference in the mean sea surface salinity in the future (2006–2055) compared with the past (1956–2005) divided by the standard deviation of the past (Z), based on the Representative Concentration Pathway 8.5 (RCP8.5) high-emissions scenario



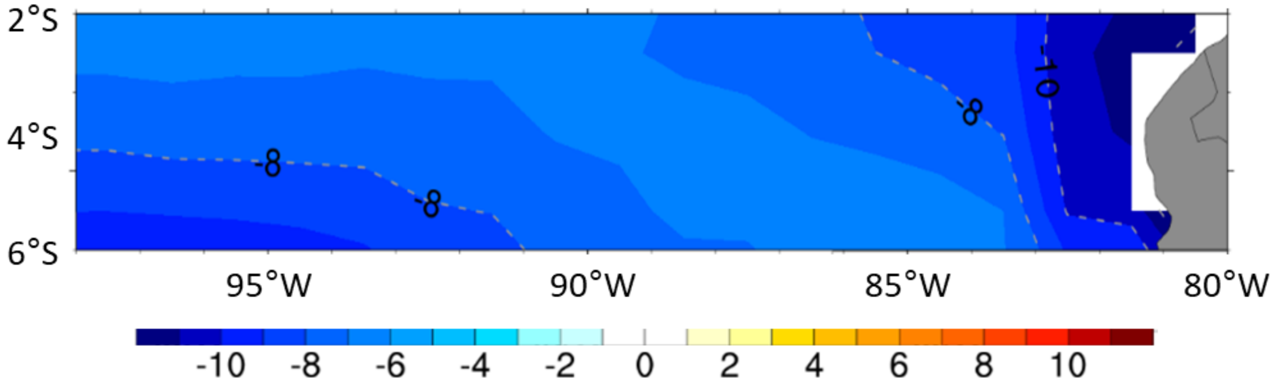
Frequency distribution of the change in mean oceanic and neritic sea surface salinity in the future (2006–2055) compared with the past (1956–2005) (Z). The solid black line indicates no change. The blue dotted line indicates one standard deviation and the red dotted line indicates two standard deviations, representing the low, medium and high magnitude of change thresholds, respectively

Categories of magnitude of change of mean sea surface salinity (SSS) and corresponding approximate probabilities

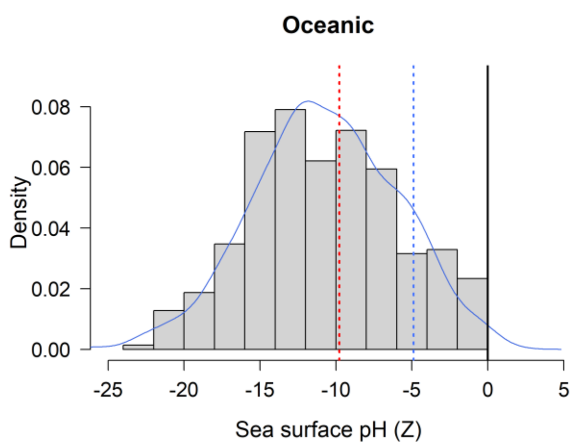
Zone	Change		Thresholds	Estimated probability
	Direction	Magnitude		
Oceanic	Negative	High	-1.41 > Z	18.6
		Medium	-0.70 > Z ≥ -1.41	34.8
		Low	0.00 > Z ≥ -0.70	33.7
	Positive	Low	0.00 < Z ≤ 0.70	12.5
		Medium	0.70 < Z ≤ 1.41	0.4
		High	1.41 < Z	0.0
Neritic	Negative	High	-1.08 > Z	28.8
		Medium	-0.54 > Z ≥ -1.08	35.1
		Low	0.00 > Z ≥ -0.54	22.3
	Positive	Low	0.00 < Z ≤ 0.54	9.4
		Medium	0.54 < Z ≤ 1.08	3.2
		High	1.08 < Z	1.2

Z = Difference of the mean SSS in the future (2006–2055) compared with the past (1956–2005)

pH



Difference in the mean pH in the future (2006–2055) compared with the past (1956–2005) divided by the standard deviation of the past (Z), based on the Representative Concentration Pathway 8.5 (RCP8.5) high-emissions scenario



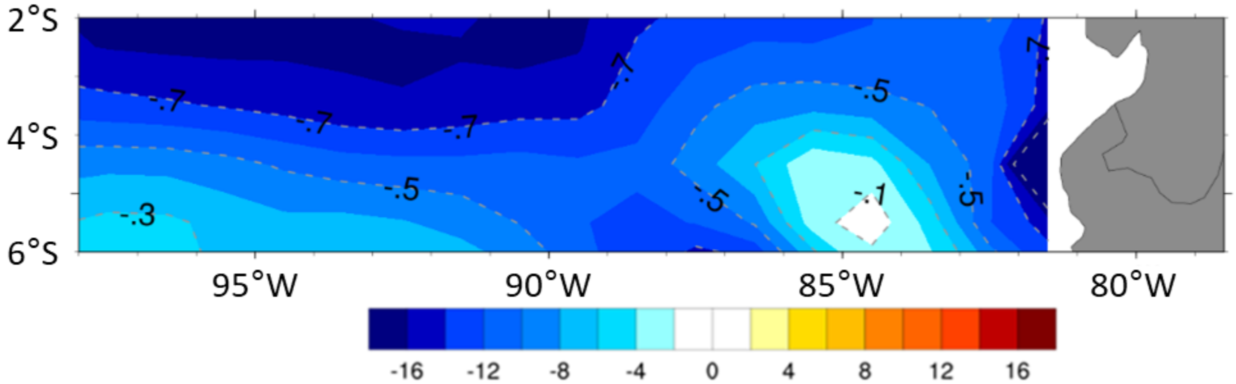
Frequency distribution of the change in mean oceanic pH in the future (2006–2055) compared with the past (1956–2005) (Z). The solid black line indicates no change. The blue dotted line indicates one standard deviation and the red dotted line indicates two standard deviations, representing the low, medium and high magnitude of change thresholds, respectively

Categories of magnitude of change of mean pH and corresponding approximate probabilities

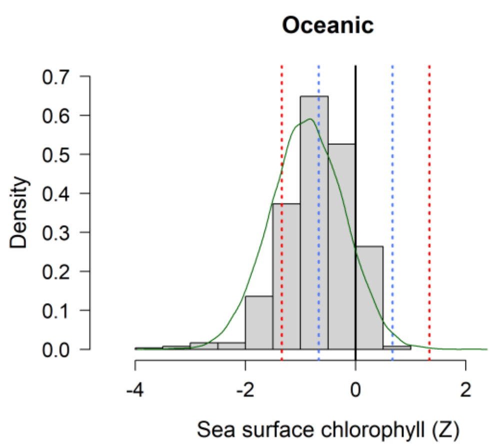
Zone	Change		Thresholds	Estimated probability
	Direction	Magnitude		
Oceanic	Negative	High	-9.78 > Z	57.6
		Medium	-4.89 > Z ≥ -9.78	31.0
		Low	0.00 > Z ≥ -4.89	10.8
	Positive	Low	0.00 < Z	0.6

Z = Difference of the mean pH in the future (2006–2055) compared with the past (1956–2005)

Chlorophyll



Difference in the mean chlorophyll mass in the future (2006–2055) compared with the past (1956–2005) divided by the standard deviation of the past (Z), based on the Representative Concentration Pathway 8.5 (RCP8.5) high-emissions scenario



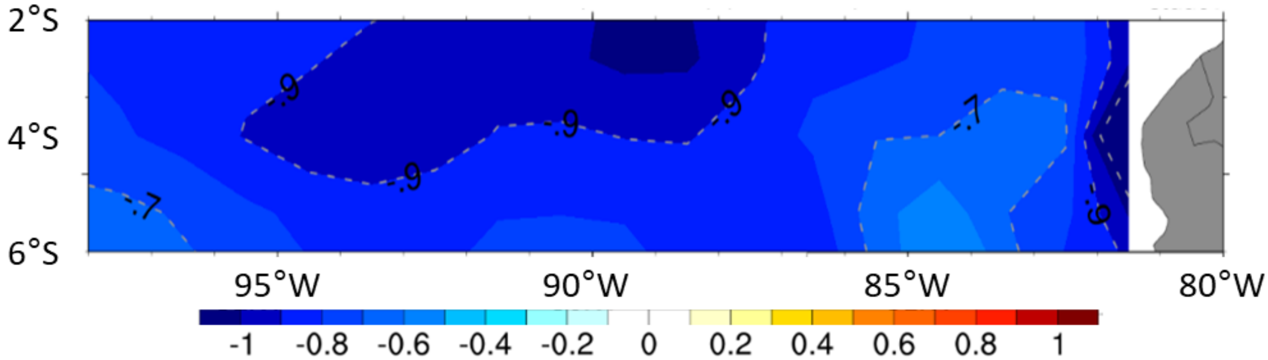
Frequency distribution of the negative and positive change in mean oceanic chlorophyll in the future (2006–2055) compared with the past (1956–2005) (Z). The solid black line indicates no change. The blue dashed line indicates one standard deviation and the red dotted line indicates two standard deviations, representing the low, medium and high magnitude of change thresholds, respectively

Categories of magnitude of change of mean chlorophyll (Chl) and corresponding approximate probabilities

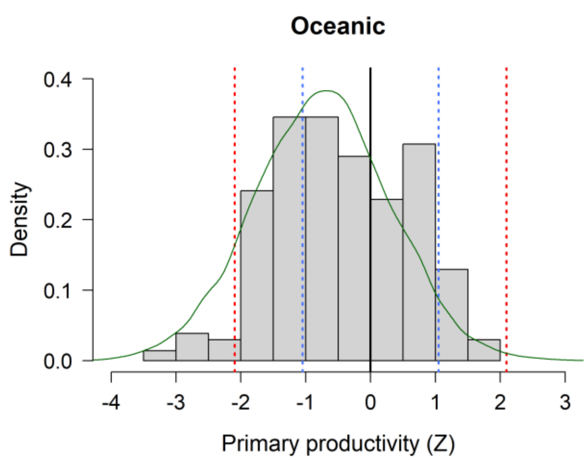
Zone	Change		Thresholds	Estimated probability
	Direction	Magnitude		
Oceanic	Negative	High	-1.34 > Z	16.0
		Medium	-0.67 > Z ≥ -1.34	32.7
		Low	0.00 > Z ≥ -0.67	37.6
	Positive	Low	0.00 < Z ≤ 0.67	13.7
		Medium	0.67 < Z ≤ 1.34	0.0
		High	1.34 < Z	0.0

Z = Difference of the mean Chl in the future (2006–2055) compared with the past (1956–2005)

Primary productivity



Difference in the mean primary productivity in the future (2006–2055) compared with the past (1956–2005) divided by the standard deviation of the past (Z), based on the Representative Concentration Pathway 8.5 (RCP8.5) high-emissions scenario



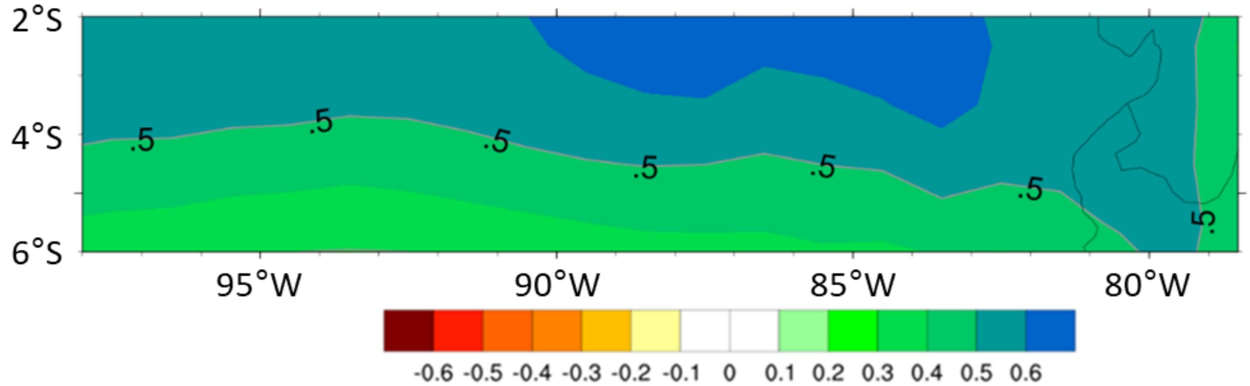
Frequency distribution of the change in mean oceanic and neritic primary productivity in the future (2006–2055) compared with the past (1956–2005) (Z). The solid black line indicates no change. The blue dotted line indicates one standard deviation and the red dotted line indicates two standard deviations, representing the low, medium and high magnitude of change thresholds, respectively

Categories of magnitude of change of mean primary productivity (PP) and corresponding approximate probabilities

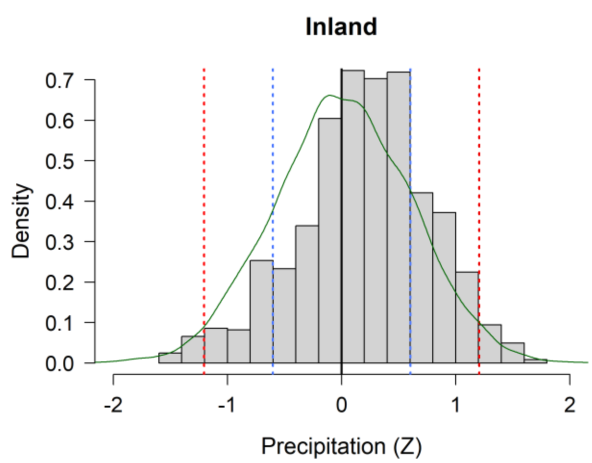
Zone	Change		Thresholds	Estimated probability
	Direction	Magnitude		
Oceanic	Negative	High	$-2.09 > Z$	5.9
		Medium	$-1.05 > Z \geq -2.09$	21.7
		Low	$0.00 > Z \geq -1.05$	37.8
	Positive	Low	$0.00 < Z \leq 1.05$	28.3
		Medium	$1.05 < Z \leq 2.09$	6.3
		High	$2.09 < Z$	0.0

Z = Difference of the mean PP in the future (2006–2055) compared with the past (1956–2005)

Precipitation



Difference in the mean precipitation in the future (2006–2055) compared with the past (1956–2005) divided by the standard deviation of the past (Z), based on the Representative Concentration Pathway 8.5 (RCP8.5) high-emissions scenario



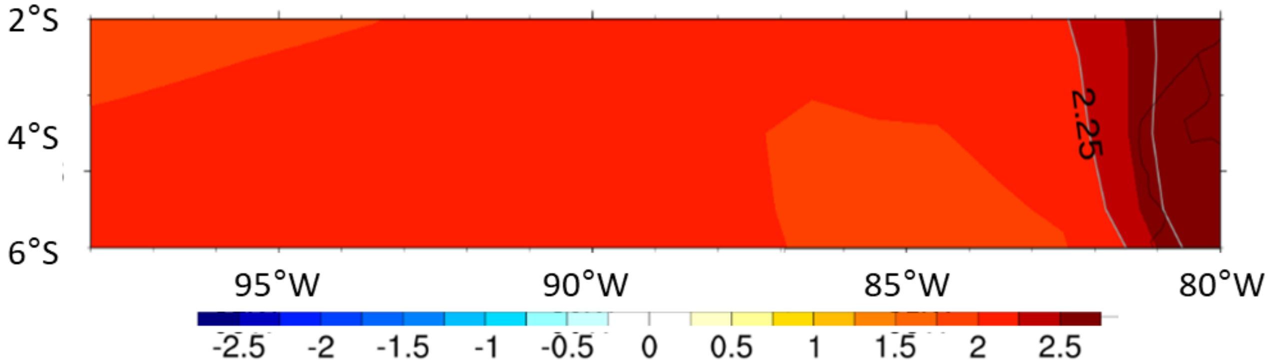
Frequency distribution of the change in mean inland precipitation in the future (2006–2055) compared with the past (1956–2005) (Z). The solid black line indicates no change. The blue dotted line indicates one standard deviation and the red dotted line indicates two standard deviations, representing the low, medium and high magnitude of change thresholds, respectively

Categories of magnitude of change of mean inland precipitation and corresponding approximate probabilities

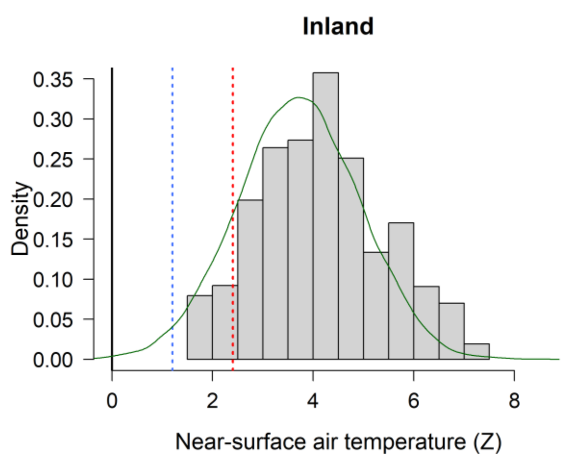
Zone	Change		Thresholds	Estimated probability
	Direction	Magnitude		
Inland	Negative	High	$-1.21 > Z$	1.0
		Medium	$-0.60 > Z \geq -1.21$	8.2
		Low	$0.00 > Z \geq -0.60$	27.0
	Positive	Low	$0.00 < Z \leq 0.60$	37.7
		Medium	$0.60 < Z \leq 1.21$	22.5
		High	$1.21 < Z$	3.6

Z = Difference of the mean precipitation in the future (2006–2055) compared with the past (1956–2005)

Air temperature



Difference in the mean coastal and inland air temperature in the future (2006–2055) compared with the past (1956–2005) divided by the standard deviation of the past (Z), based on the Representative Concentration Pathway 8.5 (RCP8.5) high-emissions scenario



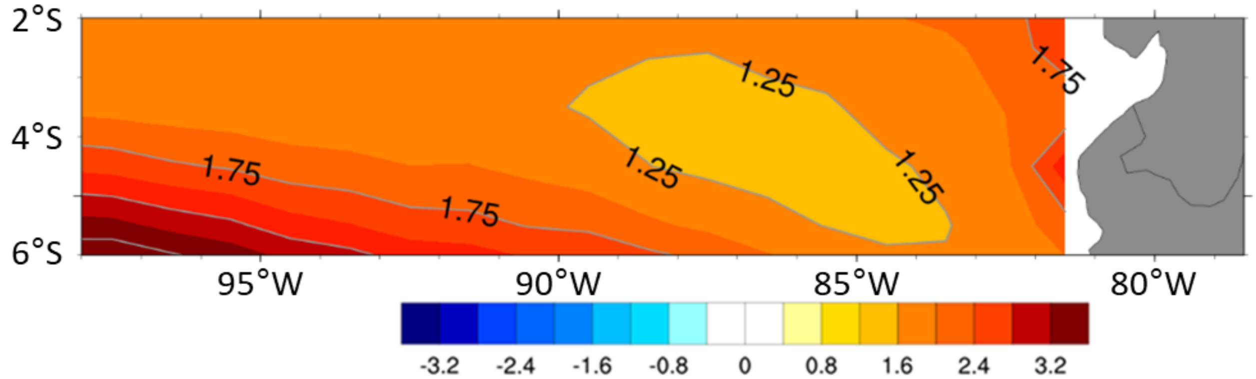
Frequency distribution of the change in mean coastal and inland air temperature in the future (2006–2055) compared with the past (1956–2005) (Z). The solid black line indicates no change. The blue dotted line indicates one standard deviation and the red dotted line indicates two standard deviations, representing the low, medium and high magnitude of change thresholds, respectively

Categories of magnitude of change of mean coastal and inland air temperature (AT) and corresponding approximate probabilities

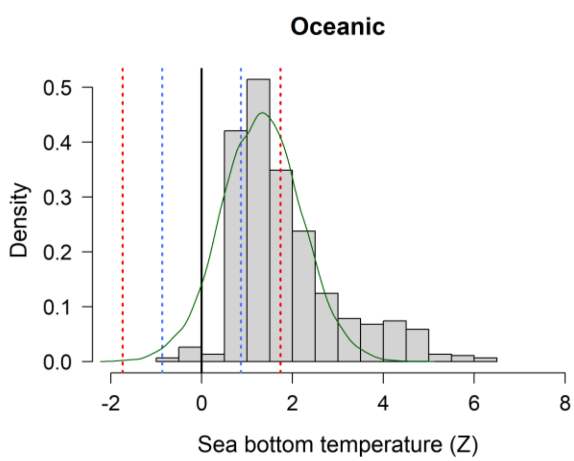
Zone	Change		Thresholds	Estimated probability
	Direction	Magnitude		
Inland	Negative	Low	Z < 0.00	0.00
	Positive	Low	0.00 < Z ≤ 1.20	0.4
		Medium	1.20 < Z ≤ 2.41	7.1
		High	2.41 < Z	92.5

Z = Difference of the mean AT in the future (2006–2055) compared with the past (1956–2005)

Sea bottom temperature



Difference in the mean sea bottom temperature in the future (2006–2055) compared with the past (1956–2005) divided by the standard deviation of the past (Z), based on the Representative Concentration Pathway 8.5 (RCP8.5) high-emissions scenario



Frequency distribution of the change in mean oceanic sea bottom temperature in the future (2006–2055) compared with the past (1956–2005) (Z). The solid black line indicates no change. The blue dotted line indicates one standard deviation and the red dotted line indicates two standard deviations, representing the low, medium and high magnitude of change thresholds, respectively

Categories of magnitude of change of mean sea bottom temperature (SBT) and corresponding approximate probabilities

Zone	Change		Thresholds	Estimated probability
	Direction	Magnitude		
Oceanic	Negative	High	-1.74 > Z	0.0
		Medium	-0.87 > Z ≥ -1.74	0.0
		Low	0.00 > Z ≥ -0.87	0.9
	Positive	Low	0.00 < Z ≤ 0.87	17.4
		Medium	0.87 < Z ≤ 1.74	35.3
		High	1.74 < Z	46.4

Z = Difference of the mean SBT in the future (2006–2055) compared with the past (1956–2005)

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Sea bottom salinity

Sea bottom salinity data were insufficient for the area of study and this exposure factor was assessed based on expert judgment and on related data.

Sea level rise

The Intergovernmental Panel on Climate Change Fifth Assessment Report (AR5) estimates that the rate of global mean sea level rise for the period 2081–2100 will be 2.0–15.7 mm/year, reaching a sea level rise between 0.26 to 0.82 m across the different Representative Concentration Pathways (RCPs). The RCP8.5 high-emissions scenario estimates a global mean sea level rise of 0.22 to 0.38 m during 2046–2065; a rate of 8–16 mm/year during 2081–2100 will result in a sea level rise of 0.52 to 0.98 m by the year 2100 (Church et al*.* 2013). Off Peru, the expected mean trend in sea level rise is of approximately 1.2–2.8 mm/year for 2010–2040, and 1.2–3.2 mm/year for the period 2040–2070 (ECLAC 2015).

Sea level rise will have considerable impacts on the structure of the shoreline and on coastal ecosystems due to intrusion of salt water, accretion of sediments, coastal erosion, increase in water depths, change in tidal variation and water movement (Short & Neckles 1999; De Silva & Soto 2009). Salt water intrusion may represent a threat for early stages of commercial or ecologically important species that use mangroves as nursery grounds. In this sense, salt water intrusion associated with sea level rise will impose ecological and habitat changes with consequences on fisheries production in deltaic areas and brackish habitats (De Silva & Soto 2009). Oceanic water intrusion into fresh or brackish water areas also will affect estuarine plant distribution because of the effect of salinity change on seed germination, propagule formation, photosynthesis, growth and biomass. Whereas increased water depth, water motion and tidal circulation reduces the amount of light that reaches plants, negatively affecting photosynthetic rates

(Short & Neckles 1999), with consequences on the structure of plant communities and animal species that rely on those habitats.

Marsh ecosystems appear to be stable at local sea level rise of 2–3 mm/year; however, projected sea level rise of ∼5 mm/year can result in a shift from marshes to unvegetated subtidal environments (Kirwan et al. 2010; Morris et al. 2016). At first glance, coastal wetlands of Peru appear to be able to resist the impacts of sea level rise rates estimated for the region (mean range = 1.2–2.8 mm/year for 2010–2040; 1.2–3.2 mm/year for 2040–2070). However, sediment accretion and tide breadth also influence the capacity of wetlands to counteract the effects of sea level rise. For instance, critical rates of sea level rise for marshes can be of only a few millimeters per year at low suspended sediment concentrations (∼1–10 mg/L); whereas adaptation can occur at high suspended sediment concentrations (30–100 mg/L) (Kirwan et al. 2010). Overall, marshes with high tidal ranges and high suspended sediment concentrations are more resilient to sea level rise compared with marshes with low tidal ranges and low suspended sediment concentrations (Kirwan et al. 2010). Critical sea level rise for Peruvian coastal wetlands should be taken with caution given that, to our knowledge, there are no estimations on accretion rate for such ecosystems in the region.

Scoring. Studies suggest that wetlands may adapt at local sea level rise of 2–3 mm/year but would be highly affected at sea level rise >5 mm/year, turning into unvegetated subtidal environments (Kirwan et al. 2010; Morris et al. 2016). Tallies were allocated across all three bins based on the dependency of the species on habitats that are expected to be affected by sea level rise. The effect of regional differences in sea level rise and fixed shoreline structures built to minimize the impact of shore erosion and floods, and that can stop coastal wetland communities from migrating inland (Nicholls 2004; Nicholls et al. 2007) were considered. The three bin scores (low, medium, high) were defined as:

Category	Score	Criteria
High	3	The species depends on wetland or estuary habitat at any given life history stage, and the regional sea level rise is >5 mm year^{-1} by 2050
Medium	2	The species depends on wetland or estuary habitat at any given life history stage, and the regional sea level rise is 2–3 mm year^{-1} by 2050
Low	1	The species does not depend on wetland or estuary habitat at any life history stage

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Additional results

Figure S1. Weighted score of climate exposure factors for key fishery resources in the Tropical Eastern Pacific Ecosystem off Peru. Thin bars correspond to the cumulative weighted score of species groups. Thick shaded bars correspond to the total cumulative weighted score. SST: Sea surface temperature; PP: Primary productivity; SSS: Sea surface salinity; pH: as a proxy for ocean acidification; Chl: Chlorophyll concentration; SBT: Sea bottom temperature; Prec: Precipitation; SLR: Sea level rise; AST: Air surface temperature; SBS: Sea bottom salinity.

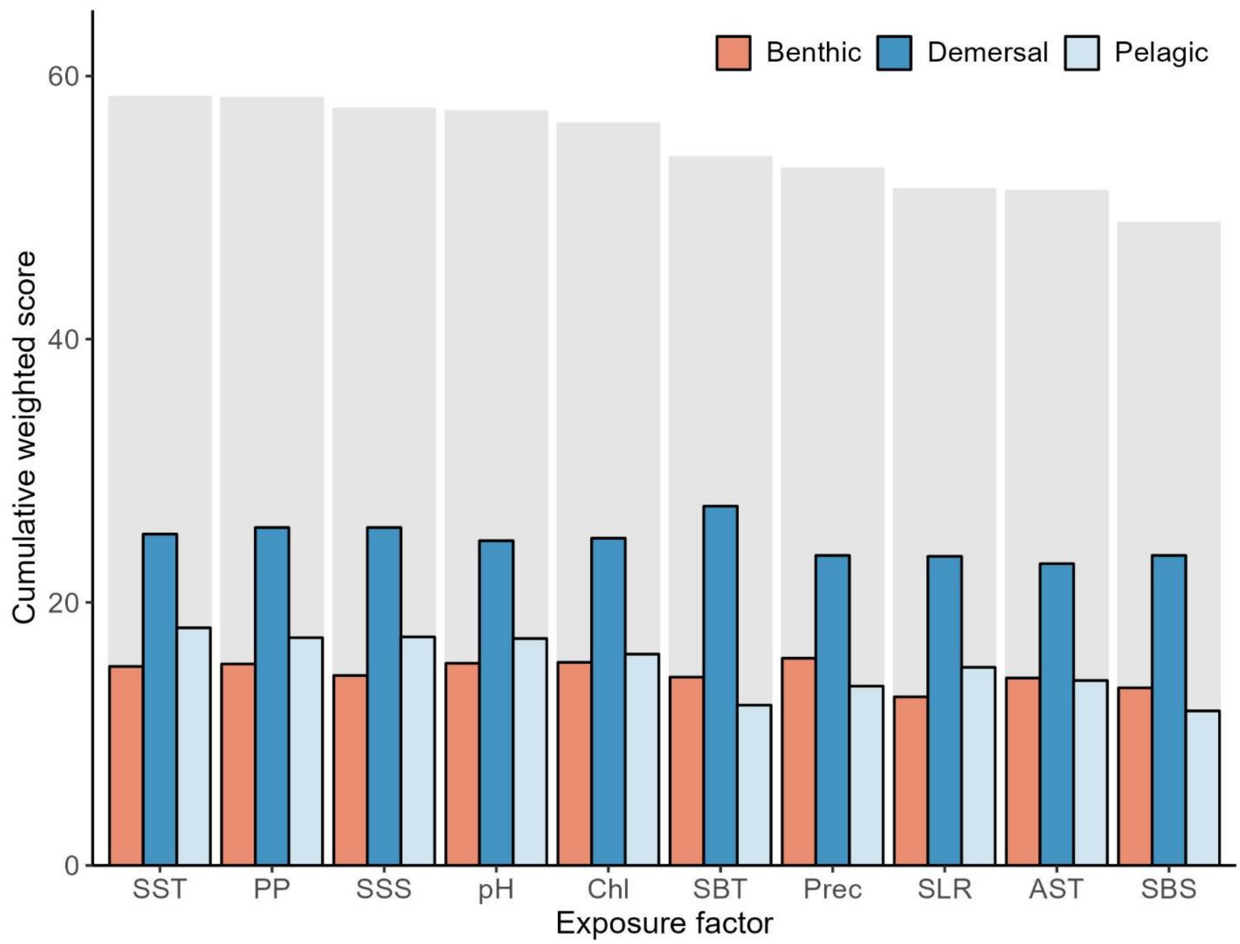

Figure S2. Data quality of climate exposure factors per group of key fishery resources in the Tropical Eastern Pacific Ecosystem off Peru. Data quality score: 3) High quality data; 2) Related data; 1) Reviewer judgment; 0) No data.

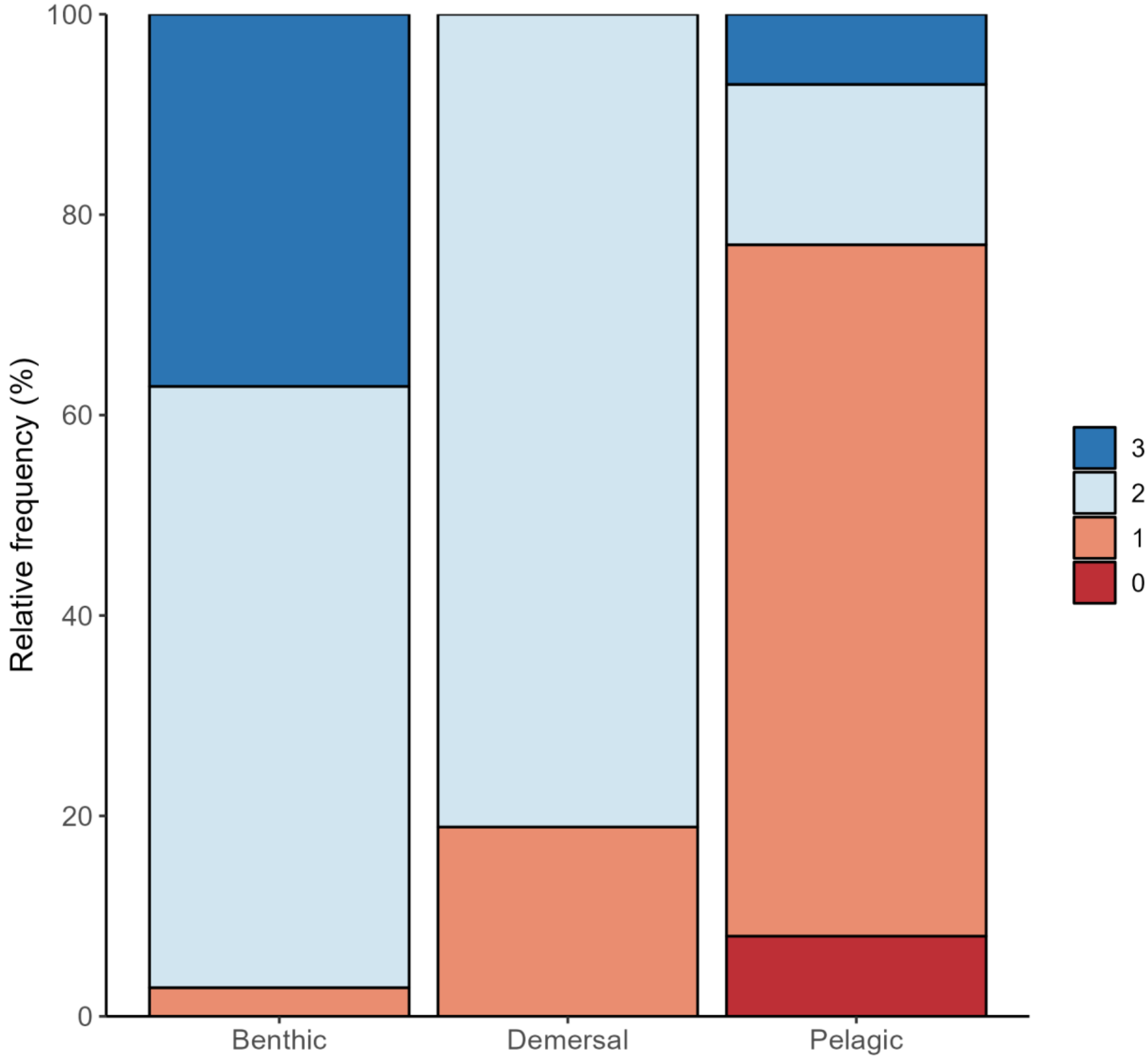

Figure S3. Data quality matrix of exposure factors for key fishery resources in the Tropical Eastern Pacific Ecosystem off Peru. Exposure factor: F1) Sea surface temperature; F2) Sea surface salinity; F3) pH; F4) Sea surface chlorophyll; F5) Primary productivity; F6) Precipitation; F7) Air surface temperature; F8) Sea bottom temperature; F9) Sea bottom salinity; F10) Sea level rise. Data quality score: 3) High quality data; 2) Related data; 1) Reviewer judgment; 0) No data.

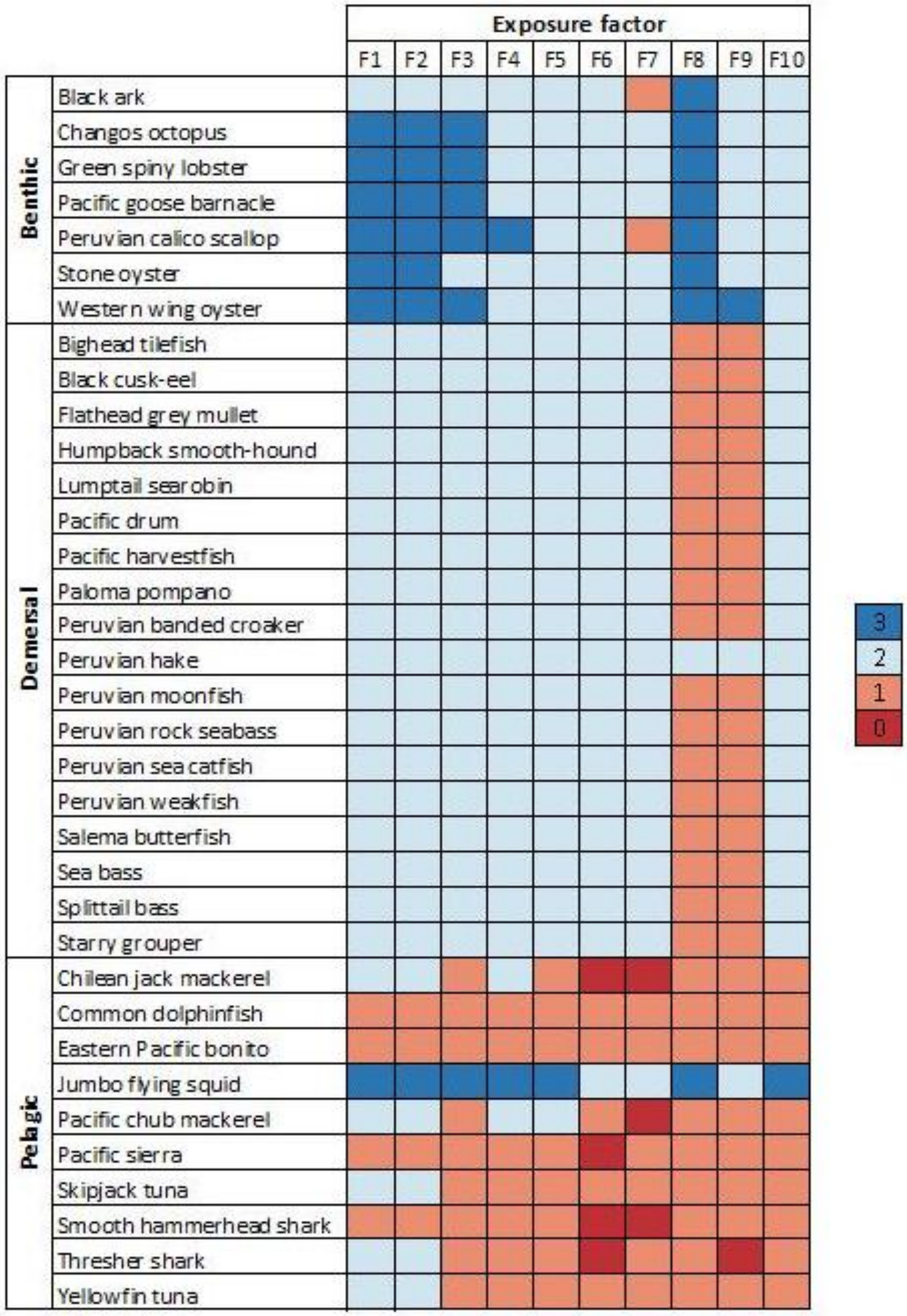

Figure S4. Data quality of sensitivity attributes per group of key fishery resources in the Tropical Eastern Pacific Ecosystem off Peru. Data quality score: 3) High quality data; 2) Related data; 1) Reviewer judgment; 0) No data.

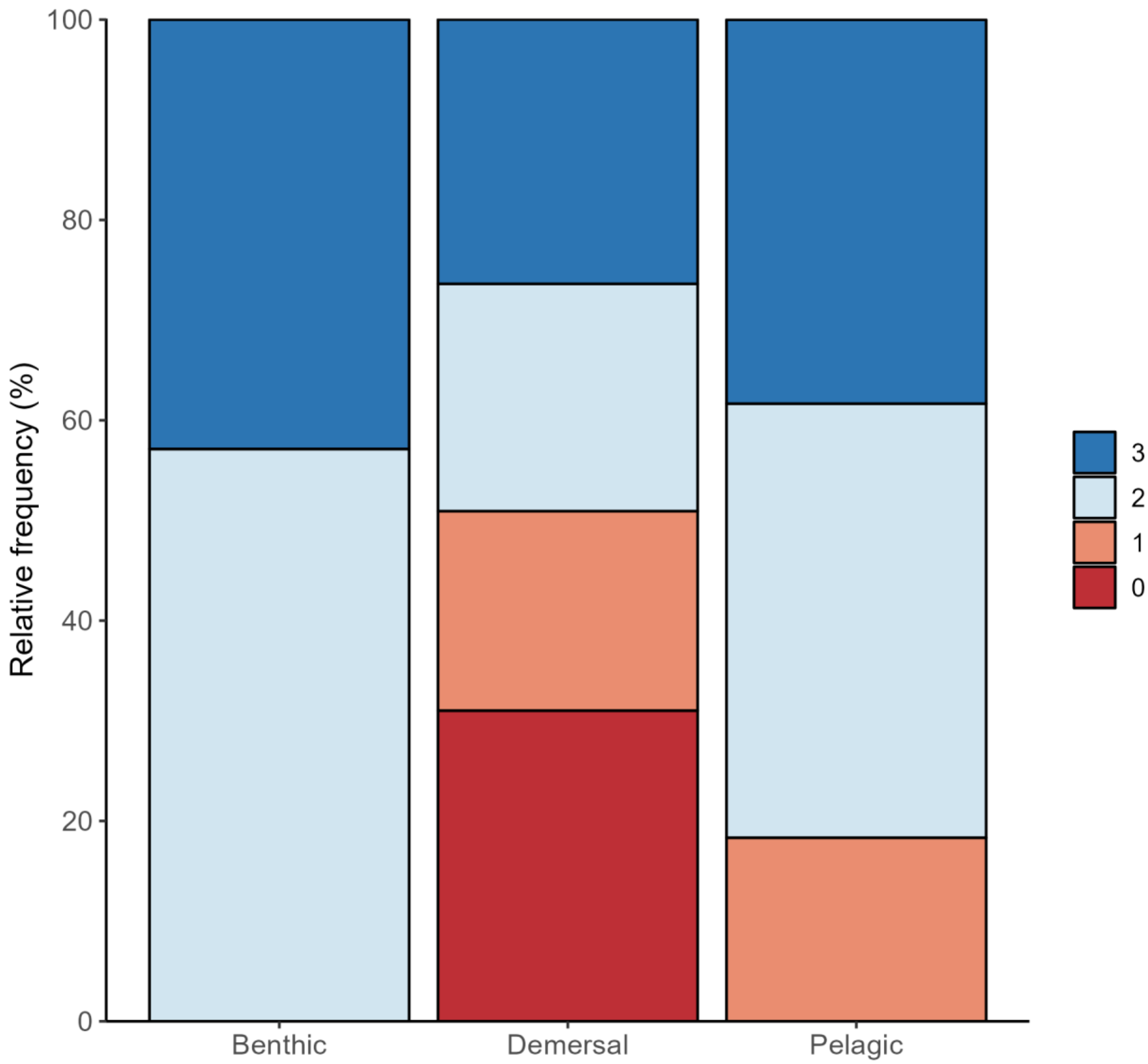

Figure S5. Data quality matrix of sensitivity attributes for key fishery resources to climate change in the Tropical Eastern Pacific Ecosystem off Peru. Sensitivity attribute: A1) Fecundity; A2) Recruitment period; A3) Average age at maturity; A4) Generalist vs. specialist; A5) Capacity for larval dispersal or larval duration; A6) Capacity for adult/juvenile movement; A7) Physiological tolerance; A8) Spatial availability of unoccupied habitat for most critical life stage; A9) Environmental variable as a phenological cue for spawning or breeding; A10) Environmental variable as a phenological cue for settlement or metamorphosis; A11) Temporal mismatches of life-cycle events; A12) Migration. Data quality score: 3) High quality data; 2) Related data; 1) Reviewer judgment; 0) No data.

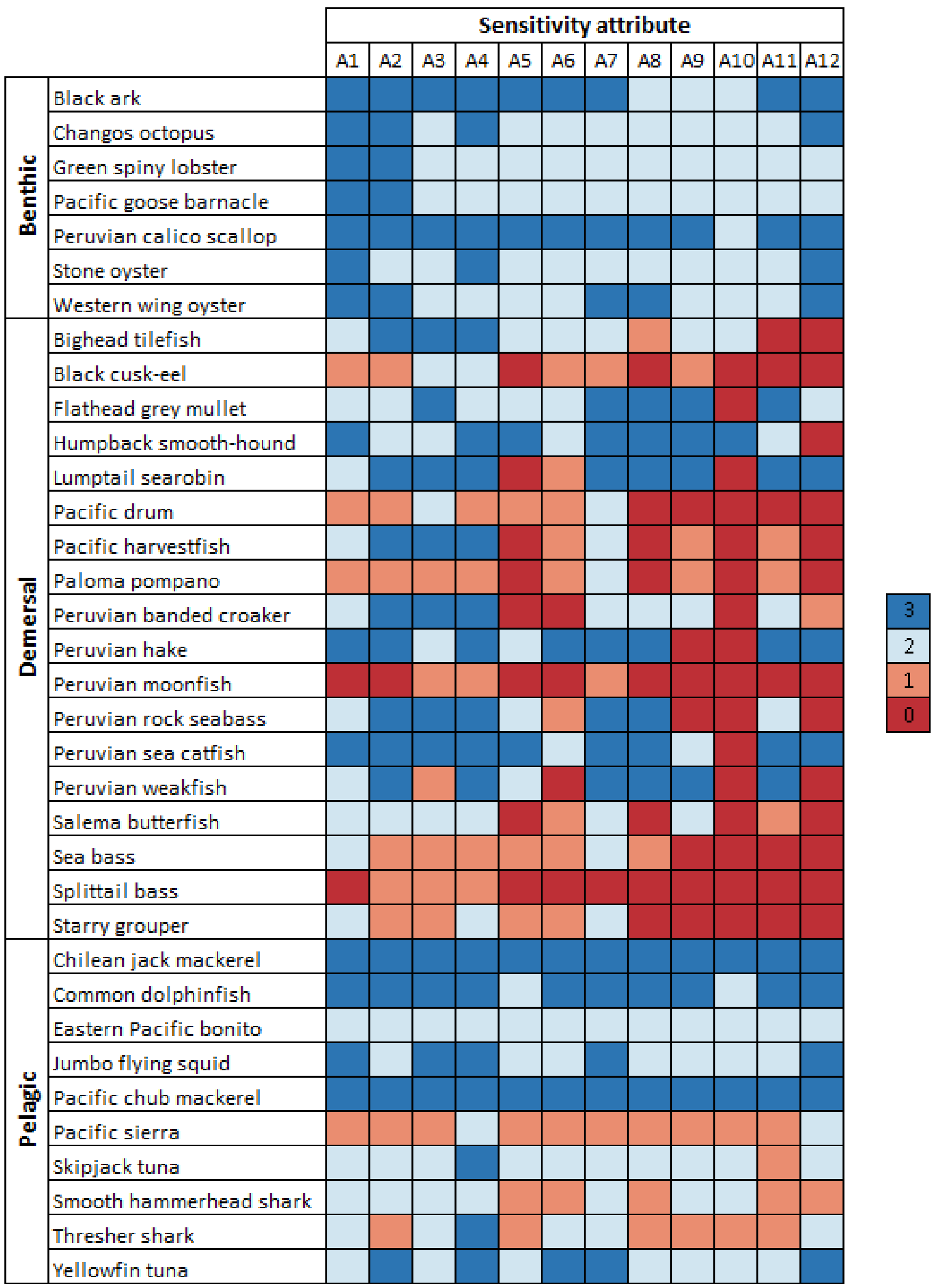

Figure S6. Data quality per group of sensitivity attributes across key fishery resources in the Tropical Eastern Pacific Ecosystem off Peru. Data quality score: 3) High quality data; 2) Related data; 1) Reviewer judgment; 0) No data.

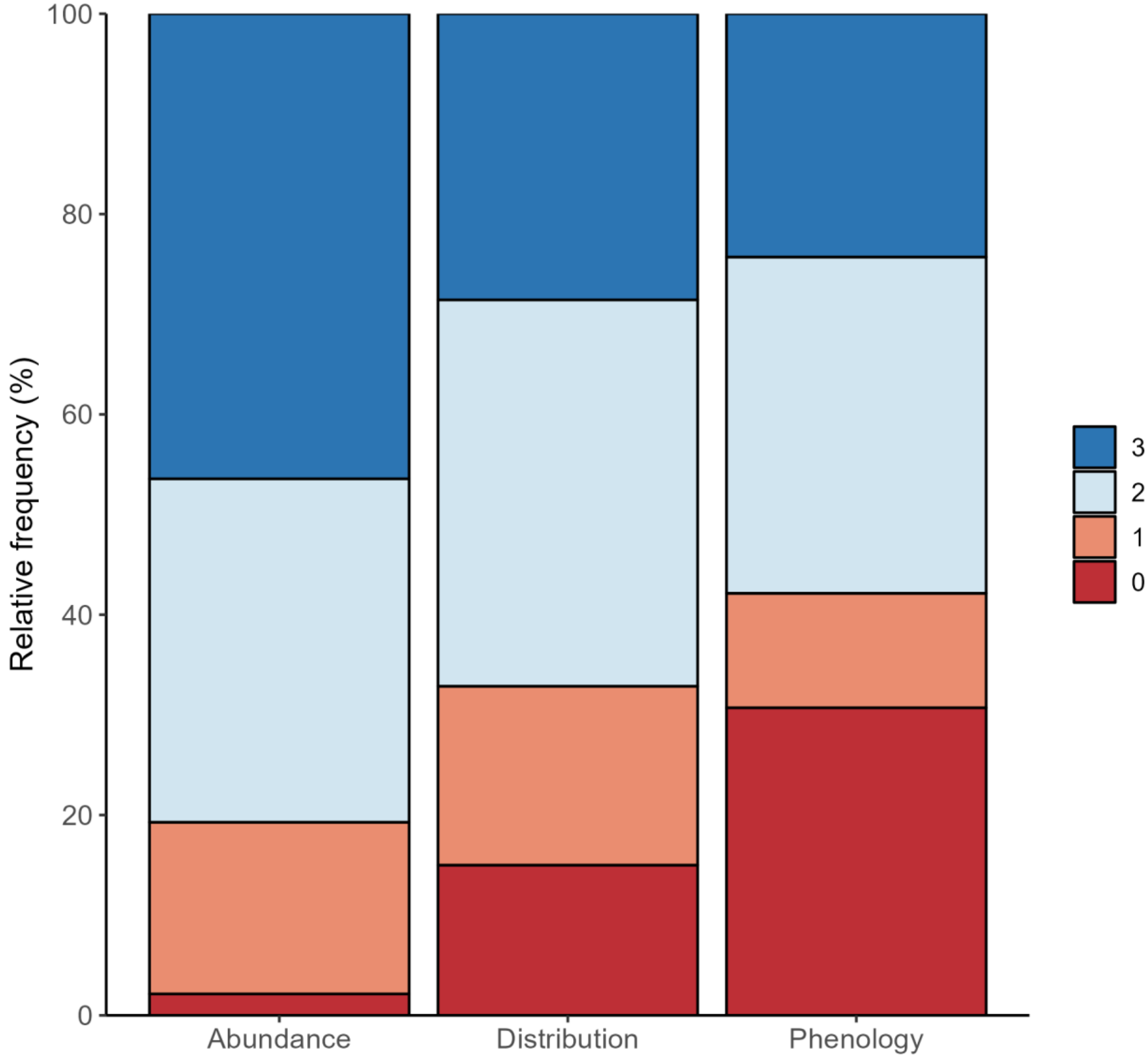

Figure S7. Weighted score of sensitivity attributes for key fishery resources in the Tropical Eastern Pacific Ecosystem off Peru. Thin bars correspond to the cumulative weighted score of species groups. Thick shaded bars correspond to the total cumulative weighted score.

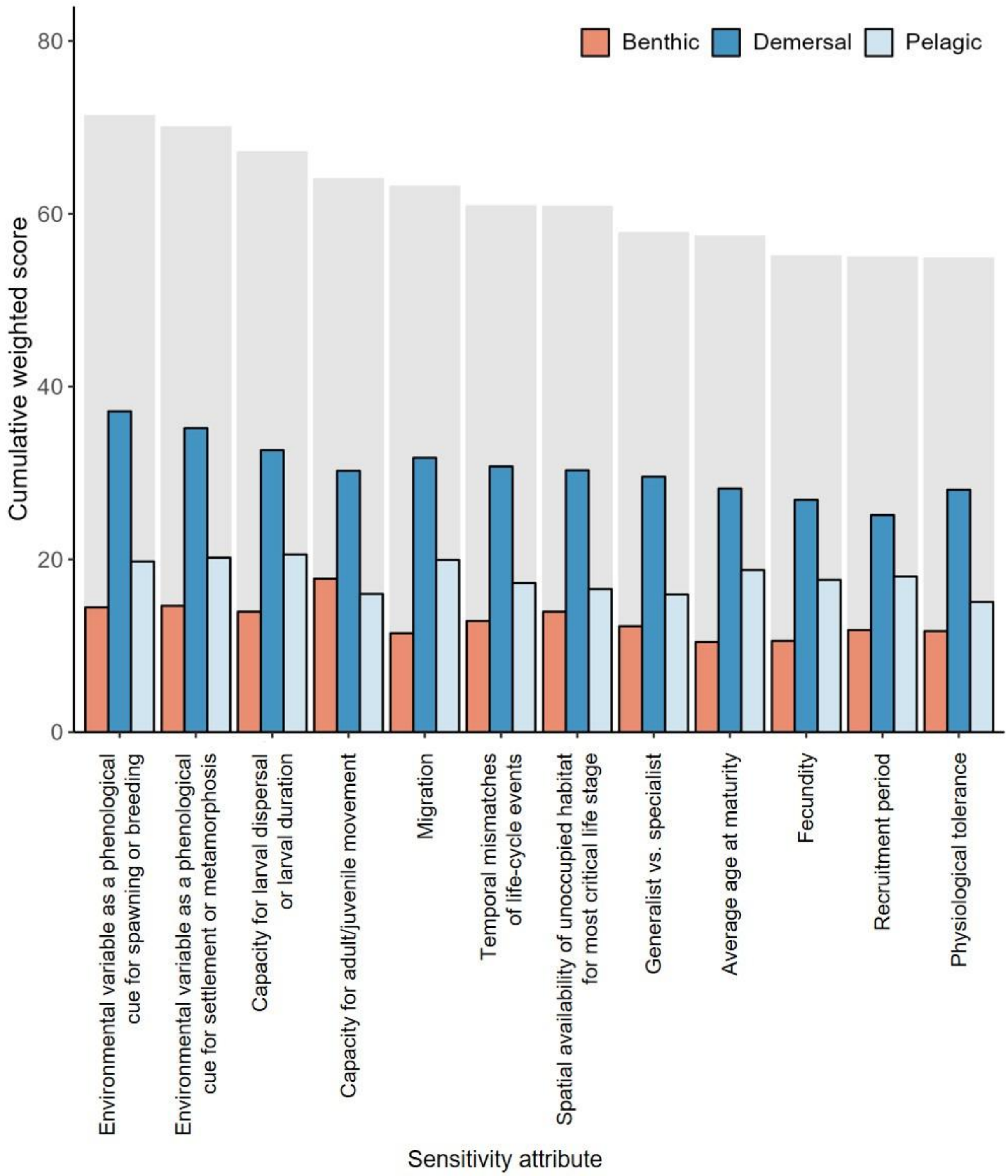

Table S1. Bootstrap outputs for exposure factors (n = 10) and sensitivity attributes (n = 12) categories (L: Low; M: Medium; H: High), and selected vulnerability category for key fishery resources in the Tropical Eastern Pacific Ecosystem off Peru.

			Exposure						Sensitivity						Vulnerability	
			Factors (n)			Certainty			Attributes (n)			Certainty			Category	Certainty
Group	**Common name**	**Species**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**	**L**	**M**	**H**		
Benthic	Black ark	*Anadara tuberculosa*	0	7	3	0.000	0.376	0.624	0	10	2	0.000	0.945	0.055	6	0.652
Benthic	Changos octopus	*Octopus mimus*	1	9	0	0.000	0.999	0.001	0	11	1	0.000	0.977	0.023	4	0.976
Benthic	Green spiny lobster	*Panulirus gracilis*	0	10	0	0.000	1.000	0.000	4	8	0	0.000	1.000	0.000	4	1.000
Benthic	Pacific goose barnacle	*Pollicipes elegans*	0	6	4	0.000	0.207	0.793	1	10	1	0.000	1.000	0.000	6	0.787
Benthic	Peruvian calico scallop	*Argopecten purpuratus*	0	5	5	0.000	0.055	0.945	1	10	1	0.000	0.788	0.212	6	0.959
Benthic	Stone oyster	*Striostrea prismatica*	0	10	0	0.000	0.976	0.024	2	9	1	0.000	0.835	0.165	4	0.815
Benthic	Western wing oyster	*Pteria sterna*	0	9	1	0.000	0.982	0.018	6	6	0	0.001	0.999	0.000	4	0.981
Demersal	Bighead tilefish	*Caulolatilus affinis*	9	1	0	0.781	0.219	0.000	3	9	0	0.000	1.000	0.000	2	0.773
Demersal	Black cusk-eel	*Genypterus maculatus*	10	0	0	0.909	0.091	0.000	3	8	1	0.000	0.999	0.001	2	0.903
Demersal	Flathead grey mullet	*Mugil cephalus*	4	6	0	0.004	0.996	0.000	6	6	0	0.002	0.998	0.000	4	0.995
Demersal	Humpback smooth-hound	*Mustelus whitneyi*	10	0	0	0.845	0.155	0.000	3	9	0	0.000	1.000	0.000	2	0.845
Demersal	Lumptail searobin	*Prionotus stephanophrys*	9	1	0	0.832	0.168	0.000	5	7	0	0.001	1.000	0.000	2	0.829
Demersal	Pacific drum	*Larimus pacificus*	10	0	0	0.896	0.104	0.000	4	8	0	0.000	0.967	0.033	2	0.872
Demersal	Pacific harvestfish	*Peprilus medius*	7	3	0	0.351	0.649	0.000	3	9	0	0.000	1.000	0.000	4	0.648
Demersal	Paloma pompano	*Trachinotus paitensis*	7	3	0	0.351	0.649	0.000	3	9	0	0.000	1.000	0.000	4	0.647
Demersal	Peruvian banded croaker	*Paralonchurus peruanus*	9	1	0	0.574	0.426	0.000	4	8	0	0.001	0.999	0.000	2	0.576
Demersal	Peruvian hake	*Merluccius peruanus*	10	0	0	0.919	0.081	0.000	2	10	0	0.000	1.000	0.000	2	0.920
Demersal	Peruvian moonfish	*Selene peruviana*	7	3	0	0.358	0.642	0.000	2	10	0	0.000	0.994	0.006	4	0.652
Demersal	Peruvian rock seabass	*Paralabrax humeralis*	8	2	0	0.122	0.878	0.000	5	7	0	0.000	1.000	0.000	2	0.884
Demersal	Peruvian sea catfish	*Galeichthys peruvianus*	9	1	0	0.638	0.362	0.000	4	8	0	0.000	1.000	0.000	2	0.639
Demersal	Peruvian weakfish	*Cynoscion analis*	9	1	0	0.518	0.482	0.000	3	9	0	0.000	1.000	0.000	2	0.526
Demersal	Salema butterfish	*Peprilus snyderi*	7	3	0	0.354	0.646	0.000	3	9	0	0.000	1.000	0.000	4	0.645
Demersal	Sea bass	*Paralabrax callaensis*	8	2	0	0.145	0.855	0.000	1	11	0	0.000	1.000	0.000	2	0.853
Demersal	Splittail bass	*Hemanthias peruanus*	7	3	0	0.360	0.640	0.000	0	12	0	0.000	0.989	0.011	4	0.643
Demersal	Starry grouper	*Epinephelus labriformis*	8	2	0	0.209	0.791	0.000	1	11	0	0.000	0.959	0.041	2	0.782
Pelagic	Chilean jack mackerel	*Trachurus murphyi*	4	6	0	0.011	0.989	0.000	1	11	0	0.000	1.000	0.000	4	0.988

Pelagic	Common dolphinfish	*Coryphaena hippurus*	4	6	0	0.001	0.999	0.000	4	8	0	0.000	1.000	0.000	4	0.999
Pelagic	Eastern Pacific bonito	*Sarda chiliensis*	3	7	0	0.000	1.000	0.000	2	10	0	0.000	1.000	0.000	4	1.000
Pelagic	Jumbo flying squid	*Dosidicus gigas*	2	7	1	0.000	1.000	0.000	4	8	0	0.000	1.000	0.000	4	1.000
Pelagic	Pacific chub mackerel	*Scomber japonicus*	5	5	0	0.000	1.000	0.000	1	11	0	0.000	0.994	0.006	4	0.994
Pelagic	Pacific sierra	*Scomberomorus sierra*	4	6	0	0.002	0.998	0.000	1	11	0	0.000	1.000	0.000	4	0.998
Pelagic	Skipjack tuna	*Katsuwonus pelamis*	7	3	0	0.456	0.544	0.000	5	7	0	0.000	1.000	0.000	4	0.534
Pelagic	Smooth hammerhead shark	*Sphyrna zygaena*	3	7	0	0.001	0.999	0.000	0	9	3	0.000	0.376	0.625	6	0.624
Pelagic	Thresher shark	*Alopias vulpinus*	2	8	0	0.000	1.000	0.000	0	8	4	0.000	0.065	0.935	6	0.935
Pelagic	Yellowfin tuna	*Thunnus albacares*	9	1	0	0.887	0.113	0.000	6	6	0	0.005	0.995	0.000	2	0.886

Table S2. Frequency of exposure factors and sensitivity attributes per category (L: Low; M: Medium; H: High) with exposure and sensitivity component scores based on the logic rule, for key fishery resources in the Tropical Eastern Pacific Ecosystem off Peru. Rubrics with 70% (†) certainty after the leave-one-out analysis. → denotes the change of score after the leave-one-out analysis. All other rubrics had 100% certainty.

Group	Common name	Scientific name	Exposure			Exposure component	Sensitivity			Sensitivity component	Vulnerability
			L	M	H		L	M	H		
Benthic	Black ark	*Anadara tuberculosa*	0	7	3	†3	0	10	2	2	6
Benthic	Pacific goose barnacle	*Pollicipes elegans*	0	6	4	3	1	10	1	2	6
Benthic	Peruvian calico scallop	*Argopecten purpuratus*	0	5	5	3	1	10	1	2	6
Pelagic	Smooth hammerhead shark	*Sphyrna zygaena*	3	7	0	2	0	9	3	3 → 2	6 → 4
Pelagic	Thresher shark	*Alopias vulpinus*	2	8	0	2	0	8	4	3	6
Benthic	Changos octopus	*Octopus mimus*	1	9	0	2	0	11	1	2	4
Benthic	Green spiny lobster	*Panulirus gracilis*	0	10	0	2	4	8	0	2	4
Benthic	Stone oyster	*Striostrea prismatica*	0	10	0	2	2	9	1	2 → 3	4 → 6
Benthic	Western wing oyster	*Pteria sterna*	0	9	1	2	6	6	0	2	4
Demersal	Flathead grey mullet	*Mugil cephalus*	4	6	0	2	6	6	0	2	4
Demersal	Pacific harvestfish	*Peprilus medius*	7	3	0	†2	3	9	0	2	4
Demersal	Paloma pompano	*Trachinotus paitensis*	7	3	0	†2	3	9	0	2	4
Demersal	Peruvian moonfish	*Selene peruviana*	7	3	0	†2	2	10	0	2	4
Demersal	Salema butterfish	*Peprilus snyderi*	7	3	0	†2	3	9	0	2	4
Demersal	Splittail bass	*Hemanthias peruanus*	7	3	0	†2	0	12	0	2	4
Pelagic	Chilean jack mackerel	*Trachurus murphyi*	4	6	0	2	1	11	0	2	4
Pelagic	Common dolphinfish	*Coryphaena hippurus*	4	6	0	2	4	8	0	2	4
Pelagic	Eastern Pacific bonito	*Sarda chiliensis*	3	7	0	2	2	10	0	2	4
Pelagic	Jumbo flying squid	*Dosidicus gigas*	2	7	1	2	4	8	0	2	4
Pelagic	Pacific chub mackerel	*Scomber japonicus*	5	5	0	2	1	11	0	2	4
Pelagic	Pacific sierra	*Scomberomorus sierra*	4	6	0	2	1	11	0	2	4
Pelagic	Skipjack tuna	*Katsuwonus pelamis*	7	3	0	†2	5	7	0	2 → 3	4 → 6
Demersal	Bighead tilefish	*Caulolatilus affinis*	9	1	0	1	3	9	0	2	2

Demersal	Black cusk-eel	*Genypterus maculatus*	10	0	0	1	3	8	1	2	2
Demersal	Humpback smooth-hound	*Mustelus whitneyi*	10	0	0	1	3	9	0	2	2
Demersal	Lumptail searobin	*Prionotus stephanophrys*	9	1	0	1	5	7	0	2	2
Demersal	Pacific drum	*Larimus pacificus*	10	0	0	1	4	8	0	2	2
Demersal	Peruvian banded croaker	*Paralonchurus peruanus*	9	1	0	1	4	8	0	2	2
Demersal	Peruvian hake	*Merluccius peruanus*	10	0	0	1	2	10	0	2	2
Demersal	Peruvian rock seabass	*Paralabrax humeralis*	8	2	0	1	5	7	0	2	2
Demersal	Peruvian sea catfish	*Galeichthys peruvianus*	9	1	0	1	4	8	0	2	2
Demersal	Peruvian weakfish	*Cynoscion analis*	9	1	0	1	3	9	0	2	2
Demersal	Sea bass	*Paralabrax callaensis*	8	2	0	1	1	11	0	2	2
Demersal	Starry grouper	*Epinephelus labriformis*	8	2	0	1	1	11	0	2	2
Pelagic	Yellowfin tuna	*Thunnus albacares*	9	1	0	1	6	6	0	2	2