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VULNERABILITY STATUS AND EFFICACY OF POTENTIAL CONSERVATION MEASURES FOR THE EAST PACIFIC LEATHERBACK TURTLE (*DERMOCHELYS CORIACEA*) STOCK USING THE EASI-FISH APPROACH

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ABSTRACT

Industrial and small-scale coastal (*i.e.*, 'artisanal') pelagic fisheries in the eastern Pacific Ocean (EPO) interact with one of the most vulnerable fishery bycatch species, the East Pacific (EP) stock of leatherback turtle (*Dermochelys coriacea*). As a result of the species' longevity, slow growth, low reproductive output, and critically low population size, it is currently classified as "Critically Endangered" by the IUCN. EPO tuna fisheries have been mandated since 2008 (Resolution C-07-03) to ensure, by all practical means, the safe handling and release of captured sea turtles. On 1 January 2021 a revised resolution on sea turtles (C-19-04) will enter into force that will subject EPO tuna fisheries to various measures designed to reduce the bycatch of sea turtles, in particular the use of circle hooks and finfish baits in shallow longline sets. The low encounter rates of sea turtles by fishing vessels make these "rare event" data difficult to analyze statistically using conventional approaches of assessing the status of sea turtle populations. Consequently, alternative means to assess vulnerability status and better understand the potential efficacy of different conservation and management measures (CMMs) for effective fisheries management. In response, the spatially-explicit ecological risk assessment (ERA) approach—Ecological Assessment for the Sustainable Impacts of Fisheries (EASI-Fish)—was developed by Inter-American Tropical Tuna Commission (IATTC) staff to quantify the vulnerability of bycatch species, such as the EP leatherback stock, to the cumulative impacts of multiple fisheries in the EPO and to simulate hypothetical CMMs scenarios that may mitigate fishery-imposed risks to the species. This paper describes a collaborative research project between the IATTC, the Inter-American Convention on the Protection and Conservation of Sea Turtles (IAC), and international sea turtle experts where EASI-Fish was used to explore the changes in the vulnerability status of the EP leatherback turtle stock under 39 different hypothetical CMM scenarios simulated for EPO industrial (purse-seine and longline) and artisanal (longline and gillnet) fisheries for 2018. CMMs involved decreasing post-capture mortality (PCM), implementing the use of circle hooks in longline fisheries, and various spatial and temporal closures adjacent to important nesting beaches of the EPO. The "*status quo*" scenario revealed a proxy for fishing mortality ($\tilde{F}_{2018}$) and the spawning stock biomass per recruit (BSR_{2018}) exceeded precautionary biological reference points ($F_{80\%}$ and $BSR_{80\%}$), classifying the EP leatherback turtle stock as "most vulnerable". Of the 39 scenarios, only 14 resulted in the species being classified as "least vulnerable". Only one scenario involved a single CMM—that achieved an estimated PCM of 20% or less—changed the status the "least vulnerable". This involved imposing an EPO closure period of at least 270 days per year for industrial fisheries; a measure that is unlikely to be feasible. The remaining effective CMMs involved using multiple strategies in concert, with the most effective being closure of coastal fishing grounds adjacent to nesting areas coupled with the use of circle hooks in all longline fisheries and exercising best handling and release practices in all fisheries. This modelling exercise provided an important first step towards assessing the potential effects of CMMs described in the recently approved IATTC Resolution C-19-04. The results of the EASI-Fish models can inform strategies to implement these CMMs within the IATTC Convention Area to reduce bycatch impacts on EP leatherbacks.

INTRODUCTION

Fisheries worldwide are undergoing a significant shift in the traditional fisheries management paradigm, from a focus on single species of economic importance, to considering the ecological impacts of fishing on non-target species, habitats, and the ecosystem more broadly. Under the Antigua Convention (IATTC, 2003), the Inter-American Tropical Tuna Commission (IATTC) has formally adopted an ecosystem-based approach to the management of tuna fisheries in the eastern Pacific Ocean (EPO). For example, Article VII 1(f) of the Convention mandates to "*adopt, as necessary, conservation and management measures and recommendations for species belonging to the same ecosystem and that are affected by fishing for, or dependent on or associated with, the fish stocks covered by this Convention…*".

However, such ecological sustainability objectives can be difficult to demonstrate in practice owing to the paucity of reliable biological and catch information for the vast array of non-target species with which fisheries interact, either directly or indirectly, especially those of little or no economic (*i.e*., consumption) value. Therefore, assessing all impacted species using traditional stock assessment approaches is often both cost-prohibitive and impractical. To address this problem, the IATTC staff developed a flexible spatially-explicit quantitative ecological risk assessment approach—Ecological Assessment of Sustainable Impacts of Fisheries (EASI-Fish)—specifically designed to quantify the cumulative impacts of multiple fisheries for data-limited bycatch species (Griffiths et al., 2019a). The approach has recently been applied to prioritize the vulnerability of bycatch species caught in EPO tuna fisheries (Griffiths et al., 2019a), and to explore the efficacy of potential conservation and management measures (CMMs) for the spinetail devil ray (*Mobula mobular*) in the EPO (Griffiths et al., 2019b).

EPO tuna fisheries have been documented to interact with at least 117 taxa including teleosts, elasmobranchs, sea turtles, seabirds, and marine mammals (Duffy et al., 2016). Under current fishing practices, some of these species are unavoidable bycatch and present significant conservation issues to be addressed by the IATTC and its CPCs. Sea turtles are a particularly vulnerable group of bycatch species in the EPO. Despite the low frequency of turtle interactions in the EPO purse-seine fishery (Hall and Roman, 2013; Lezama-Ochoa et al., 2019a), their slow growth rates, late ages at maturity, low fecundity (Avens et al., 2020), and, depending upon species, small population sizes make their populations particularly sensitive to anthropogenic sources of mortality, such as fishing. This makes sea turtle bycatch a significant conservation issue for EPO tuna fisheries, where at least 32,687 purse-seine sets were made and 175 million longline hooks were deployed in 2018 (IATTC, 2020). Sea turtle species also face similar threats by tuna (and other) fisheries throughout their worldwide distribution. Therefore, improved assessment of the relative effects of bycatch in tuna fisheries would provide valuable information for fisheries managers and conservationists.

Some international conservation instruments have been developed for sea turtles, such as their inclusion in Appendices I and II of the Convention of Migratory Species (CMS) (CMS, 2015) and under Appendix I of the Convention on International Trade in Endangered Species (CITES) (CITES, 2016). These measures were required to meet regional conservation goals as well as curb international trade of sea turtle products (*e.g*., eggs, meat, shell material). In addition, conservation measures have been developed by some tuna Regional Fisheries Management Organizations (tRMFOs), specifically to reduce the bycatch of sea turtles in longline and purse-seine fisheries. In the EPO, for example, IATTC Resolution C-19-04 was recently approved—entering into force on 1 January 2021—and prohibits the retention of sea turtles by all vessels and requires their immediate release using best handling and release practices such as those detailed by the Food and Agriculture Organization of the United Nations (FAO, 2009), to reduce post-capture mortality (PCM). Resolution C-19-04 also provides a 'menu' of options for potential mitigation techniques that have been demonstrated to reduce the frequency and severity of interactions between longline fishing gear and sea turtles, including use of large circle hooks and fish bait.

Further, the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC) is an intergovernmental treaty that provides the legal framework for countries in the North and South America continents to take actions to benefit of sea turtles, in both nesting beaches and the Parties' territorial waters. Concerned with the critical status of leatherback turtles (*Dermochelys coriacea*) in the EPO, the IAC adopted Resolution CIT-COP7-2015-R2 that requests IAC Parties to make efforts to reduce the bycatch of leatherbacks in the EPO using recommendations from IAC Resolution COP3/2006/R-2 to exercise FAO guidelines to reduce sea turtle mortality in fishing operations (FAO, 2009).

In June 2011, the IAC and the IATTC established a Memorandum of Understanding (MoU) to promote collaboration on conservation measures focused on sea turtles. Understanding the extent to which these measures previously implemented by the IATTC might decrease the vulnerability of sea turtles to fishing impacts would facilitate effective implementation of Resolution C-19-04. To address this need, the IATTC's Bycatch Working Group and Scientific Advisory Committee recommended collaborative research between the IAC and the IATTC, under the MoU between the two conventions, to assess the vulnerability of leatherback turtles in the EPO under different management scenarios described in C-19-04.

The leatherback turtle is distributed circumglobally in tropical to temperate regions and can be found in both coastal and oceanic pelagic waters (Pritchard, 2015). The species has a maximum recorded age (t_{max}) of 48 years (Jones et al., 2011), exhibits low fecundity (~65 eggs per clutch, ~5 clutches per season, nests every 3–4 years; average hatching success <50%; Laúd OPO Network, 2020), and female age of maturity is 17–19 years (Avens et al., 2009; Avens et al., 2020). For the East Pacific (EP) leatherback turtle population in particular, a combination of this low productivity and high susceptibility to capture by industrialized fisheries—and other threats such as human consumption of eggs—in the EPO have caused an estimated decline of over 90% in the number of nesting females since the 1980s. Thus, the EP leatherback population is listed as "Critically Endangered" globally by the International Union for Conservation of Nature (IUCN), Red List of Threatened Species (Wallace et al., 2013b).

There is much evidence that the EP leatherback turtle stock has been severely affected by bycatch mortality, which has driven the long-term population decline, and likely continues to prevent recovery (Wallace et al., 2013b). A recent population viability analysis of the EP stock predicted that the population, currently estimated to be fewer than 1,000 adults, may be extirpated in the region within 60 years under current fishing and environmental conditions (Laúd OPO Network, 2020). In contrast, the analysis predicted that the population could eventually stabilize and increase if conservation efforts successfully increase adult and sub-adult survival (*i.e*., reduce fishing mortality) by at least 20% and increase hatchling production through enhanced protection and nest management. Because fishing appears to be the only significant anthropogenic source of late-stage mortality currently affecting this population, reduction in late-stage mortality can be considered a proxy for reduction in bycatch mortality.

Recent reports of EP leatherback turtle capture rates indicate relatively low frequency in industrial purse-seine and longline fisheries in the EPO (Hall and Roman, 2013; Griffiths and Duffy, 2017; Lezama-Ochoa et al., 2017; Lezama-Ochoa et al., 2019a), which may be due to some combination of depleted population abundance, improved conservation measures (e.g. C-04-07 and C-07-03) in some fleets (*e.g*., use of circle hooks, best handling practices) and low reporting due to low observer coverage in most fleets (*e.g*., ~5% or less in the high seas and EPO coastal nation longline fleets). Because reported leatherback encounter rates are very low compared to catch frequencies of target species, insufficient data exists for the population to undertake traditional fisheries stock assessments.

The overarching goal of this paper is to provide IATTC and IAC Members and CPCs information relevant to the implementation of Resolution C-19-04 and IAC Resolution CIT-COP7-2015-R2 by identifying potentially effective management and/or handling strategies that may—individually or in unison—improve the conservation status of the leatherback turtle population in the EPO. Specifically, we developed hypothetical scenarios that incorporated different CMMs to understand the potential reduction in vulnerability status of the EP leatherback turtle stock due to: i) decreasing post-capture mortality (PCM) on specific size classes of turtles through improved handling and release practices, ii) implementing the use of circle hooks to reduce the interaction rate and fishing mortality due to hooking injuries, iii) increasing the duration of the existing EPO-wide fishing closure for the industrial purse-seine fishery, iv) temporarily ceasing fishing activities in coastal areas adjacent to key leatherback turtle nesting regions, and v) using a combination of the aforementioned CMMs simultaneously. This paper should be considered one of numerous steps to quantify the current impacts of EPO fisheries on bycatch, as well as efforts to reduce bycatch of EP leatherback turtles and assess their vulnerability status. As new data become available (*e.g.*, habitat suitability models, catch data from small-scale fisheries), future EASI-Fish model iterations could be explored to provide additional insights about conservation scenarios relevant for decreasing leatherback vulnerability to EPO fisheries.

1. METHODS

1.1 Spatial extent of the assessment region and definition of included fisheries

The present assessment of leatherback turtles incorporated the entire IATTC Convention Area in the EPO (defined as the region from the coast of the Americas to 150°W between 50°S and 50°N) and characterizes the turtle population and EPO fisheries for 2018 only. However, based on evidence from genetic studies (Dutton et al., 1999) and movement studies using conventional (Sarti Martínez et al., 2007; Troëng et al., 2007) and electronic (Benson et al., 2011; Shillinger et al., 2011; Schick et al., 2013) tags, the EPO supports two distinct stocks of leatherback turtles. Such evidence was used by Wallace et al. (2011) in the development of two Regional Management Units (RMUs)—hereafter referred to as "stocks"—for the species in the Pacific Ocean; the West Pacific (WP) stock, and the EP stock (Fig. 1), classified based on the location of the nesting beaches used by each stock. The IATTC Convention Area overlaps to a much greater degree with the distribution of the EP stock (100%) than the WP stock (11%). In fact, of the 112 leatherback turtle interactions recorded by observers onboard purse-seine vessels operating in the EPO in 1993–2019—of which only one confirmed mortality has been recorded—105 (94%) occurred within the EP stock boundary defined by Wallace et al. (2011) (Unpublished IATTC observer data; Fig. 1). Therefore, the present study includes only the EP stock and assesses its vulnerability to the activities of industrial and small-scale coastal (herein termed "artisanal") fishing fleets.

Industrial fisheries

The industrial fisheries included the fishery by large-scale tuna longline fishing vessels (LSTLFVs) (herein called the "industrial longline fishery") and two purse-seine fisheries (Class 6 with a carrying capacity >363 mt and Classes 1–5 <363 mt). The data for these fisheries were obtained from vessel logbooks or collected by on-board scientific observers, or submitted to the IATTC by its Members under Resolutions C-03-05 and C-19-08 and described in Document SAC-08-07b. Specifically, the industrial longline fishery data were derived from vessels >24 m length overall (LOA) included in the IATTC Regional Vessel Register that are authorized to fish for tuna and tuna-like species, which provide monthly reports of catch and fishing effort at a resolution of at least 5° x 5°, and from national scientific observer programs that monitor at least 5% of the fishing effort by LSTLFVs vessels over 20 m LOA required under Resolution C-19-08.

Effort data characterizing the fishery by Class 6 purse-seine vessels were collected by the onboard observer program of the Agreement on the International Dolphin Conservation Program (AIDCP) and National Programs in 2018, which covered 100% of the fishing effort. This fishery comprises three sub-fisheries based on set type: i) sets associated with floating objects (OBJ), ii) sets associated with dolphins (DEL), and iii) sets on unassociated schools of tuna (NOA).

There are a range of smaller purse-seine vessels that operate in the EPO from small vessels (Classes 1–2) that are generally confined to coastal areas, to larger commercial vessels (Classes 3–5) that frequently fish on the high seas. Only nine Ecuadorian Class 1–5 vessels requested Dolphin Mortality Limits and thus carried AIDCP observers in 2018. However, the Tuna Conservation Group (TUNACONS) has deployed observers on voluntary vessels since 2018, with coverage being 2.6% and 12% of the total number of trips reported for this the fleet in 2018 and 2019, respectively (IATTC, unpublished data). It has yet to be determined by IATTC scientists whether the data collected to date by TUNACONS is representative of the fleet in terms of gear characteristics, catch composition, and spatio-temporal distribution of effort.

However, given the paucity of information on this fishery in the past, we included these data that were considered to represent the minimum spatial coverage of the fishery. Copies of logbook entries summarizing the fishing activities of vessels of Classes 1–5 were available via opportunistic collection by IATTC field staff at various landing ports. The fishery comprising Classes 1–5 vessels can also be separated on the same set type as the Class 6 fleet, although the number of dolphin sets made by this fleet are too few to analyze. Each set position for Class 1–6 vessels was allocated to the nearest 0.5° x 0.5° grid cell to define each sub-fishery.

Artisanal fisheries

In contrast to the industrial purse seine and longline fisheries in the EPO, effort by the numerous small-scale artisanal fleets that operate within the EEZs of countries in the EPO is generally poorly documented by national fisheries agencies. Lack of reliable effort data has been the primary reason why artisanal fleets have not been included in previous EASI-Fish bycatch assessments in the EPO (Griffiths et al., 2019a; Griffiths et al., 2019b). However, leatherback turtles—as well as most other species of sea turtles—have been shown to be heavily impacted by coastal gillnet and longline fisheries that intercept turtles as they migrate to and from nesting beaches, or interact with young age classes in nearshore foraging areas before they begin to utilize more oceanic habitats (Wallace et al., 2013a). Therefore, it was considered especially important to collate any available fishing effort data sources for artisanal fisheries for their inclusion in the assessment.

Some information was available from fishing effort maps in published scientific papers (Andraka et al., 2013; Martínez-Ortiz et al., 2015) and reports (*e.g.*, Ayala et al., 2008; Martínez et al., 2017) or maps of unpublished observer data supplied by Mexico’s Shark Observer Program of Fideicomiso de Investigación para el desarrollo del Programa Nacional de Aprovechamiento del Atún y Protección de Delfines y Otros en torno a Especies Acuáticas Protegidas (FIDEMAR). These maps were manually geo-referenced and fishing effort allocated to grid cells of appropriate resolution—usually 0.5° x 0.5°—in QGIS software. Unfortunately, some large spatial gaps in catch and/or effort data existed in some areas where artisanal fisheries are known to operate. However, in many of these areas, detailed data were available pertaining to the locations of fishing ports for artisanal fleets. For example, Ortíz-Álvarez et al. (2020) mapped coastal artisanal fishing ports from the northern Gulf of California, Mexico to the southern border of Colombia, while Alfaro-Shigueto et al. (2018) mapped fishing ports from Ecuador to Chile. Because these two studies focused on port-based interviews with fishermen pertaining to the characteristics of their fishing operations and interactions with protected species such as sea turtles, spatially explicit effort data were not available to determine where vessels fished from these ports. However, several sources of evidence suggest that artisanal fishers frequently traverse over 1 degree of latitude (~69 km) to reach their preferred fishing grounds, although many travel significantly further offshore to target large pelagic fishes in offshore waters (see Martínez-Ortiz et al., 2015). Therefore, it was reasonable to assume that at least one unit of fishing effort was expended in 2018 within each 0.5° x 0.5° grid cell adjacent to each fishing port.

In some coastal States in the EPO there is often not a clear distinction between artisanal and industrial vessels, as the former are often multi-gear (longline and gillnets) and multi-species, shifting their target among tuna, billfish, sharks and dorado on a seasonal basis (Martínez-Ortiz et al., 2015; Siu and Aires-da-Silva, 2016). Although some of these vessels can reach offshore waters (*e.g*. medium and large-scale fleets), the majority are less than 15 m LOA (generally called “pangas”) and are more coastal in their operation. In contrast, the domestic Mexican longline fishery target sharks using vessels (often >27 m LOA) and surface-set gear configurations similar to those used by the far seas longline fleet (Sosa-Nishizaki et al., 2020). Therefore, for the purposes of the present study, this domestic Mexican longline fishery was included as part of the industrial longline fleet.

Most coastal States have some form of a landings fishing inspection program conducted mainly for compliance purposes (Siu and Aires-da-Silva, 2016). Unfortunately, observer coverage of these fleets is extremely low and data are very limited for scientific purposes. Although sampling programs are being developed for the coastal nation fleets (see Oliveros-Ramos et al., 2019), data are not yet available. Therefore, using high-resolution fishing effort distribution maps from publications was considered the only feasible alternative to represent the spatial 'footprint' of these fisheries in the current assessment. As was the case with the fishing port data, fishing effort maps were imported into QGIS software, georeferenced, and where the presence of a single set in any 0.5° x 0.5° grid cell—5° x 5° for the industrial longline fishery—was considered presence of effort (Fig. 2).

Other anthropogenic threats to leatherbacks

Illegal collection of leatherback turtle eggs on nesting beaches in the EPO can be a major source of anthropogenic-induced mortality for the EP leatherback turtle stock (Troëng et al., 2007; Santidrián Tomillo et al., 2008). Therefore, this was included in the EASI-Fish model as the "egg collection fishery". Specifically, nesting locations provided by La Red de la Conservación de la Tortuga Laúd del Océano Pacífico Oriental (hereafter referred to as the Laúd OPO Network) and the State of the World's Sea Turtles (SWOT) (http://seamap.env.duke.edu/swot) and reported in IAC Annual Reports (http://www.iacseaturtle.org/informes-eng.htm) were allocated to the nearest 0.5° x 0.5° grid cell to define the spatial extent of the 'fishery,' and mortality estimates were applied to these cells based on a recent population assessment (Laúd OPO Network, 2020). The data sources, period of data coverage and processing of datasets for each industrial and artisanal fishery included in the assessment are detailed in Table 1.

1.2 Assessing susceptibility as a proxy for instantaneous fishing mortality (*F*)

A quantitative evaluation of the vulnerability of the leatherback turtle stock under various hypothetical management scenarios was made using the EASI-Fish ecological risk assessment approach detailed in Griffiths et al. (2019a). In brief, EASI-Fish is comprised of separate susceptibility and productivity components. The susceptibility component in EASI-Fish is used to approximate the instantaneous fishing mortality rate (*F*) that is compared to biological reference points (BRPs) used in the productivity component, specifically length-structured yield and biomass per-recruit models.

EASI-Fish estimates the proportion of a length class (*j*)—with all reference to turtle lengths being curved carapace length (CCL)—of the EP leatherback turtle stock that is susceptible to incurring mortality by fishery *x* (S_{xj}) in a given year, and is represented as:

$$S_{xj} = \frac{G_x}{G}\left(D_x A_{xj} N_{xj} C_{xj} P_{xj}\right) \quad \text{(Eq. 1)}$$

where *G* is the total number of grid cells occupied by leatherback turtles and G_x is the number of occupied grid cells containing at least one unit of fishing effort by fishery *x* during 2018. In this study, *G* was estimated by using the defined boundaries for the EP leatherback turtle stock (Wallace et al., 2011) and a knife-edge probability-of-occupancy (ψ) of 1 for each 0.5° x 0.5° within these boundaries was used (see Fig. 1).

Fishing effort for each fishery in 2018 was overlaid on the stock map to calculate G_x. The percentage overlap of each fishery was calculated by dividing G_x by *G*. Effort data for purse-seine vessels and artisanal effort from published maps were resolved at 0.5° x 0.5° as described above. However, data for the industrial longline fleet were only available at 5° x 5° resolution, so it was conservatively assumed that there was at least one unit of effort in each 0.5° x 0.5° cell contained within each of these larger grid cells that contained effort.

The first four parameters in the parentheses of Equation 1 (D_x, A_{xj}, N_{xj}, and C_{xj}) comprise what is generically regarded as "selectivity" in stock assessments, which combines, often implicitly, "population availability" (the relative probability that a turtle of length class *j* is located in the area and time where the fishery is operating) and "contact selectivity" (the relative probability that a turtle of length class *j* will be retained once it comes in contact with the gear) (Millar and Fryer, 1999). Because leatherback turtle selectivity curves were not available for each fishery, it was considered important to disaggregate selectivity components as far as practicable and are described hereafter.

Fishing season duration (D_x) is the proportion of the year that the population is available to fishery *x*, expressed as the number of fishing days divided by 365. In the EPO, Resolution C-17-02 mandates an annual 72-day closure of the purse-seine fishery between 2018 and 2020, including a 30-day closure of the area known as the "corralito" (4°N–5°S, 96°–110°W).

Seasonal availability (A_{xj}) is the proportion of length class *j* that is available to capture by fishery *x*, given that some species undertake extensive intra-annual migrations outside the boundaries of the fishery, where they are unavailable for fishery interactions. Given that electronic tagging studies of leatherback turtles in the EPO indicate wide-ranging movements throughout the year (Shillinger et al., 2008; Schick et al., 2013), value of 1.0 was used for length class *j* in fishery *x*.

Encounterability (N_{xj}) is the proportion of length class *j* that may potentially encounter the gear used by fishery *x* based on the species' distribution in the water column relative to the normal fishing depth range of the gear. Minimum (0 m), maximum (914 m), and mean (49.1 ± SD 10.3 m) dive depths of leatherback turtles were defined using the results from electronic tagging studies (Shillinger et al., 2011). The effective fishing depth range for each fishery in the EPO was defined as:

- 0–200 m for purse-seine vessels Class 6 (Hall and Roman, 2013),
- 0–120 m for purse-seine vessels Classes 1–5 (Ernesto Altamirano, IATTC, pers. comm.),
- 0–300 m for longlines, which covers the depth range of both 'shallow' and 'deep' sets (see Griffiths et al., 2017),
- 0–80 m for surface-set longlines set by the artisanal fishery, which covers the depth range to the deepest hook of both shallow 'dorado' sets and deeper 'tuna/billfishes/shark' sets (see Andraka et al., 2013),
- 0–80 m for surface-set gillnets set by the artisanal fishery that typically target sharks (Ayala et al., 2008).

Therefore, given the nearly complete overlap between fishing depth ranges and leatherback dive depth range, a value of 1 was used for length class *j* after the length of first capture (see below) in fishery *x*.

For the egg collection "fishery" that operates on land, fishing depth is irrelevant and so a different, and a more precise, estimate of encounterability was used. Leatherback turtle nesting locations in Mexico, Central America, and South America have been comprehensively mapped by the Laúd OPO Network, SWOT, and IAC. Collection of leatherback turtle eggs has been estimated to occur in 1% and 4% of these nests in Costa Rica (Santidrián Tomillo et al., 2008) and Mexico (Sarti Martínez et al., 2007), respectively (Laúd OPO Network, 2020). Therefore, a precautionary approach was taken by assuming that the egg collection fishery encounters 4% of all nests at documented nesting sites in the southeastern EPO.

Contact selectivity (C_{xj}) describes the proportion of length class *j* that is retained once it encounters the gear used by fishery *x*. In the absence of reliable gear selectivity curves for leatherback turtles, a precautionary knife-edge selectivity (C_{xj} = 1.0) was assumed from the smallest leatherback turtle recorded in each fishery, which was 40 cm (Swimmer et al., 2011). Exceptions were the industrial purse-seine fisheries, where 32 cm was used (Unpublished IATTC observer data).

IATTC Resolution C-19-04 mandates the release of sea turtles in all fisheries. Therefore, fishing mortality would be overestimated unless the component of the catch that survives mandatory release is accounted for. This is introduced in the model as post-capture mortality (PCM) (P_{xj})—incorporating two separate components—the proportion of length class *j* that is caught by fishery *x* and 1) dies before or upon arrival at the vessel (*i.e.*, "at-vessel mortality") or 2) dies soon after release ("post-release mortality"). PCM was highest for the egg collection fishery (P_{xj} = 1.0) since this fishery intentionally harvests eggs for human consumption. PCM estimates for all fisheries are described in detail below; and Table 2 details each parameter value used in each scenario.

PCM estimates for sea turtles considered both at-vessel and post-release components after capture by commercial longline gear, specifically 27% for externally hooked turtles and 42% for turtles with internal injuries (*e.g.*, hook lodged in esophagus) (Ryder et al., 2006). A recent assessment of this work by (Swimmer and Gilman, 2012) validated these values, noting that PCM is likely bimodal; acute mortality (*i.e.*, <90 days post-interaction) could result from severe injuries, particularly organ damage, while chronic effects of an interaction caused by infections, slow organ failure, and ingestion of fishing line, could result in delayed mortality (>90 days post-interaction). Further, a summary of published PCM estimates ranged between 0 to ~0.9, with most values centering around 0.3 (Swimmer and Gilman, 2012). These values vary widely depending on severity of the injury and how the animal is handled after capture and prior to release. Considering this information, particularly the uncertainties about the post-release component of PCM, we used a range of PCM values for industrial longlines between 0.2 to 0.6, with a 'most likely' value of 0.4 (*i.e.*, 40% of leatherbacks that interact with industrial longline gear die as a result) (Table2).

While at-vessel mortality estimates are available for artisanal fisheries (Alfaro-Shigueto et al., 2011; Alfaro-Shigueto et al., 2018), post-release mortality estimates are lacking. At-vessel mortality is rarely observed as Alfaro-Shigueto et al. (2011) reported zero at-vessel mortality of leatherback turtles in the Peruvian artisanal longline fishery. However, because safe handling and release practices are rarely implemented in artisanal fisheries, post-release mortality is likely to be significant. PCM for the industrial longline fleet was assumed to be higher than for the artisanal longline fishery due to longer mainline length (120 km *vs*. 6 km) and deployment of more hooks per set (average ~2500 vs. <1000) (IATTC unpublished observer data for the industrial longline fleet in 2017; Alfaro-Shigueto et al., 2010). For these reasons, PCM was assumed to range between 0.1 and 0.4, with a most probable value of 0.25 for the artisanal longline fleet (Table 2).

Artisanal gillnets in the region are characterized by long soak times approximately equivalent to the artisanal longline fishery, and mesh sizes used are typically for targeting large pelagic fish and sharks, and thus frequently entangle sea turtles, including leatherbacks (see Alfaro-Shigueto et al., 2010). However, in contrast to surface-set longlines, gillnets can inhibit enmeshed turtles from reaching the surface to breathe, thus resulting in a higher PCM rate. This is particularly true for large mesh drift gillnets in Peru and Ecuador, where observed at-vessel mortality is >30% (Alfaro-Shigueto et al. 2011; 2018). Although, post-release mortality estimates are unavailable, it is likely >0, and thus would increase the total PCM in these fisheries. Thus, PCM for the artisanal gillnet fishery was assumed to range between 0.2 and 0.6 with a most probable value of 0.5 (Table 2).

The lowest PCM estimates were in all purse-seine fisheries (most probable value: 0.05, range: 0.01–0.1; Table 2) where the set times are short, turtles can swim to the surface to breathe during the net pursing procedure, and can be brailed or removed from the net relatively quickly, thus reducing at-vessel and presumed post-release mortality.

The PCM values used assume that current implementation of CMMs, such as large circle hooks in longlines and safe handling and release practices, is negligible in the fisheries included in the model. In contrast, scenarios that include such measures assume full implementation throughout each relevant fishery. We recognize that implementation of conservation measures in fisheries in practice would be incremental and achieving full compliance might not be realistically achievable. Therefore, these model estimates represent what could be possible under ideal conditions, which, when compared to *status quo* conditions, provide a reasonable range of potential effects of CMMs on leatherback vulnerability.

1.3 Productivity

Following the estimation of the overall susceptibility of length class *j* to incurring mortality from fishery *x* (S_{xj}), a proxy for the instantaneous fishing mortality rate in 2018 ($\tilde{F}_{2018}$) for leatherback turtles caught by all fisheries was estimated as:

$$\tilde{F}_{2018} = -\ln\left[1 - \sum_{x=1} q_x E_x \left(\frac{\sum_{j=1}^{n} S_{xj}}{n}\right)\right] \quad \text{(Eq. 2)}$$

Here, *n* is the number of length classes (in 2-cm increments) extending to the average length at which a leatherback turtle may grow if it were to live indefinitely (L_∞). Fishing effort (E_x) is total effort, scaled from zero to 1, of fishery *x* applied in area G_x in 2018, while the catchability coefficient (q_x) is the fraction of the stock that is caught by one unit of effort (E_x) in fishery *x*. In many data-limited fisheries values for *q* and *E* are unknown. A precautionary approach is to assume both parameters are equal to 1, meaning all leatherback turtles in a grid cell are caught if all other susceptibility parameters are fully realized. However, given the conservation importance of leatherback turtles and the observation that they are caught in the highest numbers in coastal artisanal fisheries (Wallace et al., 2013a), it was considered necessary to attempt to standardize fishing effort of the gears relative to one another. Standardization of catch rates is difficult between different gear types as their efficiency and effective fishing area, or "Domain of Potential Interaction" (Griffiths et al., 2007), can differ markedly. For example, longline and gillnet are 'passive' methods that rely on animals interacting with the gear during their normal movements. In contrast, purse-seining is an 'active' method whereby the gear is deployed in a discrete area where target species aggregate, for example, in feeding schools, in association with dolphins, or in the vicinity of floating objects.

Therefore, the most appropriate method of standardizing catch rates of leatherback turtles—*i.e*., bycatch rates—was to estimate the catch per standard unit of effort per day. The industrial longline fleet generally complete a single set in a 24-hour period, comprised of an average of 2526 hooks. Swimmer et al. (2017) estimated the catch rate of sea turtles in the Hawaiian longline fleet is 0.01 turtles per thousand hooks. Therefore, the catch rate of turtles per fishing day was estimated to be 0.505. Similarly, artisanal longline vessels in the EPO typically make one set per day, and the number of hooks per set varies widely (150–1500 in Costa Rica, 150–800 in Ecuador, 300–2500 in Peru; Alfaro-Shigueto et al., 2011; Andraka et al., 2013). Leatherback bycatch rates are relatively low in these fisheries—approximately 0.02 leatherbacks per set—across multiple countries including Costa Rica, Panama, Ecuador (Andraka et al., 2013) and Peru (Alfaro-Shigueto et al., 2011).

The artisanal gillnet fishery—using the Peruvian fleet to represent the characteristics of other gillnet fisheries in the EPO—also typically make one set per day and catch an average of 1.0 leatherback turtle per set (Alfaro-Shigueto et al., 2011).

The industrial purse-seine fleet (Class 6 vessels) can make up to 5 sets per day, but they typically make 1–2 sets per day (average 1.45 in 2018; IATTC unpublished observer data). Owing to the near 100% observer coverage of this fleet, a high-quality time series of operational-level turtle bycatch data is available for 1993–2020. Of the 32,523 sets made by the fishery in 2018, only 5 leatherback turtles were recorded by observers (IATTC 2019)—all released alive—equating to a catch rate of 0.000154 leatherback turtles per set, or 0.00022 per fishing day. Although limited bycatch information is available for purse-seine vessels of Classes 1–5 they also typically make 1 or 2 sets per day, but their nets are smaller than those deployed from Class 6 vessels and are likely to experience lower catch rates of turtles as a result. However, exercising a precautionary approach, it was assumed that all purse-seine vessels have the same catch rate as Class 6 vessels.

To calculate E_x for each fishery, the average daily catch rate was divided by the catch rate of the fishery having the highest catch rate (*i.e.*, the artisanal gillnet fishery).

$\hat{F}_{2018}$ was then compared with values for *F* for the selected BRPs derived from the per-recruit models (described below). However, it needs to be reiterated that, because of the several conservative assumptions and likely uncertainty in the parameters used in deriving the $\hat{F}_{2018}$ estimate, it should only be considered a proxy for *F*—and potentially an overestimate. It is for this reason that the results from EASI-Fish should not be used to define the status of a species' population, *sensu* a stock assessment.

1.4 Characterizing species productivity using per-recruit models

A yield-per-recruit (YPR) model was used to characterize the biological dynamics of leatherback turtles using the generic approach of Ricker (1975), which Chen and Gordon (1997) adapted for lengths as:

$$YPR = \sum_{j=1}^{n} \frac{W_j b_j F}{b_j F + M}\left(1 - e^{-(b_j F + M)\Delta T_j}\right) e^{-\sum_{k=1}^{j-1}(b_k F + M)\Delta T_k} \quad \text{(Eq. 3)}$$

Here, new recruits and fully recruited length classes are denoted by the subscripts *j* and *k*, respectively. W_j is the mean weight of a turtle in length class *j*, while selectivity (b_j) is the proportion of the population in length class *j* that is caught across all fisheries, represented as:

$$b_x = \sum_{x=1}^{l} S_{xx} \quad \text{(Eq. 4)}$$

Length-specific estimates of the instantaneous natural mortality rate (*M* yr^{-1}) were taken from concurrent long-term studies of leatherback turtles returning to nesting sites in Mexico and Costa Rica (Laúd OPO Network, 2020). These were 0.53 yr^{-1}, 0.937 yr^{-1}, 0.5 yr^{-1}, and 0.295 yr^{-1} for size classes 0–5 cm, 5–40 cm, 40–100 cm, and >100 cm, respectively. *F* was disaggregated into increments of 0.01 from zero to an L_∞ value of 147.6 cm (Zug and Parham, 1996). The parameter ΔT represents the time taken for a turtle to grow from one length class to the next, represented as:

$$\Delta T_j = \frac{1}{K} \ln \frac{L_\infty - L_j}{L_\infty - L_j - d_j} \quad \text{(Eq. 5)}$$

where K and L_∞ are parameters from the von Bertalanffy growth function (Table 3), and d is the width of the length class, calculated as $L_{j+1} - L_j$.

The spawning stock biomass-per-recruit (SSB/R) model of Quinn and Deriso (1999)—herein termed breeding stock biomass-per-recruit (BSR) to be specific to turtle life histories—is complementary to YPR, and can be modified to suit the analysis of length rather than age classes and be represented as:

$$BSY = \sum_{j=1}^{n} W_j m_j \prod_{x=r}^{j-1} e^{-(b_j F + M)} \quad \text{(Eq. 6)}$$

where W_j is the mean weight of a leatherback turtle in length class j (L_j) taken from a length-weight relationship (Table 3), m_j is the proportion of mature females at the mean length of length class j, and the product operator describes the number of turtles surviving from the length at recruitment (L_r) to L_j. Because the model calculates relative BSR, the initial number of breeding females was set to a value of one. The value for m_j was taken from a female maturity ogive for leatherback turtles in the EPO (Avens et al., 2020), represented in the logistic form:

$$m_x = \frac{1}{1 + e^{-r(L_x - L_{50})}} \quad \text{(Eq. 7)}$$

where L_j is the mean length of a turtle in length class j, L_{50} is the length at which 50% of the population is mature, and r is the curvature parameter.

1.5 Biological Reference Points (BRP)

Depending on the life history of a species, various BRPs have been used in stock assessment models to assess the status of a population relative to an estimated F value for a particular time period or specific year. EASI-Fish uses a similar approach, but it is important to emphasize that its BRPs are used to quantify the relative vulnerability of a population that would be expected to hinder the lifetime yield of an animal—regardless of the present population size—rather than to determine stock status. YPR models assume that recruitment is constant and independent of stock size—equivalent to a steepness (h) value of 1 (Gabriel and Mace, 1999). Therefore, use of a F value at which yield is maximized (F_{MAX}) can be overly optimistic owing to sea turtles often having a strong stock-recruitment relationship (*i.e.*, h<1) (Gallaway et al., 2016). Unfortunately, the stock-recruitment relationship is difficult to estimate (Lee et al., 2012), and hence taxonomic group-based proxies are often used in stock assessments as a result.

An assessment of tuna fishery bycatch species in the EPO using EASI-Fish used $F_{40\%}$ (Griffiths et al., 2019a), which had been generally regarded as precautionary for most marine finfish stocks (see Ralston, 2002). However, recent work by Cortés and Brooks (2018) suggests that for slow-growing and long-lived species, such as elasmobranchs, a BRP of between $F_{60\%}$ and $F_{80\%}$ should be used. Considering leatherbacks' life history traits of slow growth and low fecundity, $F_{80\%}$ was adopted for the present assessment. Explicitly, $F_{80\%}$ is the F value corresponding to 80% of the breeding potential ratio (BPR), which is the BSR at the $\tilde{F}_{2018}$ value divided by the BSR where F=0. The corresponding $BSR_{80\%}$ BRP is the BSR value at $F_{80\%}$.

The vulnerability of leatherback turtles in each hypothetical management scenario was determined using $\tilde{F}_{2018}$ and the corresponding BSR value (BSR_{2018}) relative to the $F_{80\%}$ and $BSR_{80\%}$ values and displayed on a 4-quadrant "vulnerability phase plot" (Fig. 3). The vulnerability definitions of these quadrants are: i) "Least vulnerable" (green; $\tilde{F}_{2018}/F_{80\%}$ <1 and $BSR_{2018}/BSR_{80\%}$ >1), ii) "Increasingly vulnerable" (orange; $\tilde{F}_{2018}/F_{80\%}$ >1 and $BSR_{2018}/BSR_{80\%}$ >1), iii) "Most vulnerable" (red; $\tilde{F}_{2018}/F_{80\%}$ >1 and $BSR_{2018}/BSR_{80\%}$ <1), and iv) "Decreasingly vulnerable" (yellow; $\tilde{F}_{2018}/F_{80\%}$ <1 and $BSR_{2018}/BSR_{80\%}$ <1).

1.6 Implementation of the model

The model was built in Microsoft Excel, with add-ins to perform Monte Carlo simulations to generate uncertainty estimates for specific model parameters using a triangular prior distribution ranging between two plausible values with an apex at the most probable value. The YPR and BSR models were then run 10,000 times using Monte Carlo simulations, each time using a random sample from the distribution prior defined for each parameter. The mean, standard error (SE), and 95% confidence intervals (95% CI) were derived for the BRPs $\tilde{F}_{2018}$, $F_{80\%}$, BSR_{2018}, and $BSR_{80\%}$.

1.7 Definition of hypothetical scenarios aiming to reduce vulnerability status of leatherback turtles

The flexibility of EASI-Fish allows specific spatial and temporal CMMs for the leatherback turtle stock in the EPO to be explored in isolation or in concert. Using the CMMs described in IATTC Resolution C-19-04, as well as other existing CMMs (*e.g.*, 72-day EPO-wide closure), we developed a total of 39 hypothetical CMMs under five categories:

1) Improved handling and release practices,
2) Temporary closure of coastal waters adjacent to key leatherback turtle nesting sites,
3) Mandatory use of large circle hooks in industrial and/or longline fisheries,
4) Extension of the existing 72-day EPO-wide purse-seine fishing closure,
5) Various combinations of the above CMMs.

For each category of CMMs, specific scenario values were compared to the "*status quo*" fishery situation for 2018 ("S1"), which was an EPO-wide closure of 72 days, a 30-day closure of the existing "corralito", a length-at-first-capture of 40 cm for all fisheries, except the purse-seine fisheries (32 cm), and a 'most probable' PCM rate of 0.4, 0.05, 0.5, 0.25, and 1.0 for industrial longline, purse-seine, artisanal gillnet, artisanal longline, and the egg collection fisheries, respectively. The S1 scenario also includes some existing national-scale conservation measures, such as marine protected areas (Revillagigedo Archipelago, Mexico; Galápagos Marine Reserve, Ecuador), that might affect leatherback bycatch. However, we recognize that there may be other small spatial and/or temporal closures implemented by coastal States that are not represented in the model scenarios.

For each of the 39 scenarios in EASI-Fish, inputs for CMM effects on leatherback bycatch values were assumed to reflect 100% compliance for the entire fleet for each relevant fishery. This approach provides information about the extent of possible effects of CMMs on the vulnerability of the EP leatherback turtle stock. However, future model iterations could explore interim input values to reflect incremental or incomplete implementation of CMMs. All susceptibility parameter values contributing to the overall susceptibility (S_{xj}) estimate in EASI-Fish are provided in Table 2, including the distribution type, the 'most probable' and minimum and maximum PCM values. Descriptions of the derivation of all susceptibility values are given in Table 4.

2. RESULTS

2.1. Estimates of susceptibility and a proxy for fishing mortality (*F*)

For the *status quo* scenario (S1), the areal overlap of the industrial longline fishery with the distribution of leatherback turtles was high (87%), due to the fishery being distributed across most of the EPO between 40°N and 40°S (Fig. 4). With respect to Class 6 purse-seine vessels, areal overlap was 7%, 16%, and 26% for NOA, DEL, and OBJ sets, respectively. For purse-seine vessels of Classes 1–5, areal overlap was 1.2% (NOA) and 4.9% (OBJ), with effort concentrated around the Galapagos Islands and the waters of Ecuador and Peru (Fig. 4).

With respect to artisanal fisheries, the gillnet fleet overlapped with just 2.7% of the EP leatherback stock distribution, while the longline fleet had an areal overlap of 14.9%, with effort being widely dispersed from the coastline between Guatemala and Chile to as far east as the 100°W longitude (Fig. 4). The egg collection "fishery" overlapped with 0.006% of the stock, but because this fishery operates where the entire EP stock lays their eggs each year, this was interpreted in the model as a 100% overlap of the population.

The fishing season duration provided no protection from the industrial longline fishery and the artisanal longline and gillnet fisheries that all fish year-round (D_x =1.0), except for a 3-month closure in Mexican waters. Each purse-seine fishery fished for 81% of the year due to the 72-day EPO-wide closure and the 30-day closure of the "corralito".

Electronic tagging studies of the EP leatherback turtle stock revealed year-round presence of leatherback turtles within the IATTC Convention Area (see Benson et al., 2011; Shillinger et al., 2011; Schick et al., 2013) and were therefore considered to be available to all fisheries year-round (A_{xj}=1.0). Encounterability was fully realized (E_{xj}=1.0) for all fisheries because each gear fishes from the surface to depths that include typical depths occupied by leatherback turtles. The only exception was the egg collection fishery, which was assumed to encounter only 4% of the total leatherback turtle nests within the EP stock boundaries.

Average contact selectivity was highest for the five purse-seine fisheries (C_{xj}=0.801) due to the surface orientation and the small mesh of the gear, and the lowest length-at-first-capture of 32 cm. Contact selectivity was slightly lower (0.736) for the industrial longline fishery and the artisanal longline and gillnet fisheries due to the length at first capture being 40 cm. Average selectivity was lowest for the egg collection fishery (0.056), which is a result of this fishery only being selective for turtle eggs, with estimate pre-hatchling sizes of <5 cm.

Under the *status quo* scenario (S1) in 2018, the industrial longline fishery imposed the highest fishing mortality ($\tilde{F}_{2018}$ =0.124 yr^{-1}), mainly due to its high volumetric overlap with the stock. The artisanal longline fishery had the second highest fishing mortality (0.057 yr^{-1}), despite having a lower volumetric overlap with the stock. The artisanal gillnet fishery had a comparatively low fishing mortality (0.008 yr^{-1}), owing to a very low (25%) areal overlap with the stock. The remaining fisheries (purse-seine and egg collection) each contributed a fishing mortality of less than 0.0002 yr^{-1}. In the purse-seine fisheries, this is attributed to PCM rates of <5% despite relatively high volumetric overlap with the stock, while the egg collection fishery had low encounterability of nests and only impacted a narrow range of size classes.

2.2. Vulnerability status of leatherback turtles in the EPO

The biological parameter values (and their sources) used in the YPR and BSR models are shown in Table 3, while EASI-Fish estimates of $\tilde{F}_{2018}$ and BSR$_{2018}$ and the $F_{80\%}$ and BSR$_{80\%}$ BRPs for each scenario are provided in Table 5.

Under the S1 scenario characterizing the fishery in 2018, $\tilde{F}_{2018}$ and BSR$_{2018}$ exceeded the $F_{80\%}$ and BSR$_{80\%}$ BRPs, resulting in the classification of the EP leatherback turtle stock as "most vulnerable" (Fig. 5a; Table 5). However, S1 is considerably more optimistic than if all fisheries had PCM rates that were 50% (S4) or 100% (S5) higher (Fig. 5a). Under very optimistic conditions, it is possible that PCM could be 50% (S3) or even 75% (S2) lower than for S1, meaning the stock would be considered "least vulnerable" (Fig. 5a).

Temporary closure of coastal waters adjacent to four key nesting sites (Fig. 6) for between 60 and 180 days (S6–S10) resulted in a negligible change in vulnerability status compared to the *status quo* (Fig. 5b). This was primarily due to industrial fleets not being present in the nesting site region, and the exclusion only of the artisanal gillnet and longline fleets from only 1.8% and 10.2% of their respective fished areas, which overlapped very little with the stock overall.

The hypothetical introduction of large circle hooks to longline fisheries (S11–12) was assumed to reduce PCM by 50% (from 0.4 to 0.2 preferred value, from 0.2 to 0.6 minimum value, and from 0.1 to 0.3 maximum value) relative to S1 by reducing both the at-vessel mortality as well as the post-release mortality (Swimmer et al., 2017; Tables 2 and 3). This change improved the stock's vulnerability status compared to the *status quo* but was not sufficient to change the status from "most vulnerable" (red quadrant) to "decreasingly vulnerable" (yellow quadrant) or "least vulnerable" (green quadrant) (Fig. 5c).

Similarly, the use of best handling and release practices (S13–S14) that were assumed to reduce PCM by 50% of S1 (Tables 2 and 3) for all longline fisheries and all fisheries combined were both successful in reducing vulnerability. As in the circle hook scenarios (S11–S12), this change improved the stock's vulnerability status versus the *status quo* but was not sufficient to change the status from "most vulnerable" to "decreasingly vulnerable" or "least vulnerable" (Fig. 5d).

When combining the assumed benefits of using circle hooks in all longline fisheries with the use of best handling and release practices in all fisheries (75% total reduction in PCM)—*i.e.*, PCM is first reduced by 50% to account for circle hooks, then a further 50% reduction to account for best handling practices for animals surviving hooking; Tables 2 and 3—vulnerability significantly decreased in all three scenarios (S15–S17) to the extent where the vulnerability status improved to "least vulnerable" (Fig. 5d).

Scenarios involving EPO-wide closure to all purse-seine fisheries decreased vulnerability with increasing closure duration of between 60 and 270 days, but none of the 5 scenarios (S18–S22) resulted in a change in vulnerability status (Fig. 5f). Scenarios excluding all purse-seine and longline fleets (S23–S27) across the EPO showed significant reductions in vulnerability with increasing closure duration. However, only an EPO-wide closure of at least 270 days was predicted to improve the vulnerability status to "least vulnerable" (Fig. 5f).

Other combinations of CMMs applied in concert produced variable results. Combining the closure of areas adjacent to key nesting sites for 60–270 days with the use of circle hooks in all longline fleets reduced vulnerability but did not result in a clear change of status from "most vulnerable" (Fig. 5g). In contrast, the four scenarios (S32–S35) involving closure of nesting areas coupled with the use of best handling and release practices in all fleets resulted in significant decrease in vulnerability, improving the vulnerability status to "least vulnerable" (Fig. 5h).

The scenarios that resulted in the largest changes to vulnerability status involved the combination of closing areas adjacent to key nesting sites for 60–270 days with the use of circle hooks in all longline fleets and the use of best practices in all fleets. These four scenarios (S36–S39) resulted in a significant improvement in vulnerability status from "most vulnerable" (S1) to "least vulnerable" (Fig. 5i). It is important to point out that although closure of areas adjacent to key nesting sites was involved in all combination scenarios, the closures alone resulted in a negligible change in vulnerability compared to the *status quo* (see Fig. 5b). These results demonstrate clearly that use of circle hooks and best handling and release practices contribute most to the predicted reduction in vulnerability of the EP leatherback turtle stock.

3. DISCUSSION

Ecological risk assessment (ERA) has been widely used in fisheries as a rapid and cost-effective means by which fisheries managers can identify species most vulnerable to fishing impacts and take steps to mitigate identified risks, or collect further information to facilitate more formal stock assessment (Hobday et al., 2011). There have been at least three ERAs undertaken in the EPO (Griffiths et al., 2017; Griffiths et al., 2018; Duffy et al., 2019), one of which included leatherback turtles, that indicated this species is among the most vulnerable species in the diverse suite of bycatch species impacted by tuna fisheries (Griffiths et al., 2018). However, this paper has provided a demonstration of the utility of the EASI-Fish approach to quantify the cumulative impacts of multiple fisheries—including artisanal fisheries for the first time—on this critically endangered species under several hypothetical CMM scenarios. The advantage of using the EASI-Fish approach over other ERA methods is that various management measures—that can be implemented individually or in unison—may be simulated to determine their potential efficacy of reducing the vulnerability of the EP leatherback turtle stock to becoming unsustainable in the long term.

However, EASI-Fish, like many other ERA approaches, was not designed to serve as a replacement for formal stock assessment—despite having a simple stock assessment model at its core—to assess stock status for bycatch species. The results from the exploratory analyses of CMM scenarios presented in this paper can now guide future research where more formal assessments may be undertaken using modern integrated stock assessment models. Such models provide a more definitive assessment of stock status and the potential benefits of fisheries employing apparently effective mitigation measures identified by EASI-Fish, such as the use of circle hooks and best handling and release practices, to reduce PCM of leatherback turtles in the pelagic fisheries of the EPO. Overall, our results suggest that the CMMs described in IATTC Resolution C-19-04 and IAC Resolution CIT-COP7-2015-R2 are appropriate and have the potential to significantly reduce the vulnerability of the EP leatherback turtle stock to fishing impacts in the EPO.

3.1. Spatial and temporal closures

Spatial and/or temporal closures are CMMs commonly used by fisheries managers to reduce the fishing impacts on target species or species of conservation concern if particular areas and periods can be identified where a species is abundant and susceptible to capture. One such example in the EPO that the IATTC has implemented is the EPO-wide closure of purse-seine fishing for varying periods through the history of the fishery—depending on the status of the target stocks—from 31 days in 2002–2003 (Resolutions C-02-04 and C-03-03) to 72 days in 2018–2020 (Resolution C-17-01). In addition, the IATTC later implemented an annual 30-day closure of the "corralito" to further reduce fishing mortality on juvenile bigeye tuna (*Thunnus obesus*) (see Resolution C-02-04), but now serves a concomitant purpose for reducing the mortality on the complex of small-sized tunas caught in the same region including yellowfin tuna (*Thunnus albacares*) and skipjack (*Katsuwonus pelamis*). Although spatial-temporal closures of the "corralito" and other tuna catch 'hotspots' were predicted by Harley and Suter (2007) to reduce the catch of bigeye tuna by up to 24%, they were insufficient for reducing fishing mortality to biological sustainable levels. As an alternative, they recommended increasing the area and duration of closures.

The potential management options simulated by EASI-Fish for infrequently encountered bycatch species such as leatherback turtles in the EPO seem complex. Simulations of various spatial-temporal closures in the present study complemented the results of Harley and Suter (2007) in that the duration of recent EPO-wide closures (*i.e.*, 72 days) and the closures of coastal areas adjacent to key nesting areas were insufficient to reclassify the stock's vulnerability status to "least vulnerable". Extending the EPO-wide closure duration certainly reduced the species' vulnerability, but the only scenario where the species' classification changed to "least vulnerable" was that achieved by a assuming a closure of the fishery for most of the year (270 days). This is unlikely to be a feasible management option due to its consequential major reduction in the catch of tuna target species.

There are several countries already contributing by implementing important measures that include their nesting beaches in management categories such as National Parks or other categories of protected areas. For those nesting sites and their adjacent areas that do not fall under these categories, the implementation of management measures identified and developed through participative governance could be analyzed as well. Such scenarios would involve multiple actors, under country-specific mechanisms, in management and implementation of best practices for responsible use of fishing resources within relevant marine areas.

3.2. Reducing post-capture mortality as a conservation measure

Of the 39 CMM scenarios conducted on the EP leatherback turtle stock using EASI-Fish, those that resulted in the greatest improvement in the vulnerability status involved a significant reduction in PCM, that would be presumed to occur with implementation of large circle hooks and/or improved handling and release practices. The efficacy of circle hooks (and fish bait) in reducing the hooking rate and fishing-induced mortality of sea turtles, including leatherbacks, has been published in several studies of longline fisheries (Watson et al., 2005; Gilman et al., 2006; FAO 2009; Sales et al., 2010; Andraka et al., 2013; Swimmer et al., 2017). As for safe handling and release techniques, IATTC Resolution C-19-04 requires that purse-seine and longline operations "*Ensure that vessel operators and/or at least one crew member on board of vessels targeting species covered by the Convention in fisheries that have reported sea turtle interactions, and particularly those without observers, are trained in techniques for handling and release of sea turtles to improve survival after release*." These techniques are described in the 2009 FAO *Guidelines to Reduce Sea Turtle Mortality in Fishing Operations* (FAO 2009), and include:

- Boating a captured turtle using appropriate techniques (dipnets for small turtles, hoists for larger turtles like leatherbacks, never pulling turtles on the line) that minimize harm to the turtle whenever logistically feasible,
- When a turtle cannot be brought aboard and a hook cannot be removed, the line should be cut as close to the eye of the hook as possible,
- Once on deck, maintain the turtle in a moist, shaded area, isolated and immobilized, with hind flippers raised higher than the head,
- All external hooks and hooks in the mouth should be removed; if the hook is lodged in the throat or swallowed, or if it is uncertain whether hook removal will cause more damage, then the hook should not be removed,
- Comatose turtles should be revived before being released,
- Once gear is removed and the turtle recovered, boated turtles should be released in water of a similar temperature as at capture, preferably in a non-fishing area,
- Turtles should be released by lowering over the aft portion of the vessel, close to the surface, when gear is not in use and the engine is in neutral, and the turtle's swimming behavior and diving ability should be monitored after release and recorded in the daily logbook.

There are, however, added challenges to reducing post-capture mortality from small-scale vessels that should be considered, since animal handling may be more difficult, resources and available equipment are more limited, and it may not be possible to bring the animal onboard.

In the absence of reliable data relating to PCM in the longline fishery and the multiple set types made by the six size classes of purse-seine vessels, we needed to make the precautionary assumption that PCM >

0% for each fishery, in spite of some limited evidence suggesting leatherbacks are infrequently captured in purse-seine fisheries and tend to survive these interactions. A total of 109 leatherback turtle interactions have been observed as bycatch—with only one confirmed mortality—in the 156,094 sets made by Class 6 purse-seine vessels between 1993–2019. However, mortality of other sea turtle species has been observed in the EPO purse-seine fleet, and thus we could not completely discount the possibility of leatherback turtle PCM in our scenarios.

There is some evidence to suggest that leatherback PCM may be relatively low for longline fisheries. For example, in the Chilean pelagic longline fishery the at-vessel mortality rate for leatherback turtles was estimated to be 7% (Donoso and Dutton, 2010). However, observer coverage by each IATTC CPC industrial longline fleet in the EPO has often failed to reach the 5% requirement under Resolution C-19-08. Availability of data from onboard observers during fishing operations is a critical need to inform and improve decision making processes. Therefore, promoting permanent observer programs onboard artisanal fleets (vessels <24 m LOA) by human and/or electronic monitoring is relevant to access information. However, these programs require permanent funding to be successful in the long term.

Therefore, recommendations from the present study are:

1) for robust observer programs to be developed for the fleet of LSTLFVs—where electronic monitoring could be trialed as a possible cost-effective method to complement human observers—to comply with existing requirements of IATTC Resolution C-19-08, and IAC Resolution CIT-COP7-2015-R2, and
2) to undertake electronic tagging studies for EPO longline fisheries to quantify at-vessel mortality and PRM rates for leatherback turtles. These studies would benefit by quantifying PCM using best handling and release practices, such as *in situ* release after cutting the leader, compared to release from the deck. The experimental design could be further stratified by animal size and handling time to release to better understand the efficacy of each release procedure.

It may be fortuitous that minimizing PCM has the potential to significantly reduce the mortality of leatherback turtles in EPO tuna fisheries, which are already subjected to a range of spatial and temporal closures as a means of managing fishing mortality of target tuna species. Handling and release practices that allow a significant proportion of captured turtles (and other vulnerable, non-target species) to survive the sub-lethal effects of capture and release are much simpler and cost-effective to implement—if fishers maintain a high level of care in the recommended release procedures—than small-scale spatial and temporal closures to reduce the capture of leatherback turtles.

These scenarios assume 100% compliance and high degrees of efficacy of implemented CMMs, which are perhaps optimistic assumptions, and clearly will not be achieved immediately. Thus, the results of the model scenarios provide estimates of what is possible under such conditions in comparison to current conditions—that is, the ideal target for CMMs. In reality, improvements to leatherback vulnerability should be expected to occur incrementally as CMMs are implemented and fishing crews employ more effective methods of handling captured turtles, as circle hooks are implemented in more longline operations. However, only the scenarios that combined ideal implementation assumptions for multiple CMMS examined in this paper successfully improved leatherback vulnerability to "least vulnerable" (green quadrant area). This highlights the need for widespread implementation of effective CMMs across the IATTC Convention Area to improve EP leatherback status.

4. DIRECTIONS FOR FUTURE WORK

This paper examined potential effects of multiple CMM scenarios on leatherback vulnerability, including spatio-temporal fishing closures at multiple scales, gear modifications (*e.g*., circle hooks), and best practices (*e.g*., safe handling and release of turtles), as well as combinations of CMMs. While the results of these model scenarios provided ample information to inform strategies for implementing conservation measures in EPO fisheries, they also highlighted several priorities for future work. For example, the effects of incremental implementation of CMMs on leatherback vulnerability might be useful to provide interim targets for IATTC and IAC staff responsible for developing and monitoring CMM implementation in the EPO. Below, we describe other areas for future iterations of EASI-Fish models focused on leatherbacks.

4.1. Species distribution models

Given that the EP leatherback stock has a well-defined management boundary (see Fig. 1 and Wallace et al., 2010), this was used as the habitat 'basemap' in the EASI-Fish model. The habitat basemap is a critically important component of the EASI-Fish approach since it defines the boundary of the species' distribution where it can be exposed to fishing. In previous applications of EASI-Fish to data-poor bycatch species that lack such well-defined stock boundaries (Griffiths et al., 2019a; Griffiths et al., 2019b), simple Relative Environmental Suitability (RES) models have been used to predict the probability-of-occupancy (ψ) in each 0.5° x 0.5° grid cell in the EPO by using presence records collected from various sources, such as fishery catch reports, and relating presence to covariates from remotely sensed environmental data (see Kaschner et al., 2006). However, the spatial extent of the distribution is dependent upon value of ψ used, which can influence the proportion of the population exposed to fishing, and therefore the *F* value and the subsequent vulnerability classification produced by EASI-Fish.

In contrast to many other data-poor bycatch species with which EPO pelagic fisheries interact, the EP leatherback turtle stock can be considered relatively data-rich in that high-quality species-specific data pertaining to their biology, ecology and threats by anthropogenic sources are available (see review by Spotila and Tomillo, 2015). Although some limited modelling has been undertaken to define high-use internesting habitats adjacent to key nesting locations in the southeastern EPO based on electronic tag data (Shillinger et al., 2010), it is surprising that more comprehensive studies have not focused on developing dynamic habitat models for this critically endangered population. The present study showed that the industrial longline fishery contributed significantly to the total fishing mortality on the EP leatherback turtle stock, a result that was mostly due to the high areal overlap between the fleet and the stock's distribution, which is assumed to be homogenous within the defined stock boundaries. However, their distribution is almost certainly heterogeneous, and is more likely to disproportionately overlap with artisanal fisheries, despite the relatively limited areas in which these fisheries tend to operate (Fig. 4). For example, adult male and female leatherbacks—as well as hatchlings—tend to aggregate in areas off nesting beaches in the EPO during each breeding season from around September to March (Spotila and Tomillo, 2015). In addition, leatherback turtle interaction rates can be significantly higher in artisanal fisheries than in industrial fisheries (Alfaro-Shigueto et al., 2010). This indicates that leatherback turtles are most likely present in higher densities year-round in neritic waters off South America where artisanal fisheries operate than in high-seas areas where industrial fisheries operate (Shillinger et al., 2008; Hoover et al., 2019). For these reasons, future iterations of EASI-Fish focused on leatherback turtles may be improved by using habitat distribution models that can capture these patterns of spatial heterogeneity of leatherback turtle presence (*e.g*., Hoover et al., 2019).

To address a similar issue in the central north Pacific Ocean—*i.e*., to mitigate loggerhead (*Caretta caretta*) and leatherback turtle bycatch by longline fisheries—a simple environmental envelope model was developed for NOAA's TurtleWatch tool (Howell et al., 2008; Howell et al., 2015). TurtleWatch identifies potential turtle 'hotspots' based on environmental characteristics, such as favorable sea surface temperatures and the presence of current fronts. However, this model relies heavily upon data collected by observers who have observed 100% of shallow sets in the Hawaiian longline fishery since 2004 (Sippel et al., 2014), providing turtle catch counts as well as information on turtle absences. A comparable tool has been developed for EP leatherback turtles but it relies heavily on habitat use data limited to post-nesting females from a single nesting population (Hoover et al., 2019).

Unfortunately, the EPO industrial longline fleet has only 5% observer coverage of the total number of hooks deployed by the fishery each year, which was 175 million hooks in 2018 (IATTC, 2020). For many coastal States however, the observer coverage is even lower, with most artisanal fleets having no observer coverage at all. As a result, insufficient data exist in the EPO to build high-resolution dynamic habitat models for leatherback turtles equivalent to that of Howell et al. (2015), although a recent attempt Hoover et al. (2019) provided a useful foundation for future efforts. In such data-poor settings, species distribution models may only be possible using presence-only datasets, and there are now several sophisticated modelling approaches available that can make use of species presence data and environmental data to make habitat predictions. Some of these models include Generalized Additive Models (GAMs) (Guisan et al., 2002), boosted regression trees (Soykan et al., 2014; Scales et al., 2017), EcoCast (Hazen et al., 2018) and Integrated Nested Laplace Approximation (INLA) models. These models are being increasingly used to model the habitats of large pelagic marine species in the EPO that, like leatherback turtles, are infrequently encountered as bycatch in tuna fisheries, such as the spinetail devil ray (*Mobula mobular*) (Lezama-Ochoa et al., 2019b; Lezama-Ochoa et al., In Press).

4.2. Improved reporting of spatially explicit fishing effort

Previous ERAs have not included coastal artisanal fisheries that commonly interact with leatherback turtles since they are generally poorly documented, if at all (Salas et al., 2007). For example, sea turtles are caught as bycatch in small-scale commercial or artisanal fisheries throughout Mexico (Bizzarro et al., 2009a; Smith et al., 2009), Central America (Swimmer et al., 2011; Whoriskey et al., 2011), and South America (Alfaro-Shigueto et al., 2007; Martínez-Ortiz et al., 2015; Alfaro-Shigueto et al., 2018; Ortíz-Álvarez et al., 2020)—often in far higher numbers than in industrial purse-seine and longline fisheries in the EPO (Wallace et al., 2013a). In addition to accidental capture, retention of turtles for human consumption still occurs in artisanal fisheries in central Peru. For example, approximately 1,000 turtles were found in several dumping sites near Pisco, Peru between 2009 and 2015, where 95% were believed to be used for human consumption, of which 3% were leatherback turtles (Quiñones et al., 2017).

EASI-Fish was designed to overcome such problems of scant or unreliable catch data by using spatial maps of fishing effort overlaid on a species' habitat distribution. As a result, the current assessment is the first ERA that has included artisanal fisheries to quantify the cumulative impact of all fisheries on a species in the EPO. However, considering information could only be sourced opportunistically from published sources as there are large areas of coastline of the Americas for which artisanal fisheries operate, but no data are available, such as the central mainland of Mexico and northern Peru, and areas beyond the conservative limits on putative fishing areas that we imposed within 0.5° of each fishing port in this study. Due to a lack of coverage of all fisheries that are likely to have leatherback turtle bycatch and the several conservative assumptions of the model, the estimated fishing mortality ($\hat{F}_{2018}$) and the subsequent vulnerability status of the EP leatherback turtle stock for 2018 and for each hypothetical scenario is likely to be underestimated, and should be considered conservative. Therefore, the results presented in this paper should be considered a conservative step toward informing precautionary management of fisheries bycatch impacts on the critically endangered EP leatherback turtle stock.

However, the IATTC is continuing its collaboration with Central American IATTC Members in an extension of a project funded by the Global Environment Facility (GEF) to maintain data collection programs for these small coastal fisheries (Siu and Aires-da-Silva, 2016; Oliveros-Ramos et al., 2019). In addition, the MoU between IATTC and IAC provides opportunities for further collaboration and information sharing between the two conventions. Therefore, future assessments on bycatch species such as leatherback turtles may be improved as high resolution spatially explicit fishing effort data become available for use by the IATTC staff.

5. CONCLUSIONS

EASI-fish was primarily developed as a tool for assessing the vulnerability of data-poor bycatch species and allowing the identification of priority species that may be recommended to become candidates for future research and catch monitoring. This will facilitate re-assessment by EASI-Fish or by more sophisticated quantitative assessment if sufficient data exist (*e.g*. formal stock assessment), or the development of mitigation measures to reduce the specific risk(s) that contribute to the vulnerability of the species assessed. This study demonstrated the flexibility and usefulness of the EASI-Fish approach for exploring the relative efficacy of potential CMMs in reducing the vulnerability of leatherback turtles that are impacted by multiple pelagic fisheries in the EPO.

As more data become available from national and IATTC monitoring programs, post-release mortality studies, and improved species distribution models that may better define the stock boundaries of the EP leatherback turtle stock, EASI-Fish's utility will increase as a particularly rapid and inexpensive tool to explore potential impacts of various CMM scenarios that reduce vulnerability of other vulnerable non-target bycatch species. Further, refined EASI-Fish outputs will highlight CMMs that may be cost-effectively implemented by fishery managers to comply with existing mandates and resolutions that require the demonstration of responsible fishing practices that ensure ecological sustainability of all species in which their fisheries interact.

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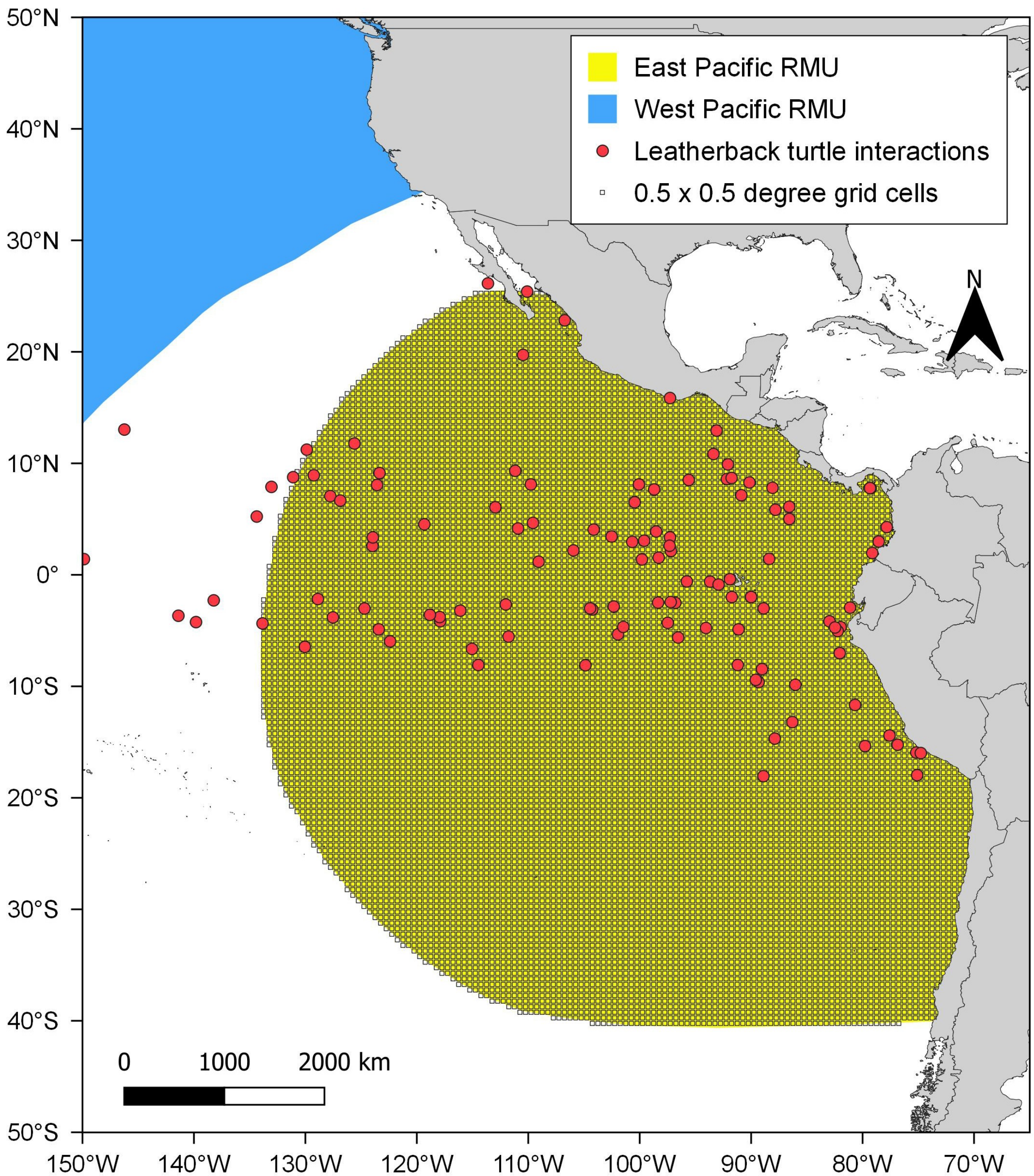

FIGURE 1. Map showing the boundaries of the two Regional Management Units (RMU) of leatherback turtles (*Dermochelys coriacea*) in the eastern Pacific Ocean (EPO) as defined by Wallace et al. (2010). The present assessment for 2018 considers only the East Pacific RMU (yellow) since 105 of the 112 leatherback turtle interactions recorded by observers onboard purse-seine vessels in the EPO between 1993–2019 (red dots) occurred within this RMU. Overlaid 0.5° x 0.5° grid cells define the species' distribution in the EASI-Fish model, where each cell had an assumed probability-of-occupancy (ψ) of 1.

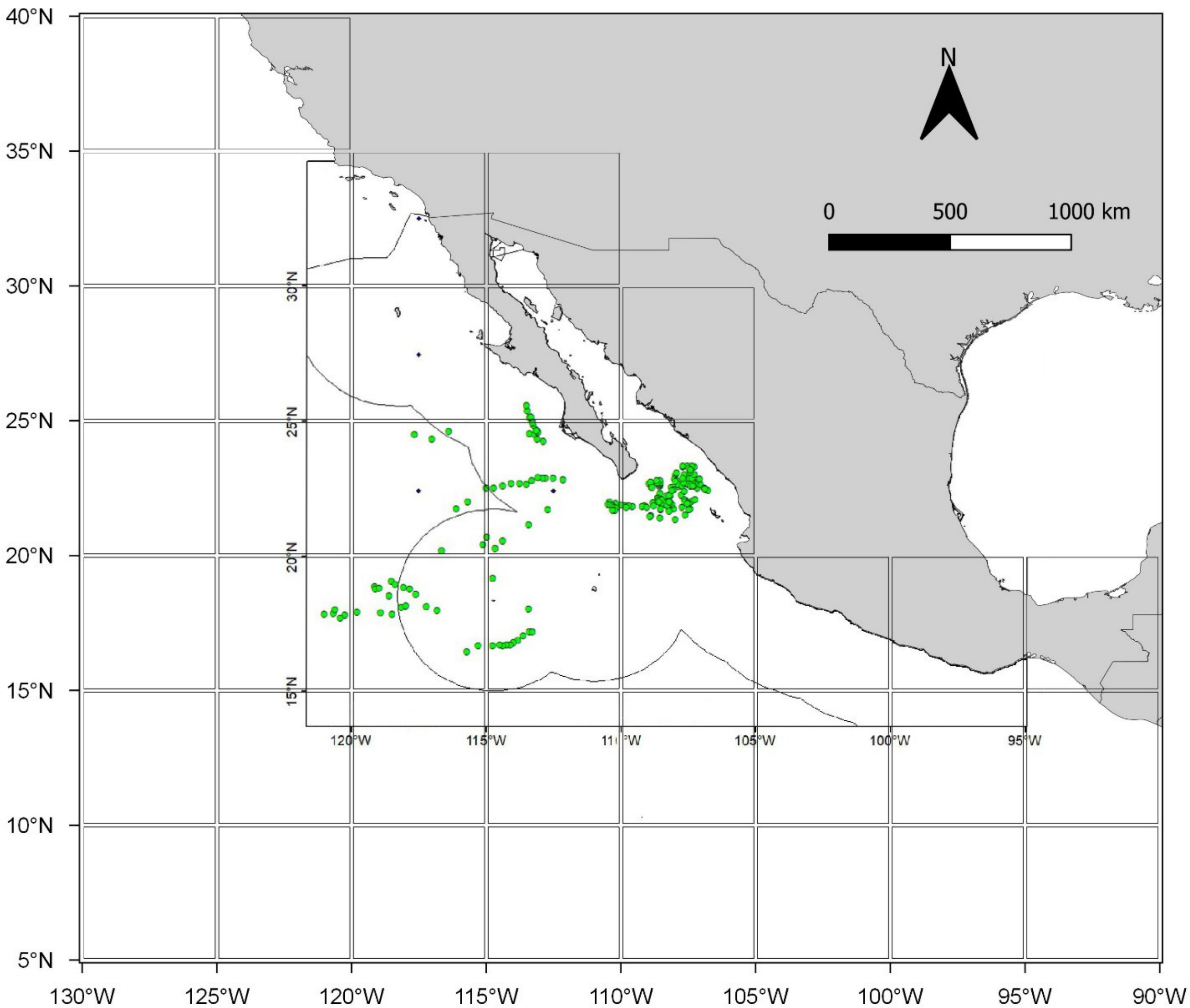

FIGURE 2. Map showing how publicly available fishing effort distribution maps were geo-referenced in QGIS software and effort allocated to cells in the C-squares global spatial indexing system. In this case, a map of observed sets made by the commercial Mexican shark longline fleet in 2018 (supplied by Mexico's Shark Observer Program) was overlaid with 5° x 5° cells in order for these data to be added to the 'industrial' longline fleet in the EASI-Fish model to assess the vulnerability of the southeastern EPO stock of leatherback turtles (*Dermochelys coriacea*) in the eastern Pacific Ocean.

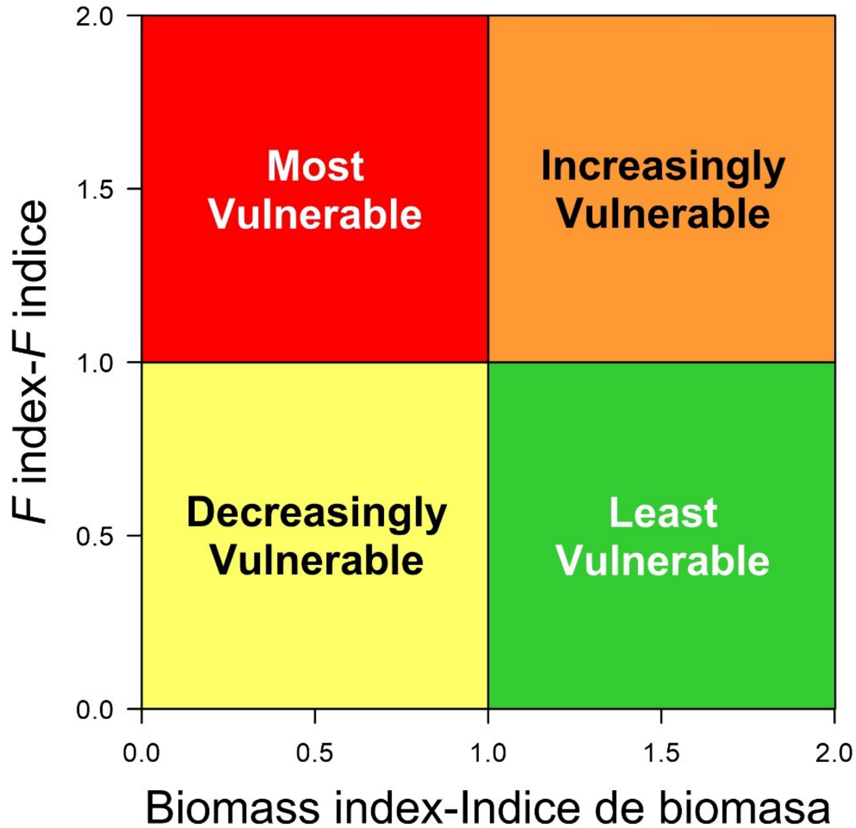

FIGURE 3. Phase plot illustrating how vulnerability status was defined for the East Pacific leatherback turtle stock assessed using $F_{80\%}$ and $BSR_{80\%}$ from the EASI-Fish model as a reference point on the x and y axis, respectively. Vulnerability was defined by its position within one of four quadrants in the phase plot as: “Least vulnerable” (green, $F_{2018}/F_{80\%}$ <1 and $BSR_{2018}/BSR_{80\%}$ >1), “Increasingly vulnerable” (orange, $F_{2018}/F_{80\%}$ >1 and $BSR_{2018}/BSR_{80\%}$ >1), “Most vulnerable” (red, $F_{2018}/F_{80\%}$ >1 and $BSR_{2018}/BSR_{80\%}$ <1), and “Decreasingly vulnerable” (yellow, $F_{2018}/F_{80\%}$ <1 and $BSR_{2018}/BSR_{80\%}$ <1). Maximum axis limits of 2.0 are for illustrative purposes only.

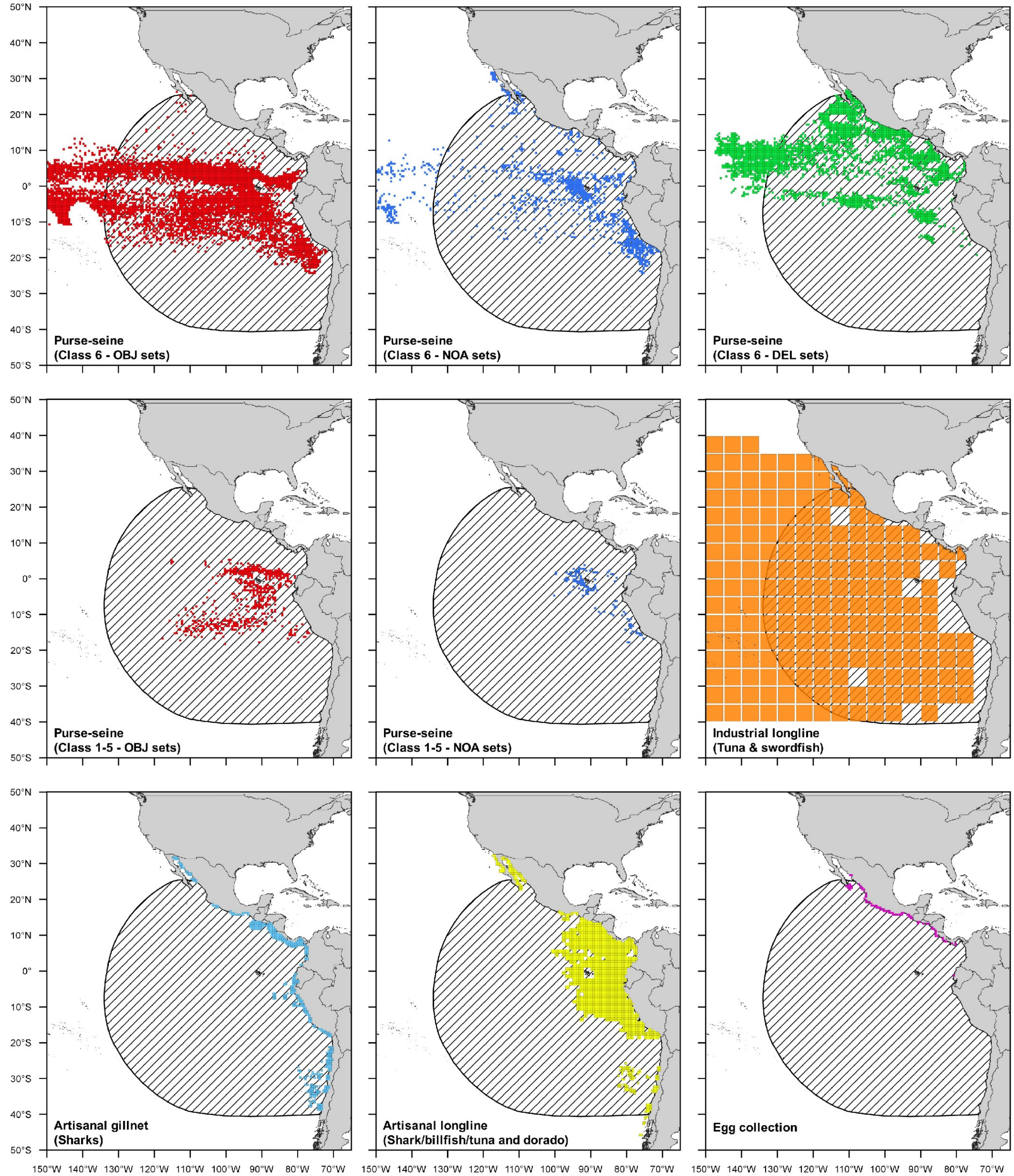

FIGURE 4. Maps showing the distribution of fishing effort by nine fisheries in the eastern Pacific Ocean in 2018 relative to the East Pacific stock of leatherback turtles (*Dermochelys coriacea*) defined by (Wallace et al., 2010) (grey hatched area). Effort data are at 0.5° x 0.5° resolution for each fishery except for the longline fishery, which are shown at 5° x 5° resolution. Set types for the purse seine fisheries are: i) sets associated with floating objects (OBJ), ii) sets on unassociated schools of tuna (NOA), and iii) sets associated with dolphins (DEL).

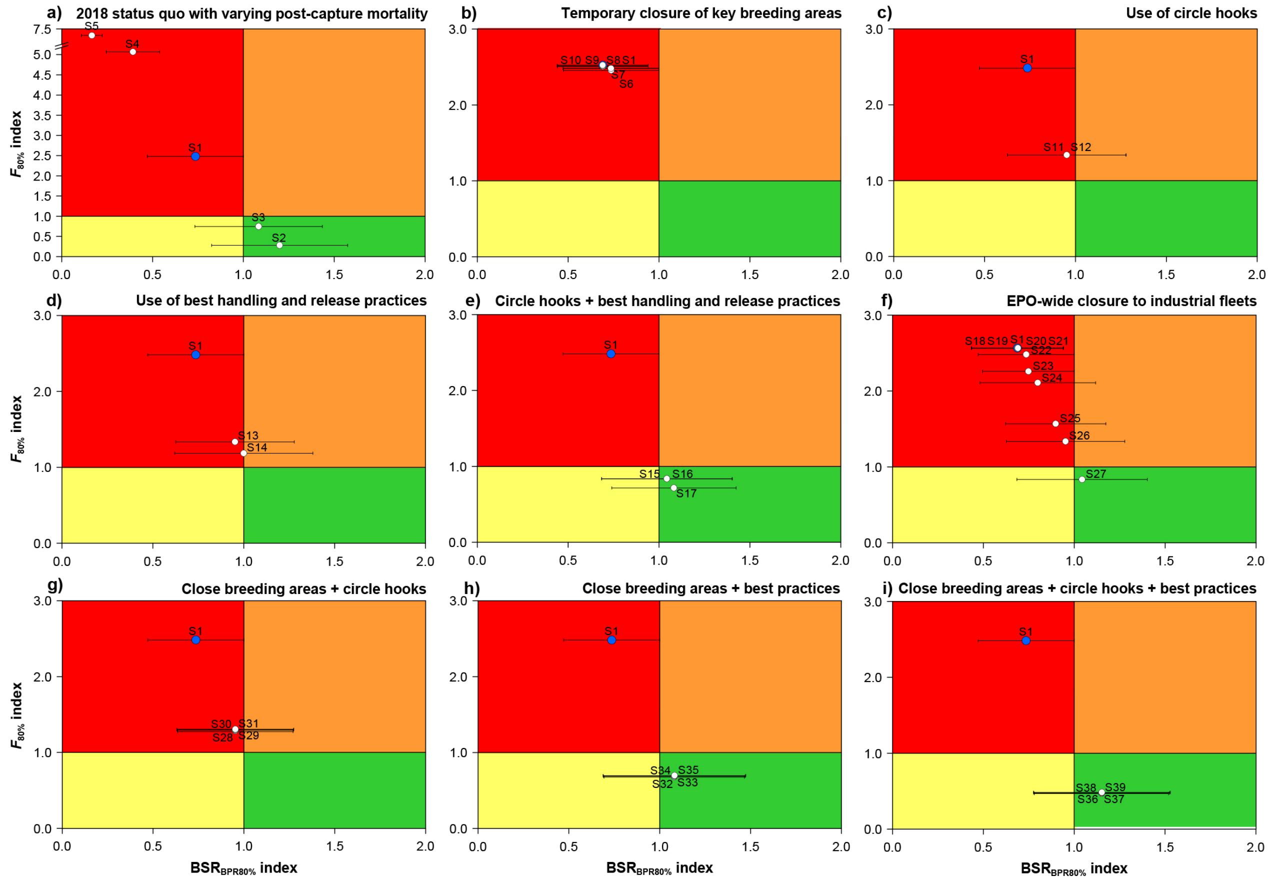

FIGURE 5. Vulnerability phase plots showing the vulnerability status of the East Pacific leatherback turtle (*Dermochelys coriacea*) stock estimated by EASI-Fish with respect to EPO industrial and artisanal pelagic fisheries represented by the mean (± 95% CI) biological reference points $\hat{F}_{2018}/F_{80\%}$ and $BSR_{2018}/BSR_{80\%}$ for each hypothetical scenario. Note the blue symbol labelled "S1" in each plot shows the vulnerability status under the assumed *status quo* fishing effort and management scenario in 2018 to allow comparisons with other scenarios. Labels adjacent to symbols denote the scenario detailed in Table 2. Status values for each of the 39 scenarios are provided in Table 5**.**

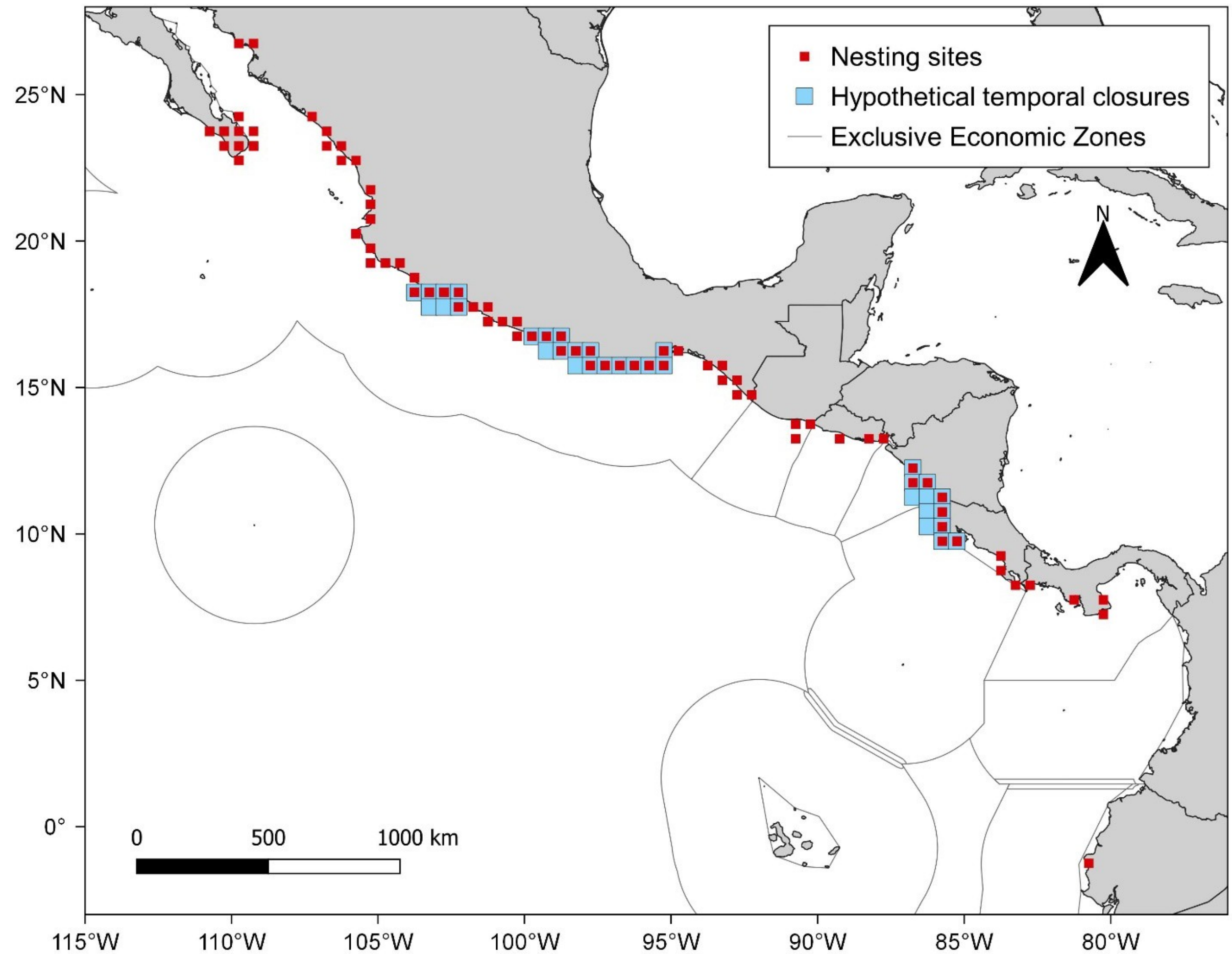

FIGURE 6. Map showing nesting sites (red squares) for the East Pacific leatherback turtle stock (data source: La Red de la Conservación de la Tortuga Laúd del Océano Pacífico Oriental (Laúd OPO Network, 2020), State of the World's Sea Turtles (http://seamap.env.duke.edu/swot), and IAC Annual Report (http://www.iacseaturtle.org/informes-eng.htm) and the 0.5° x 0.5° grids adjacent to important breeding areas that were closed to fishing (light blue) for various durations under hypothetical scenarios.

TABLE 1. Data sources and period of coverage of fishing effort data used to define the spatial distribution of effort by each fishery in the EPO. Data sources with an asterisk (*) contained fishing effort distribution maps that were manually geo-referenced and the locations of each fishing event attributed to an appropriate grid cell to indicate presence of fishing.

Fishery	Country	Year	Data resolution	Comments and data source
Industrial fisheries				
Longline	IATTC Convention Area	2018	Monthly aggregates of number of hooks deployed at 5°x5° resolution.	Unpublished data from logbooks and national observer programs submitted to the IATTC.
	Mexico (Pacific Ocean and Gulf of California)	2006–2009; 2006–2013; 2009–2012; 2018	Positional set data downscaled to 5°x5° resolution to enable incorporation with LSTLFVs.	Castillo-Geniz et al. (2016)*; Castillo-Geniz et al. (2017)*; Carreón-Zapiain et al. (2018)*; Pacific Large Pelagics Program, INAPESCA*.
	Mexico (Central Pacific coast)	2003–2011	Positional set data downscaled to 5°x5° resolution to enable incorporation with LSTLFVs.	Hernández and Valdez Flores (2016)*
Purse-seine (Class 6 - all set types)	IATTC Convention Area	2018	Positional set data downscaled to 0.5°x0.5° resolution.	Unpublished data collected by the AIDCP and National observer programs and held by the IATTC.
Purse-seine (Class 1–5 - all set types)	IATTC Convention Area	2018	Positional set data downscaled to 0.5°x0.5° resolution.	Unpublished data collected by TUNACONS observer program and IATTC staff at landing ports (logbooks).
Artisanal fisheries				
Surface-set gillnet	Chile (Northern and Central)	2016	Positional set data downscaled to 0.5°x0.5° resolution.	Martínez et al. (2017)*
	Guatemala, El Salvador, Nicaragua, Costa Rica, Panama	2018	Positions of access and unloading points allocated to adjacent 0.5°x0.5° grid cells	Oliveros-Ramos et al. (2019)
	Mexico (Northwestern Gulf of California)	1998–1999	Positions of fishing camps allocated to adjacent 0.5°x0.5° grid cells	Smith et al. (2009)*
	Mexico (Southwestern Gulf of California)	1998–1999	Positions of fishing camps allocated to adjacent 0.5°x0.5° grid cells	Bizzarro et al. (2009a)*
	Mexico (Northeastern Gulf of California)	1998–1999	Positions of fishing camps allocated to adjacent 0.5°x0.5° grid cells	Bizzarro et al. (2009b)*
	Mexico, Panama	2017–2018	Positions of fishing ports allocated to adjacent 0.5°x0.5° grid cells	Ortíz-Álvarez et al. (2020)
	Nicaragua, Costa Rica, Colombia	2016–2017	Positions of fishing ports allocated to adjacent 0.5°x0.5° grid cells	Ortíz-Álvarez et al. (2020)
	Peru and Chile	2005–2007;	Positional set data downscaled to 0.5°x0.5° resolution.	Alfaro-Shigueto et al. (2011)*
	Peru	2007	Positional set data downscaled to 0.5°x0.5° resolution.	Ayala et al. (2008)*
Surface-set longline	Chile (Northern and Central)	2001–2005; 2016	Positional set data downscaled to 0.5°x0.5° resolution.	Donoso and Dutton (2010); Martínez et al. (2017)*
	Chile (Southern)	2002	Positional set data downscaled to 1°x1° resolution.	Moreno et al. (2006)*
	Chile and Peru	2005–2010	Annual aggregates of number of sets at 1°x1° resolution.	Doherty et al. (2014)*
	Ecuador	2008–2012	Positional set data downscaled to 0.5°x0.5° resolution.	Martínez-Ortiz et al. (2015)*
	Ecuador, Panama, Costa Rica	2004–2010	Annual aggregates of number of sets at 1°x1° resolution.	Andraka et al. (2013)*
	Guatemala, El Salvador, Nicaragua, Costa Rica, Panama	2018	Positions of access and unloading points allocated to adjacent 0.5°x0.5° grid cells	Oliveros-Ramos et al. (2019)
	Mexico (Western Sea of Cortez)	1998–1999	Positions of fishing camps allocated to adjacent 0.5°x0.5° grid cells	Bizzarro et al. (2009a)*
	Mexico (Northeastern Gulf of California)	1998–1999	Positions of fishing camps allocated to adjacent 0.5°x0.5° grid cells	Bizzarro et al. (2009b)*
	Mexico, Panama	2017–2018	Positions of fishing ports allocated to adjacent 0.5°x0.5° grid cells	Ortíz-Álvarez et al. (2020)
	Nicaragua, Costa Rica, Colombia	2016–2017	Positions of fishing ports allocated to adjacent 0.5°x0.5° grid cells	Ortíz-Álvarez et al. (2020)
	Peru	2004–2006; 2007	Positional set data downscaled to 0.5°x0.5° resolution.	Ayala et al. (2008)*; Alfaro-Shigueto et al. (2011)*
Egg collection	Costa Rica	1995–2006	Nest positions allocated to adjacent 0.5°x0.5° grid cells	La Red de la Conservación de la Tortuga Laúd del Océano Pacífico Oriental; Troëng et al. (2007)*
	Mexico	1982–2004	Nest positions allocated to adjacent 0.5°x0.5° grid cells	La Red de la Conservación de la Tortuga Laúd del Océano Pacífico Oriental; Sarti Martínez et al. (2007)*

TABLE 2. Susceptibility parameter values (see Eq. 1) for the 39 hypothetical scenarios implemented in the EASI-Fish vulnerability assessment of the East Pacific stock of leatherback turtles (*Dermochelys coriacea*) with regards to fishing impacts by EPO pelagic fisheries in 2018. All parameter values were fixed in the model except for P_{xj}, which were allowed to vary following a triangular (^{T}) or uniform (^{U}) distribution between the values shown in parentheses.

		Industrial longline						Purse-seine - Class 6 (DEL)						Purse-seine - Class 6 (NOA)					
Scenario description	**Scenario**	G_x/G	D_x	A_{xj}	E_{xj}	C_{xj}	P_{xj}	G_x/G	D_x	A_{xj}	E_{xj}	C_{xj}	P_{xj}	G_x/G	D_x	A_{xj}	E_{xj}	C_{xj}	P_{xj}
2018 *Status quo*																			
72 d PS EPO closure; L_c=40 cm	**S1**	0.873	1.000	1.000	1.000	1.000	0.40 (0.20–0.60)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
72 d PS EPO closure; L_c=40 cm	**S2**	0.873	1.000	1.000	1.000	1.000	0.10 (0.05–0.20)^{T}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{T}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{T}
72 d PS EPO closure; L_c=40 cm	**S3**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.01 (0.005–0.05)^{T}	0.070	0.807	1.000	1.000	1.000	0.01 (0.005–0.05)^{T}
72 d PS EPO closure; L_c=40 cm	**S4**	0.873	1.000	1.000	1.000	1.000	0.60 (0.40–0.80)^{T}	0.157	0.807	1.000	1.000	1.000	0.10 (0.05–0.20)^{T}	0.070	0.807	1.000	1.000	1.000	0.10 (0.05–0.20)^{T}
72 d PS EPO closure; L_c=40 cm	**S5**	0.873	1.000	1.000	1.000	1.000	0.80 (0.75–0.95)^{T}	0.157	0.807	1.000	1.000	1.000	0.15 (0.20–0.30)^{T}	0.070	0.807	1.000	1.000	1.000	0.15 (0.20–0.30)^{T}
Closure of waters adjacent to key nesting sites																			
60 d nesting area closure (NAC); using S1 conditions	**S6**	0.873	1.000	1.000	1.000	1.000	0.40 (0.20–0.60)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
90 d nesting area closure (NAC); using S1 conditions	**S7**	0.873	1.000	1.000	1.000	1.000	0.40 (0.20–0.60)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
120 d nesting area closure (NAC); using S1 conditions	**S8**	0.873	1.000	1.000	1.000	1.000	0.40 (0.20–0.60)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
180 d nesting area closure (NAC); using S1 conditions	**S9**	0.873	1.000	1.000	1.000	1.000	0.40 (0.20–0.60)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
270 d nesting area closure (NAC); using S1 conditions	**S10**	0.873	1.000	1.000	1.000	1.000	0.40 (0.20–0.60)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
50% Reduction in PCM by use of circle hooks (CIRC) for longline																			
S1 conditions; reduce **PCM** for industrial longline fleet	**S11**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
S1 conditions; reduce **PCM** for all longline fleets	**S12**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
Use of best handling and release practices (BHRP)																			
S1 conditions; reduce **PCM** for all industrial fleets	**S13**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}
S1 conditions; reduce **PCM** for all fleets	**S14**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}
Use of circle hooks + best handling and release practices																			
S1 conditions; reduce **PCM** for industrial longline fleet	**S15**	0.873	1.000	1.000	1.000	1.000	0.10 (0.05–0.15)^{U}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
S1 conditions; reduce **PCM** for all longline fleets	**S16**	0.873	1.000	1.000	1.000	1.000	0.10 (0.05–0.15)^{U}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
S1 conditions; reduce **PCM** for all fleets	**S17**	0.873	1.000	1.000	1.000	1.000	0.10 (0.05–0.15)^{U}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}
EPO-wide closure of purse seine fisheries only																			
60 d EPO closure; S1 conditions	**S18**	0.873	1.000	1.000	1.000	1.000	0.40 (0.20–0.60)^{T}	0.157	0.250	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.250	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
90 d EPO closure; S1 conditions	**S19**	0.873	1.000	1.000	1.000	1.000	0.40 (0.20–0.60)^{T}	0.157	0.500	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.500	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
120 d EPO closure; S1 conditions	**S20**	0.873	1.000	1.000	1.000	1.000	0.40 (0.20–0.60)^{T}	0.157	0.667	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.667	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
180 d EPO closure; S1 conditions	**S21**	0.873	1.000	1.000	1.000	1.000	0.40 (0.20–0.60)^{T}	0.157	0.750	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.750	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
270 d EPO closure; S1 conditions	**S22**	0.873	1.000	1.000	1.000	1.000	0.40 (0.20–0.60)^{T}	0.157	0.833	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.833	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
EPO-wide closure of all industrial fisheries																			
60 d EPO closure; S1 conditions	**S23**	0.873	0.250	0.250	0.250	0.250	0.40 (0.20–0.60)^{T}	0.157	0.250	0.250	0.250	0.250	0.05 (0.005–0.15)^{T}	0.070	0.250	0.250	0.250	0.250	0.05 (0.005–0.15)^{T}
90 d EPO closure; S1 conditions	**S24**	0.873	0.500	0.500	0.500	0.500	0.40 (0.20–0.60)^{T}	0.157	0.500	0.500	0.500	0.500	0.05 (0.005–0.15)^{T}	0.070	0.500	0.500	0.500	0.500	0.05 (0.005–0.15)^{T}
120 d EPO closure; S1 conditions	**S25**	0.873	0.667	0.667	0.667	0.667	0.40 (0.20–0.60)^{T}	0.157	0.667	0.667	0.667	0.667	0.05 (0.005–0.15)^{T}	0.070	0.667	0.667	0.667	0.667	0.05 (0.005–0.15)^{T}
180 d EPO closure; S1 conditions	**S26**	0.873	0.750	0.750	0.750	0.750	0.40 (0.20–0.60)^{T}	0.157	0.750	0.750	0.750	0.750	0.05 (0.005–0.15)^{T}	0.070	0.750	0.750	0.750	0.750	0.05 (0.005–0.15)^{T}
270 d EPO closure; S1 conditions	**S27**	0.873	0.833	0.833	0.833	0.833	0.40 (0.20–0.60)^{T}	0.157	0.833	0.833	0.833	0.833	0.05 (0.005–0.15)^{T}	0.070	0.833	0.833	0.833	0.833	0.05 (0.005–0.15)^{T}
Combination strategies - NAC + CIRC																			
60 d **NAC** + **CIRC** in longline fleets (Scenarios S6+S16)	**S28**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
90 d **NAC** + **CIRC** in longline fleets (S7+S16)	**S29**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
120 d **NAC** + **CIRC** in longline fleets (S8+S16)	**S30**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
180 d **NAC** + **CIRC** in longline fleets (S9+S16)	**S31**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	0.070	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}
Combination strategies - NAC + BHRP																			
60 d **NAC** + **BHRP** all fleets (S6+S14)	**S32**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}
90 d **NAC** + **BHRP** all fleets (S7+S14)	**S33**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}
120 d **NAC** + **BHRP** all fleets (S8+S14)	**S34**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}
180 d **NAC** + **BHRP** all fleets (S9+S14)	**S35**	0.873	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}
Combination strategies - NAC + BHRP + CIRC																			
60 d **NAC** + **BHRP** all fleets + **CIRC** in longline fleets (S6+S14+S16)	**S36**	0.873	1.000	1.000	1.000	1.000	0.10 (0.05–0.15)^{U}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}
90 d **NAC** + **BHRP** all fleets + **CIRC** in longline fleets (S7+S14+S16)	**S37**	0.873	1.000	1.000	1.000	1.000	0.10 (0.05–0.15)^{U}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}
120 d **NAC** + **BHRP** all fleets + **CIRC** in longline fleets (S8+S14+S16)	**S38**	0.873	1.000	1.000	1.000	1.000	0.10 (0.05–0.15)^{U}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}
180 d **NAC** + **BHRP** all fleets + **CIRC** in longline fleets (S9+S14+S16)	**S39**	0.873	1.000	1.000	1.000	1.000	0.10 (0.05–0.15)^{U}	0.157	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}	0.070	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)^{U}

Table 2 continued.

	Purse-seine - Class 6 (OBJ)						Purse-seine - Class 1-5 (NOA)						Purse-seine - Class 1-5 (OBJ)					
Scenario	G_x/G	D_x	A_{xj}	E_{xj}	C_{xj}	P_{xj}	G_x/G	D_x	A_{xj}	E_{xj}	C_{xj}	P_{xj}	G_x/G	D_x	A_{xj}	E_{xj}	C_{xj}	P_{xj}
S1	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S2	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[T]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[T]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[T]
S3	0.263	0.807	1.000	1.000	1.000	0.01 (0.005–0.05)[T]	0.012	0.807	1.000	1.000	1.000	0.01 (0.005–0.05)[T]	0.049	0.807	1.000	1.000	1.000	0.01 (0.005–0.05)[T]
S4	0.263	0.807	1.000	1.000	1.000	0.10 (0.05–0.20)[T]	0.012	0.807	1.000	1.000	1.000	0.10 (0.05–0.20)[T]	0.049	0.807	1.000	1.000	1.000	0.10 (0.05–0.20)[T]
S5	0.263	0.807	1.000	1.000	1.000	0.15 (0.20–0.30)[T]	0.012	0.807	1.000	1.000	1.000	0.15 (0.20–0.30)[T]	0.049	0.807	1.000	1.000	1.000	0.15 (0.20–0.30)[T]
S6	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S7	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S8	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S9	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S10	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S11	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S12	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S13	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]
S14	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]
S15	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S16	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S17	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]
S18	0.263	0.250	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.250	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.250	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S19	0.263	0.500	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.500	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.500	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S20	0.263	0.667	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.667	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.667	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S21	0.263	0.750	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.750	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.750	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S22	0.263	0.833	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.833	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.833	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S23	0.263	0.250	0.250	0.250	0.250	0.05 (0.005–0.15)[T]	0.012	0.250	0.250	0.250	0.250	0.05 (0.005–0.15)[T]	0.049	0.250	0.250	0.250	0.250	0.05 (0.005–0.15)[T]
S24	0.263	0.500	0.500	0.500	0.500	0.05 (0.005–0.15)[T]	0.012	0.500	0.500	0.500	0.500	0.05 (0.005–0.15)[T]	0.049	0.500	0.500	0.500	0.500	0.05 (0.005–0.15)[T]
S25	0.263	0.667	0.667	0.667	0.667	0.05 (0.005–0.15)[T]	0.012	0.667	0.667	0.667	0.667	0.05 (0.005–0.15)[T]	0.049	0.667	0.667	0.667	0.667	0.05 (0.005–0.15)[T]
S26	0.263	0.750	0.750	0.750	0.750	0.05 (0.005–0.15)[T]	0.012	0.750	0.750	0.750	0.750	0.05 (0.005–0.15)[T]	0.049	0.750	0.750	0.750	0.750	0.05 (0.005–0.15)[T]
S27	0.263	0.833	0.833	0.833	0.833	0.05 (0.005–0.15)[T]	0.012	0.833	0.833	0.833	0.833	0.05 (0.005–0.15)[T]	0.049	0.833	0.833	0.833	0.833	0.05 (0.005–0.15)[T]
S28	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S29	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S30	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S31	0.263	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.012	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]	0.049	0.807	1.000	1.000	1.000	0.05 (0.005–0.15)[T]
S32	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]
S33	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]
S34	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]
S35	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]
S36	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]
S37	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]
S38	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]
S39	0.263	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.012	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]	0.049	0.807	1.000	1.000	1.000	0.005 (0.001–0.01)[U]

Table 2 continued.

	Artisanal gillnet						Artisanal longline						Egg collection					
Scenario	G_x/G	D_x	A_{xj}	E_{xj}	C_{xj}	P_{xj}	G_x/G	D_x	A_{xj}	E_{xj}	C_{xj}	P_{xj}	G_x/G	D_x	A_{xj}	E_{xj}	C_{xj}	P_{xj}
S1	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	1.000	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S2	0.027	1.000	1.000	1.000	1.000	0.10 (0.05–0.20)^{T}	0.149	1.000	1.000	1.000	1.000	0.05 (0.005–0.15)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S3	0.027	1.000	1.000	1.000	1.000	0.20 (0.10–0.30)^{T}	0.149	1.000	1.000	1.000	1.000	0.10 (0.05–0.20)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S4	0.027	1.000	1.000	1.000	1.000	0.60 (0.40–0.80)^{T}	0.149	1.000	1.000	1.000	1.000	0.40 (0.15–0.50)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S5	0.027	1.000	1.000	1.000	1.000	0.80 (0.75–0.95)^{T}	0.149	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S6	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	0.892	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S7	0.027	0.917	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	0.917	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S8	0.027	0.942	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	0.942	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S9	0.027	0.950	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	0.950	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S10	0.027	0.958	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	0.958	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S11	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	1.000	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S12	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	1.000	1.000	1.000	1.000	0.125 (0.05–0.20)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S13	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	1.000	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S14	0.027	1.000	1.000	1.000	1.000	0.40 (0.16–0.48)^{T}	0.149	1.000	1.000	1.000	1.000	0.125 (0.05–0.20)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S15	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	1.000	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S16	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	1.000	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S17	0.027	1.000	1.000	1.000	1.000	0.40 (0.16–0.48)^{T}	0.149	1.000	1.000	1.000	1.000	0.063 (0.025–0.10)^{U}	1.000	1.000	1.000	0.400	1.000	1.000
S18	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	1.000	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S19	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	1.000	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S20	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	1.000	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S21	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	1.000	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S22	0.027	1.000	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	1.000	1.000	1.000	1.000	0.25 (0.10–0.40)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S23	0.027	1.000	0.250	0.250	0.250	0.50 (0.20–0.60)^{T}	0.149	1.000	0.250	0.250	0.250	0.25 (0.10–0.40)^{T}	1.000	1.000	0.250	0.400	0.250	1.000
S24	0.027	1.000	0.500	0.500	0.500	0.50 (0.20–0.60)^{T}	0.149	1.000	0.500	0.500	0.500	0.25 (0.10–0.40)^{T}	1.000	1.000	0.500	0.400	0.500	1.000
S25	0.027	1.000	0.667	0.667	0.667	0.50 (0.20–0.60)^{T}	0.149	1.000	0.667	0.667	0.667	0.25 (0.10–0.40)^{T}	1.000	1.000	0.667	0.400	0.667	1.000
S26	0.027	1.000	0.750	0.750	0.750	0.50 (0.20–0.60)^{T}	0.149	1.000	0.750	0.750	0.750	0.25 (0.10–0.40)^{T}	1.000	1.000	0.750	0.400	0.750	1.000
S27	0.027	1.000	0.833	0.833	0.833	0.50 (0.20–0.60)^{T}	0.149	1.000	0.833	0.833	0.833	0.25 (0.10–0.40)^{T}	1.000	1.000	0.833	0.400	0.833	1.000
S28	0.027	0.917	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	0.917	1.000	1.000	1.000	0.125 (0.05–0.20)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S29	0.027	0.942	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	0.942	1.000	1.000	1.000	0.125 (0.05–0.20)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S30	0.027	0.950	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	0.950	1.000	1.000	1.000	0.125 (0.05–0.20)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S31	0.027	0.958	1.000	1.000	1.000	0.50 (0.20–0.60)^{T}	0.149	0.958	1.000	1.000	1.000	0.125 (0.05–0.20)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S32	0.027	0.917	1.000	1.000	1.000	0.40 (0.16–0.48)^{T}	0.149	0.917	1.000	1.000	1.000	0.125 (0.05–0.20)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S33	0.027	0.942	1.000	1.000	1.000	0.40 (0.16–0.48)^{T}	0.149	0.942	1.000	1.000	1.000	0.125 (0.05–0.20)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S34	0.027	0.950	1.000	1.000	1.000	0.40 (0.16–0.48)^{T}	0.149	0.950	1.000	1.000	1.000	0.125 (0.05–0.20)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S35	0.027	0.958	1.000	1.000	1.000	0.40 (0.16–0.48)^{T}	0.149	0.958	1.000	1.000	1.000	0.125 (0.05–0.20)^{T}	1.000	1.000	1.000	0.400	1.000	1.000
S36	0.027	0.917	1.000	1.000	1.000	0.40 (0.16–0.48)^{T}	0.149	0.917	1.000	1.000	1.000	0.063 (0.025–0.10)^{U}	1.000	1.000	1.000	0.400	1.000	1.000
S37	0.027	0.942	1.000	1.000	1.000	0.40 (0.16–0.48)^{T}	0.149	0.942	1.000	1.000	1.000	0.063 (0.025–0.10)^{U}	1.000	1.000	1.000	0.400	1.000	1.000
S38	0.027	0.950	1.000	1.000	1.000	0.40 (0.16–0.48)^{T}	0.149	0.950	1.000	1.000	1.000	0.063 (0.025–0.10)^{U}	1.000	1.000	1.000	0.400	1.000	1.000
S39	0.027	0.958	1.000	1.000	1.000	0.40 (0.16–0.48)^{T}	0.149	0.958	1.000	1.000	1.000	0.063 (0.025–0.10)^{U}	1.000	1.000	1.000	0.400	1.000	1.000

TABLE 3. Biological parameters and their data sources for the East Pacific leatherback turtle (*Dermochelys coriacea*) stock used in the EASI-Fish model.

	t_{max} (yrs)	L_{inf} (yr^{-1})	K (yr^{-1})	Length-weight a	Length-weight b	L_{50} (cm)	M (yr^{-1})
Parameter value(s)	48	147.6	0.286	0.0214	2.86	129.7	0.295–0.937
Data source	Jones et al. (2011)	Zug and Parham (1996)	Zug and Parham (1996)	Jones et al. (2011)	Jones et al. (2011)	Avens et al. (2020)	Santidrián Tomillo et al. (2017); Laúd OPO Network (2020)

TABLE 4. Justifications and assumptions for the use of parameter values (see Table 2) in the *status quo* scenario describing the susceptibility of capture of leatherback turtles (*Dermochelys coriacea*) in the nine fisheries included in the EASI-Fish assessment for the eastern Pacific Ocean stock in 2018.

Fishery	Resolution of grid cells for (G_x)	Fishing season duration (D_x)	Seasonal availability (A_{xj})	Encounterability (E_{xj})	Contact selectivity (C_{xj})	Post-release mortality (PCM) (P_{xj})
Industrial longline	5°x5°	Fishery open year-round	Species available year-round	Deep sets assumed to fish 0-300 m. Species primarily inhabits 0-58 m (Shillinger et al., 2011)	In absence of selectivity ogive for EPO longline fleet, US observer length-frequency data from the Pacific Ocean used to assume knife-edge selectivity from 40 cm (Swimmer et al., 2017).	Leatherback turtle post-release mortality estimates available for the US longline fleet and summarized for industrial longlines in other parts of the world (Ryder et al., 2006; Swimmer and Gilman, 2012). Reductions in leatherback bycatch from use of circle hooks (and fish bait) area available for the US longline fleet (Swimmer et al., 2017). Mean mortality assumed was 0.4 but allowed to vary within a triangular distribution between 0.2–0.6. Assumed these estimates were valid for the entire EPO longline fleet.
Purse-seine Class 6 (DEL)	0.5°x0.5°	72-d closure	Species available year-round	DEL sets assumed to fish 0-200 m. Species primarily inhabits 0-58 m (Shillinger et al., 2011).	In absence of selectivity ogive for Class 6 purse-seine vessels in the EPO, assumed knife-edge selectivity from 32 cm, being the smallest leatherback turtle recorded by observers to be captured by Class 6 vessels in the EPO (Unpublished IATTC observer data).	There is currently no estimate for the post-release mortality estimates for leatherback turtles caught in purse-seine dolphin sets. However, given short set/retrieval time, the IATTC Resolution C-19-04 mandate of use of best handling and release practices, and near 100% observer coverage on Class 6 vessels, there is strong evidence for very high survival rate. Therefore, PCM assumed to be 0.01 but allowed to vary within a triangular distribution between 0.001–0.05.
Purse-seine Class 6 (NOA)	0.5°x0.5°	72-d closure	Species available year-round	NOA sets assumed to fish 0-200 m. Species primarily inhabits 0-58 m (Shillinger et al., 2011).	In absence of selectivity ogive for Class 6 purse-seine vessels in the EPO, assumed knife-edge selectivity from 32 cm, being the smallest leatherback turtle recorded by observers to be captured by Class 6 vessels in the EPO (Unpublished IATTC observer data).	There is currently no estimate for the post-release mortality estimates for leatherback turtles caught in purse-seine unassociated sets. However, given short set/retrieval time, the IATTC Resolution C-19-04 mandate of use of best handling and release practices, and near 100% observer coverage on Class 6 vessels, there is strong evidence for very high survival rate. Therefore, PCM assumed to be 0.01 but allowed to vary within a triangular distribution between 0.001–0.05.
Purse-seine Class 6 (OBJ)	0.5°x0.5°	72-d closure	Species available year-round	OBJ sets assumed to fish 0-200 m. Species primarily inhabits 0-58 m (Shillinger et al., 2011).	In absence of selectivity ogive for Class 6 purse-seine vessels in the EPO, assumed knife-edge selectivity from 32 cm, being the smallest leatherback turtle recorded by observers to be captured by Class 6 vessels in the EPO (Unpublished IATTC observer data).	There is currently no estimate for the post-release mortality estimates for leatherback turtles caught in purse-seine floating object sets. However, given short set/retrieval time, the IATTC Resolution C-19-04 mandate of use of best handling and release practices, and near 100% observer coverage on Class 6 vessels, there is strong evidence for very high survival rate. Therefore, PCM assumed to be 0.01 but allowed to vary within a triangular distribution between 0.001–0.05.
Purse-seine Classes 1–5 (NOA)	0.5°x0.5°	72-d closure	Species available year-round	NOA sets assumed to fish 0-200 m. Species primarily inhabits 0-58 m (Shillinger et al., 2011).	In absence of selectivity ogive for Classes 1–5 purse-seine vessels in the EPO, assumed knife-edge selectivity from 32 cm as per Class 6 vessels in the EPO.	There is an absence of detailed operational and catch information from Class 1–5 purse-seine vessels in the EPO due to a lack of onboard observers. Although these vessels use smaller nets than Class 6 vessels, it was assumed PCM of leatherback turtles was the same as for Class 6 vessels conducting unassociated sets.
Purse-seine Classes 1–5 (OBJ)	0.5°x0.5°	72-d closure	Species available year-round	OBJ sets assumed to fish 0-200 m. Species primarily inhabits 0-58 m (Shillinger et al., 2011).	In absence of selectivity ogive for Classes 1–6 purse-seine vessels in the EPO, assumed knife-edge selectivity from 32 cm as per Class 6 vessels in the EPO.	There is an absence of detailed operational and catch information from Class 1–5 purse-seine vessels in the EPO due to a lack of onboard observers. Although these vessels use smaller nets than Class 6 vessels, it was assumed PCM of leatherback turtles was the same as for Class 6 vessels conducting sets on floating objects.

Table 4 continued

Artisanal gillnet	0.5°x0.5°	Fishery open year-round	Species available year-round	Gillnets assumed to fish 0–42 fathoms (0–82 m) (Martínez et al., 2017). Species primarily inhabits 0-58 m (Shillinger et al., 2011)	In absence of selectivity ogive for EPO artisanal gillnet fleets assumed knife-edge selectivity from 40 cm (Swimmer et al., 2017).	There is little available catch information from artisanal gillnet vessels in the EPO due to a lack of onboard observers. However, available information indicates relatively high at-vessel mortality due to turtles becoming entangled and unable to surface to breathe (Alfaro-Shigueto et al., 2011). Therefore, it was assumed PCM would be slightly higher than longlines, being 50%, but allowed to vary within a triangular distribution between 20–60%.
Artisanal longline	1°x1°	Fishery open year-round	Species available year-round	Surface sets assumed to fish 0-50 m (see Andraka et al., 2013). Species primarily inhabits 0-58 m (Shillinger et al., 2011)	In absence of selectivity ogive for EPO artisanal longline fleets, the same assumption made as for the US longline fleet in the Pacific Ocean where length at first capture is 40 cm (Swimmer et al., 2017).	There is little available catch information from artisanal longline vessels in the EPO due to a general lack of onboard observers. However, available information indicates lower interaction rates and at-vessel mortality between leatherbacks and artisanal longlines than with gillnets (Alfaro-Shigueto et al., 2011). Although these vessels use shorter mainlines and deploy fewer hooks per set than LSTLFVs, they fish in more coastal areas where leatherback turtles are more abundant. Therefore, it was assumed PCM would be slightly higher than for LSTLFVs, being 25%, but allowed to vary within a triangular distribution between 10–40%.
Egg collection	0.5°x0.5°	Fishery operates only during nesting season (Oct–Mar)	Nesting on EPO beaches occurs during Oct–Mar.	Precautionarily assumed 4% of all nests encountered (Santidrián Tomillo et al., 2008)	In absence of extraction efficiency of leatherback turtle eggs from nests, assumed all size classes smaller than the average size of a hatchling (5 cm) (Santidrián Tomillo et al., 2017) are extracted.	Assumed all eggs are consumed and that no eggs are hatched and no hatchlings are released back into the wild.

TABLE 5. Estimated mean values for proxy fishing mortality ($\hat{F}_{2018}$), breeding stock biomass-per-recruit (BSR_{2018}) and biological reference points ($F_{80\%}$ and $BSR_{80\%}$) for the East Pacific leatherback turtle stock in 2018 under hypothetical conservation and management measures. Red and green colors indicate scenarios where the stock was classified as "most vulnerable" or "least vulnerable", respectively. Specific model parameter values used in each scenario are shown in Table 2.

Scenario description	Scenario	$\hat{F}_{2018}$	BSR_{2018}	$F_{80\%}$	$BSR_{80\%}$	$\hat{F}_{2018}/F_{80\%}$	$BSR_{2018}/BSR_{80\%}$
2018 *Status quo*							
72 d PS EPO closure; reduce **PCM** in all fleets; L_c=40 cm	**S1**	0.199	0.517	0.080	0.703	2.482	0.736
72 d PS EPO closure; reduce **PCM** in all fleets; L_c=40 cm	**S2**	0.045	0.848	0.160	0.708	0.279	1.199
72 d PS EPO closure; reduce **PCM** in all fleets; L_c=40 cm	**S3**	0.090	0.767	0.120	0.708	0.747	1.084
72 d PS EPO closure; reduce **PCM** in all fleets; L_c=40 cm	**S4**	0.304	0.278	0.060	0.708	5.067	0.392
72 d PS EPO closure; reduce **PCM** in all fleets; L_c=40 cm	**S5**	0.440	0.111	0.060	0.667	7.340	0.166
Closure of waters adjacent to key nesting sites							
60 d nesting area closure (NAC); using S1 conditions	**S6**	0.202	0.080	0.080	0.701	2.525	0.690
90 d nesting area closure (NAC); using S1 conditions	**S7**	0.201	0.080	0.080	0.702	2.516	0.690
120 d nesting area closure (NAC); using S1 conditions	**S8**	0.201	0.080	0.080	0.702	2.507	0.691
180 d nesting area closure (NAC); using S1 conditions	**S9**	0.199	0.080	0.080	0.703	2.482	0.736
270 d nesting area closure (NAC); using S1 conditions	**S10**	0.196	0.080	0.080	0.704	2.456	0.737
Reduction in PCM due to use of circle hooks (CIRC) for longlines							
S1 conditions; reduce **PCM** for industrial longline fleet	**S11**	0.134	0.670	0.100	0.704	1.338	0.952
S1 conditions; reduce **PCM** for all longline fleets	**S12**	0.134	0.670	0.100	0.704	1.338	0.952
Use of best handling and release practices (BHRP)							
S1 conditions; reduce **PCM** for all industrial fleets	**S13**	0.133	0.670	0.100	0.704	1.334	0.952
S1 conditions; reduce **PCM** for all fleets	**S14**	0.119	0.715	0.100	0.715	1.185	1.000
Use of circle hooks + best handling and release practices							
S1 conditions; reduce **PCM** for industrial longline fleet	**S15**	0.100	0.728	0.120	0.698	0.837	1.043
S1 conditions; reduce **PCM** for all longline fleets	**S16**	0.100	0.728	0.120	0.698	0.837	1.043
S1 conditions; reduce **PCM** for all fleets	**S17**	0.086	0.770	0.120	0.711	0.715	1.082
EPO-wide closure of purse seine fisheries only							
60 d EPO closure; S1 conditions	**S18**	0.205	0.481	0.080	0.700	2.568	0.687
90 d EPO closure; S1 conditions	**S19**	0.205	0.481	0.080	0.700	2.567	0.687
120 d EPO closure; S1 conditions	**S20**	0.205	0.481	0.080	0.700	2.567	0.687
180 d EPO closure; S1 conditions	**S21**	0.205	0.481	0.080	0.700	2.566	0.687
270 d EPO closure; S1 conditions	**S22**	0.205	0.481	0.080	0.700	2.564	0.687
EPO-wide closure of purse seine and industrial longline fisheries							
60 d EPO closure; S1 conditions	**S23**	0.181	0.533	0.080	0.713	2.260	0.748
90 d EPO closure; S1 conditions	**S24**	0.169	0.575	0.080	0.719	2.109	0.799
120 d EPO closure; S1 conditions	**S25**	0.157	0.618	0.100	0.688	1.568	0.898
180 d EPO closure; S1 conditions	**S26**	0.134	0.670	0.100	0.704	1.336	0.952
270 d EPO closure; S1 conditions	**S27**	0.100	0.729	0.120	0.698	0.835	1.043
Combination strategies - NAC + CIRC							
60 d **NAC** + **CIRC** in longline fleets (Scenarios S6+S16)	**S28**	0.131	0.672	0.100	0.706	1.306	0.952
90 d **NAC** + **CIRC** in longline fleets (S7+S16)	**S29**	0.130	0.673	0.100	0.706	1.300	0.953
120 d **NAC** + **CIRC** in longline fleets (S8+S16)	**S30**	0.129	0.673	0.100	0.707	1.294	0.953
180 d **NAC** + **CIRC** in longline fleets (S9+S16)	**S31**	0.128	0.675	0.100	0.708	1.275	0.953
Combination strategies - NAC + BHRP							
60 d **NAC** + **BHRP** all fleets (S6+S14)	**S32**	0.083	0.771	0.120	0.714	0.696	1.081
90 d **NAC** + **BHRP** all fleets (S7+S14)	**S33**	0.083	0.772	0.120	0.714	0.692	1.081
120 d **NAC** + **BHRP** all fleets (S8+S14)	**S34**	0.083	0.772	0.120	0.714	0.688	1.080
180 d **NAC** + **BHRP** all fleets (S9+S14)	**S35**	0.081	0.773	0.120	0.716	0.676	1.080
Combination strategies - NAC + BHRP + CIRC							
60 d **NAC** + **BHRP** all fleets + **CIRC** in longline fleets (S6+S14+S16)	**S36**	0.068	0.810	0.140	0.703	0.484	1.152
90 d **NAC** + **BHRP** all fleets + **CIRC** in longline fleets (S7+S14+S16)	**S37**	0.067	0.811	0.140	0.704	0.480	1.152
120 d **NAC** + **BHRP** all fleets + **CIRC** in longline fleets (S8+S14+S16)	**S38**	0.067	0.811	0.140	0.704	0.477	1.151
180 d **NAC** + **BHRP** all fleets + **CIRC** in longline fleets (S9+S14+S16)	**S39**	0.065	0.812	0.140	0.706	0.467	1.150

d = days; EPO = eastern Pacific Ocean; PCM = post-capture mortality, L_c = curved carapace length at first capture