DOCTOR OF PHILOSOPHY

No-take or no way: The case for a no-take policy along the Cocos-Galapagos Swimway
Critical analysis of published works

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No-take or no way: The case for a no-take policy along the Cocos-Galapagos Swimway.

Critical analysis of Published Works

Submission by Randall Arauz
For the degree of Doctor of Philosophy (Published Works)
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‘I hereby declare that this thesis is the results of my own investigations, except where otherwise stated. All other sources are acknowledged by bibliographic references. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree unless, as agreed by the University, for approved dual awards.

I confirm that I am submitting this work with the agreement of my Supervisor(s).’

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‘Yr wfy drwy hyn yn datgan mai canlyniad fy ymchwil fy hun yw’r thesis hwn, ac eithrio lle nodir yn wahanol. Caiff ffynonellau eraill eu cydnabod gan droednodiadau yn rhoi cyfeiriadau eglur. Nid yw sylwedd y Gwaith hwn wedi caei el dderbyn o’r blaen ar gyfer unrhyw radd, ac nic yw’n cael el gyflwyno ar yr un pryd mewn ymgeisliaeth am unrhyw radd oni bai ei fod, fel y cytunwyd gan y Brifysgol, am gymwysterau deuoi cymeradwy.

Rwy’n cadarnhau fy mod yn cyflwyno’r Gwaith hwn gyda chytundeb fy Ngoruchwyliwr (Goruchwylwyr).

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Abstract

Overfishing, fueled by the demand for pelagic fish to supply domestic and international markets, is the main threat to marine biodiversity in the Eastern Tropical Pacific. Fishery-induced mortality has been pointed out as the main cause for the decline of populations of sea turtles and sharks in the region, especially during pelagic longline operations. The collapse of the main regional leatherback sea turtle nesting colonies throughout the 1990s fostered the evaluation of different sea turtle avoidance strategies during longline operations, mainly bait and gear modifications. A migratory corridor was described for Costa Rican post-nesting leatherbacks in 2005, which migrate to the southern gyres along the northeastern flank of the Submerged Cocos Ridge (SCR), a bathymetric feature connecting Cocos Island and the Galapagos Archipelago, thus providing immediate regions where conservation measures can be implemented. Unique independent observer data sets compiled on board Costa Rican longliners from 1999 to 2010, revealed a catch constituted of 62 species, widely dominated by mahimahi, olive ridley sea turtles, and increasingly smaller silky sharks. Field trials testing different sea turtle avoidance strategies (blue dyed bait and circle hooks) either failed to reduce turtle catch, or when they did, they caused higher threatened shark catch rates, particularly vulnerable silky sharks, and critically endangered hammerhead sharks. Generalized linear models (GLMs) of catch rates provide evidence supporting a seasonal closure of the longline fishery from April to October which would benefit sea turtle and shark conservation. Costa Rica, Ecuador, Panama, and Colombia initiated a process in 1978 to provide protection to the oceanic islands of their EEZs, which culminated with the current amalgam of marine protected areas in the Eastern Tropical Pacific, under both no-take and multiple-use regimes. The existence of biological connectivity between Cocos Island, Malpelo Island, and the Galapagos Archipelago, has been confirmed through the movements of critically endangered hammerhead sharks. More recently, the seamounts along the SCR have been identified as biodiversity hotspots, where hammerhead sharks also form large schooling aggregations during the day, using the seamounts as steppingstones as they move towards different aggregation sites, not necessarily in a unidirectional fashion. A no-take policy is recommended in a 40 nm radius surrounding each of the shallow (less than 400 m deep) seamounts of the SCR, as well as in the buffer area in between them to protect hammerhead sharks during their movements from one biodiversity hotspot to another. This network of interconnected seamounts and their proposed 40 nm no-take areas and buffer zones is called the Cocos-Galapagos Swimway (CGS). West Cocos seamount in Costa Rica's portion of the SCR, and Paramount seamount in Ecuador's, are the most important seamounts of the Cocos – Galapagos Swimway in terms of Large Pelagic Species (LPS) richness and abundance. The recent expansion of Cocos Island National Park (CINP) from a 2,000 km^2 no-take marine protected area to 54,844 km^2 is viewed as very positive as it provides strict protection to critical habitats, such as Las Gemelas and West Cocos seamounts. Unfortunately, the design of the surrounding multiple-use 106,285 km^2 Bicentennial Marine Management Area (BMMA) fails to provide the opportunity to safeguard biological connectivity along Costa Rica's portion of the Cocos-Galapagos Swimway, whereas Ecuador's Brotherhood Marine Reserve (BMR) commits the same flaw by not protecting critically important Paramount seamount in its own waters. I hereby discuss management options to be considered during the current process to design the Management Plan for the BMMA and offer two scenarios to the

governments of Costa Rica and Ecuador regarding future expansions of the MPAs and policies that respond, in my view, to these considerations.

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Chapter 1: Eastern Tropical Pacific marine biodiversity under threat.

The Eastern Tropical Pacific (ETP) is one of the twelve marine realms that cover the coastal waters and continental shelves of the world's oceans, covering 28 million km^2 of ocean that extends from the southern tip of the Baja California Peninsula in the north, to northern Peru in the south (Spalding et al, 2007), including international waters, and the territorial waters of 12 nations, as well as several oceanic islands such as the Galapagos Archipelago of Ecuador, the Revillagigedo Islands of Mexico, Clipperton Island of France, Cocos Island of Costa Rica, and Malpelo Island of Colombia. While occupying about 18% of the Pacific Ocean by area, it accounts for 22-23% of its productivity (Pennington et al, 2006).

The region's hydrography is highly dynamic, in space and time, due to the confluence of several marine currents involving subtropical surface water, tropical surface water, and equatorial surface waters (Fielder and Talley, 2006; Jiménez, 2016). Located between the subtropical gyres of the North and South Pacific, it contains the eastern terminus of the equatorial current system (North Equatorial Countercurrent NECC) of the Pacific which flows into the ETP from the west. As the NECC approaches the Central American coastline, a part of it is diverted north, joining the Costa Rican Coastal Current (CRCC), which heads northwest until the coast of Mexico, where it turns west to join the North Equatorial Current (NEC). The cold California Current at the northern limit of the ETP flows south following the North American coastline, to later flow west as it meets the warm North Equatorial Current. The interaction of these three currents, coupled with the influence of the trade winds, is responsible for the creation of the eastern Pacific warm pool that forms half of the western hemisphere warm pool straddling Central America, as well as the Costa Rica Dome (CRD), a large area in front of the coasts of Central America where the upwelling of nutrient-rich subsurface cold water (less than 20°C) occurs in the shape of a bell at a depth of less than 50 m (Kessler, 2006). The breadth of the CRD is constantly expanding, contracting, and displacing itself, depending on the annual cycle and the conditions of each year, from a diameter of 200-300 km during February and March, to up to 1,000 km in August, encompassing the jurisdictional waters of all the Central American nations except Panamá (Brenes et al, 2008 in Jiménez, 2016). The cold Peru Current or Humboldt Current flows north along the coast of Chile and Peru and diverts west in front of the coast of Ecuador joining the South Equatorial Current, forming the Equatorial Cold Tongue. The region is also subject to the anomalous oceanographic conditions known as El Niño-Southern Oscillation (ENSO), characterized by the weakening of the Peru Current and presence of warmer water along the south American coast and the South Equatorial Current (Fiedler and Talley, 2006) (Figure 1).

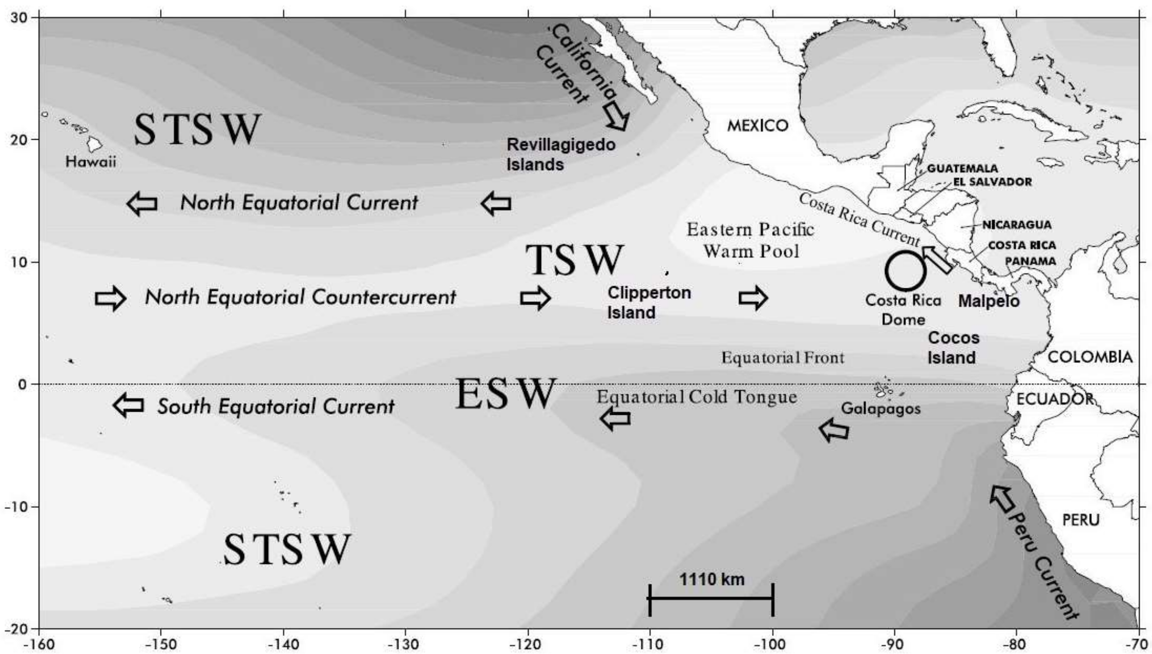

Figure 1. Diagram of surface water masses and currents in the eastern tropical Pacific Ocean. STWS, Subtropical Surface Water; TSW, Tropical Surface Water; ESW, Equatorial Surface Water, including oceanic islands in the Eastern Tropical Pacific. Shading represents mean sea surface temperature (darker = colder, Shea et al., 1992 in Freidler and Tally, 2006; Brenes et al, 2008 in Jiménez, 2016).

These combined conditions, along with the diversity of oceanic and coastal habitats that occur in the region, including oceanic islands, submerged ridges and associated seamounts, coral reefs, large mangrove swamps and estuaries, extensive rocky outcrops, and sandy beaches favor the region's biological productivity and rich biodiversity of highly migratory marine megafauna, particularly sea turtles and sharks.

Sea turtles thrive in these habitats, which serve as developmental, foraging, nesting and inter-nesting habitat for green turtles (Dieseldorff, 2017), hawksbill turtles (*Eretmochelys imbricata*) (Gaos et al, 2010; Liles et al, 2017; Heidemeyer et al, 2014), olive ridley turtles (Plotkin et al, 1996) and leatherback turtles (Shillinger et al, 2010). The massive synchronous nesting of hundreds of thousands of olive ridley sea turtles (*Lepidochelys olivacea*), an event also known as the arribada, occurs at three sites in the region: Ostional and Nancite in Costa Rica (Cornelius, 1986) and Escobilla in Mexico (Marquez et al, 1982). Thousands of leatherback sea turtles (*Dermochelys coriacea*) formerly nested in the region (Spotila et al, 1996), with major nesting activity reported in Playa Grande, Costa Rica (Steyermark et al, 1996) and in Mexiquillo, Tierra Colorada, Cahuitán, and Barra de la Cruz, Mexico (Sarti-Martinez et al, 2007). Green turtles (*Chelonia mydas*) are relatively common in the region, with important nesting beaches in Colola and Maruata (Alvarado and Figueroa, 1986) and Isla Clarion of the Revillagigedo Islands, Mexico (Holroyd and Trefey, 2010), the Galapagos Islands of Ecuador (Seminoff et al, 2008), and Isla San José (Fonseca et al, 2014), Cabuyal (Santidrian et al, 2014) and Nombre de Jesus (Blanco et al, 2012) along the north Pacific coast of Costa Rica.

Certain shark species, such as hammerhead sharks (*Sphyrna* spp) (Zanella et al, 2009; Zanella y López-Garro, 2015; Zanella et al. 2019), and bull sharks (*Carcharhinus leucas*) (Chávez, 2017; De la Llata et al, 2023) also breed in these coastal habitats, with thresher sharks (*Alopias sp*) and silky sharks (*Carcharhinus falciformis*) breeding abundantly along the extensive outer continental shelf (Alejo-Plata et al. 2007; Cartamil et al, 2011). As hammerhead sharks approach adulthood, they move to deeper waters and eventually migrate from coastal reproductive and foraging habitats to oceanic habitats, heading towards oceanic islands and seamounts along submerged mountain ranges or ridges that are associated with “hotspots” of pelagic biodiversity (Worm et al, 2003; Acuña-Marrero et al. 2017), where they may even give birth (Cambra et al, 2021a; Zanella et al, 2016).

This rich biodiversity is currently under threat. Globally, 6 of the 7 existing sea turtle species are catalogued as threatened with extinction (Mazaris et al, 2017), as well as one third of all shark species, most of which are pelagic sharks (Dulvy et al, 2021). Although several anthropogenic threats are implicated in the population declines, overfishing and the lack of efficient controls over the activity by riverine States is widely accepted by the IUCN’s Red List of Threatened Species as the gravest and most immediate.

Overfishing in the ETP is fueled by the demand for pelagic fish to supply domestic and international markets, such as tunas (*Thunnus albacares*, *T obesus*), billfish (Istiophoridae, Xiphiidae), mahimahi (*Coryphaena hippurus*) and sharks (Carcharhinidae, Sphyrnidae, Alopidae), which have been targeted using purse seines (a large wall of netting deployed around an entire area or school of fish with a skiff) since the mid-1950s, and longlines (a 20 km to 150 km monofilament main line from which 800 to 5,000 baited hooks dangle from gangeons or droplines), in use regionally since the early 1980s.

Costa Rica was the gateway for the regional introduction of the longline industry in 1982, through a Cooperative Agreement with the government of Taiwan, and by the late 1980s the country had already consolidated a national longline fleet of 380 “middle scale” vessels (10–20 ton capacity, iced holds, two week autonomy) and 150 “advanced scale” vessels (100-150 ton capacity, freezer holds, 6 month autonomy), which branded itself as a “multi specific” fishery that targets, tuna, billfish, mahimahi and sharks (Porras, 1996 in Arauz, 2002). Furthermore, foreign-flagged advanced scale longline vessels operating in the ETP, but not in the Exclusive Economic Zone (EEZ) of Costa Rica were allowed to perform an average of 150 landings of shark products per year in Costa Rican ports (Arauz, 2002). Fishing pressure on sharks was exacerbated by a fleet of at least 150 Taiwanese flagged longline freezer vessels that operated in the region targeting sharks for their fins (IOC, 2005).

Acknowledging the importance of conserving oceanic island hotspots from the effects of overfishing, Costa Rica, Ecuador, Colombia, and Panama initiated processes since 1978 to create marine protected areas at these sites, under either multiple-use or no-take regimes, that culminated in 2022 with the current amalgam of marine protected areas in the ETP (Figure 2).

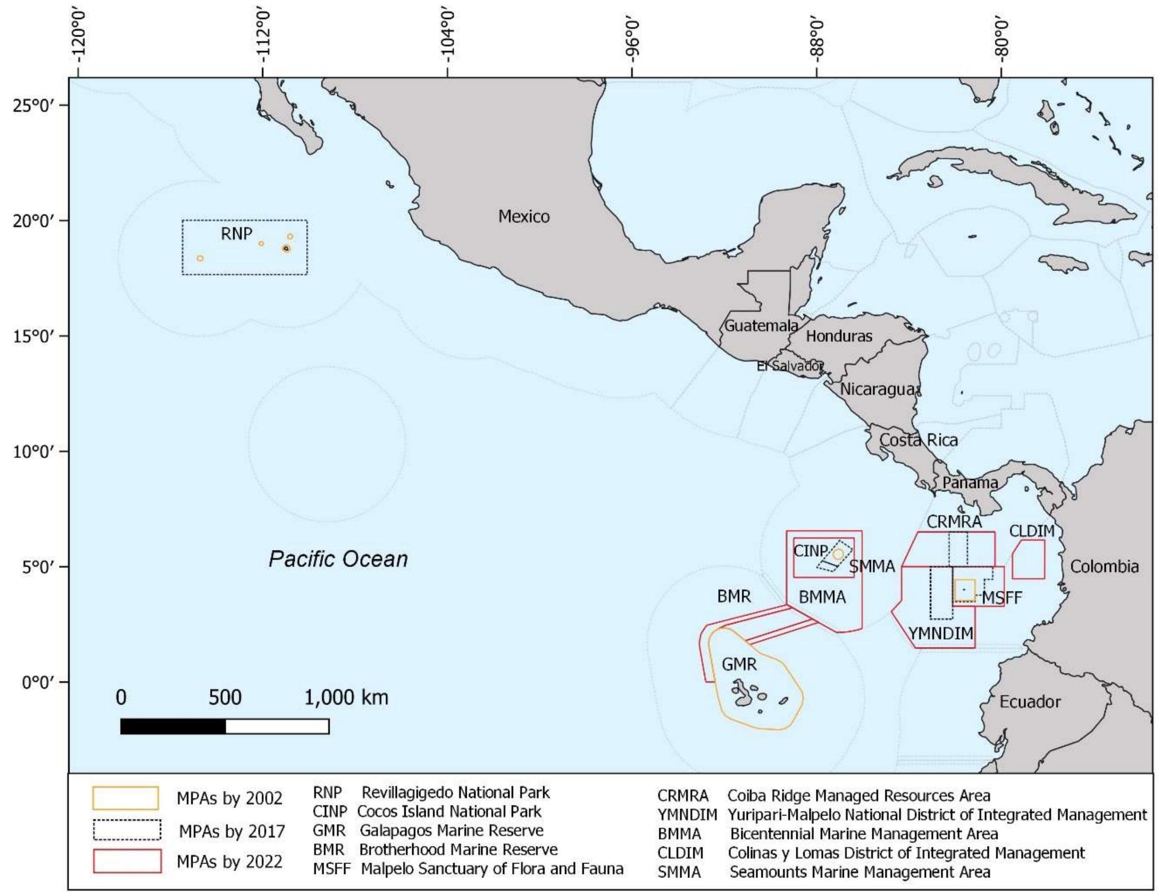

Figure 2. Creation of marine protected areas in the Eastern Tropical Pacific by 2002 (CINP, GMR and MSFF), 2017 (SMMA, CRMRA, YMNDIM, RNP) and 2022 (expansion of CRMRA and CINP, and creation of BMMA and BMR). Acronyms explained in text.

Costa Rica took the first step by creating Cocos Island National Park (CINP) in 1978, which by 2001 included a marine protected area consisting of a 12 nm (22 km) radius surrounding the island covering 1,989 km^2 of waters under a no-take regime (Executive Decree Nº 29834-MINAE, of August 23, 2001). Ecuador created the Galapagos Marine Reserve (GMR) in 1986 to control illegal fishing and overexploitation of fishery resources, which by 1998 had been expanded to cover an area of 138,000 km^2 (Organic Law of the Special Regime for the Conservation and Sustainable Development of Galápagos). Colombia created the Malpelo Sanctuary of Fauna and Flora (MSFF) in 1995 (Ministerio de Ambiente, Resolución 1292), which by 2002 included a no-take marine protected area covering 3,880 km^2 (Ministerio de Ambiente, Resolución 0761).

In 2004, the Eastern Tropical Pacific Marine Corridor (CMAR for its Spanish acronym), a voluntary regional cooperation mechanism agreed upon by the Ministries of Environment of Costa Rica, Ecuador, Colombia, and Panama in response to the anthropogenic pressures that threaten marine biodiversity in the ETP (Enright et al, 2021), encouraged processes to promote increased MPA coverage in the EEZ of each country with the specific goal of promoting biological connectivity. In March 2011, Costa Rica created the Seamounts Marine Management Area (SMMA) a 10,312 km^2 rectangle surrounding CINP (DE Nº 36452-MINAET), in which a zoning plan approved in 2013 (but never officialized) establishes a no-take policy in 36% of the area and allows sustainable fishing in 64% (SINAC, 2013). Panama created the Coiba Ridge Managed Resources Area (CRMRA) covering an area of 17,224 km^2 on September 22, 2015 (DE N°2, Gaceta Oficial N°27873-B). Ecuador banned fishing in the northern area of the GMR, covering 38,000 km2 surrounding Wolf and Darwin Islands (Acuerdo Ministerial 026-A). In a bold move on September 14, 2017, Colombia simultaneously expanded the MSFF to 26,679.08 km^2 of no-take waters (Ministerio de Ambiente y Desarrollo Sostenible, Colombia, Resolución N°1907) and created the adjacent Yuruparí – Malpelo National District of Integrated Management (YMNDIM) covering 26,919.81 km^2 (Ministerio de Ambiente y Desarrollo Sostenible, Colombia Resolución N°1908). Mexico soon came through with the creation of the 148,000 km^2 Revillagigedo National Park (RNP) in November of 2017, currently the largest MPA under a no-take policy in the region.

Furthermore, in response to the Convention on Biological Diversity's Post-2020 Framework, and its proposed target to safeguard at least 30% of the ocean in a network of highly or fully protected, well managed marine protected areas (MPAs) and other Effective Area-Based Conservation Measures (OECMs) by 2030 (OECD, 2019), Panama, Costa Rica, Ecuador, and Colombia made recent major expansions of their MPAs in the ETP. Panama expanded the CRMRA to 67,908.9 km^2 in June 2021 (Ministerio de Ambiente, 9 de junio, 2021). Costa Rica expanded CINP in January 2022 to a 54,844 km^2 no-take rectangle imbedded within a 106,285 km^2 new multiple-use marine protected area called the Bicentennial Marine Management Area (BMMA) (Decreto Ejecutivo 43368-MINAE, La Gaceta 26 de enero, 2022) which stretches all the way to Ecuador's EEZ, but that still lacks a Management Plan. Ecuador simultaneously created the 60,000 km^2 Brotherhood Marine Reserve (BMR), which stretches out to Costa Rica's EEZ, half of which is fully protected under a no-take regime, whereas the other half bans longline fishing yet allows industrial tuna purse seining (Decreto 319, 14 de enero, 2022). Finally, on June 28, 2022, in a single stroke Colombia expanded both the MSFF by 20,959 km^2, for a current total no-take area of 48,151.14 km^2, and the YMNDIM by 96,118.3 km^2, for a total area of 123,709.6 km^2, and created the Colinas y Lomas District of Integrated Management, covering 27,611.15 km^2 (Ministerio de Ambiente, Resolución 0669, Resolución 0670 and Resolución 0671).

Now, Costa Rica must undergo a political process to design a management plan for the BMMA that guarantees biological connectivity with the new BMR of Ecuador, scheduled to initiate in mid-2023 with a public consultation process.

In the following 3 chapters, I will:

1) Review the impact of longline fisheries on sea turtles and sharks in the ETP since their introduction in the early 80s, including sea turtle avoidance strategies that have been tested and their impact on sharks.
2) Review the migratory movements of turtles and sharks in the ETP, particularly hammerhead sharks and their association to seamounts.
3) Provide a critical review of the political process Costa Rica underwent for the recent expansion of CINP and the creation of the BMMA with recommendations for the design of its Management Plan.

My contribution to the advancement of scientific evidence in this field is highlighted in the next two chapters. My capacity to carry out and coordinate the field work needed to generate unique and high-quality science, as well as fund raising and manuscript writing skills, has earned me contributions with prestigious research institutions. The over 60 published peer-reviewed results of my research regarding sea turtle nesting biology, fisheries interactions with threatened marine fisheries, as well as the migratory movements of threatened marine species in the ETP has provided a guideline for future research in the region and served to influence public policy in a domestic and regional context (Klimley et al, 2022). In Chapter 4 I will discuss how these results, as well as results from other relevant regional studies, should guide the future process to design the BMMA's Management Plan.

Chapter 2. Impact of overfishing on sea turtles and sharks in the Eastern Tropical Pacific.

Like canaries in a coal mine, leatherback turtles gave the first sign of alarm that overfishing was occurring in the ETP. Five major nesting colonies formerly occurred along the leatherback's eastern Pacific nesting range, which extends from Northern Mexico to Panama, with four in Mexico (Mexiquillo, Tierra Colorada, Cahuitán and Barra de la Cruz) (Sarti-Martínez et al., 2007), and one in Costa Rica (Playa Grande) (Guadamuz-Rosales, 1990), but all declined abruptly throughout the 1990s (Spotila et al, 2000).

My work describing the decline of the leatherback nesting colony in Playa Grande was the first published record of the collapse of a major leatherback nesting population, and in which a link was made between such collapse and fishery-induced mortality [PAPER 1; Steyermark, Williams…and Arauz (1996)]. I compiled and organized leatherback turtle nesting data that had been collected in Playa Grande from 1988 to 1991, and personally directed the field work monitoring the nesting leatherback turtles in 1992 and 1993. Through a collaboration with Drexel University, we analyzed this and latter nesting data (1994-1998) and published these results documenting the collapse of the nesting population. We found that the number of nesting females in Playa Grande had declined from 1,600 nesters during each of the region's 1988-1989 and 1989-1990 nesting seasons (November to April), to just 830 the following 1990-1991 season, and then 202 in 1993-1994. It was hypothesized that El Niño events could be responsible for short-term fluctuations in the numbers of nesting turtles in Playa Grande, but that they could not account for the long-term continued decline from 1988 to 1995. Intense traditional illegal extraction of eggs (over 90% of all nests), or poaching, to satisfy domestic demand up until 1990 presumably contributed to the decline by diminished recruitment to the population. At this point, gillnet and longline fisheries had already been identified as a source of fishery-induced mortality for leatherbacks, but their overall contribution to the nesting population decline in Playa Grande was unknown. Thus, if poaching up to 1990 was responsible for the decline of the nesting population, and if illegal extraction has since been essentially controlled, then a recovery of the population would have been expected at the age of maturation, estimated at 6 to 13 years. However, if the primary cause of the nesting population decline is fishery-induced mortality, then a long-term declining trend would be expected. This paper has been widely cited by scientists studying the global decline of marine megafauna and the impact of industrial fisheries on these species. [Google Scholar 123 citations; Research Gate 80 citations (*Research Interest = 40.3, higher than 95% of research items on Research Gate)]*.

The continued declining trend of regional leatherback nesting populations led Spotila et al (2000) to conclude that the decline of the nesting leatherback population in Playa Grande was due to fishery-induced mortality, rather than turtles nesting less frequently or at other sites. Furthermore, they warn that recovery of the population cannot be achieved by increasing hatchling production alone and call for needed immediate action to minimize fishery-induced mortality by reforming fisheries practices in the ETP.

On February 18th, 2003, I was one of the 1000 co-signers of a scientist letter from 43 nations that was published in the New York Times, calling for the United Nations, the United States, and other nations to institute a moratorium on pelagic longline, gillnet and other fishing techniques that harm Pacific leatherback sea turtles until such activities can be conducted without harm to the species. The signatories also urged fishing nations to assess their impacts and reduce fishing effort, which would enable the long-term survival of targeted fish populations and the fishers and communities who depend on them, and to implement precautionary fishing principles to avoid extinction crises among sea turtles, tuna, swordfish, sharks, sea birds, and other impacted species.

Eastern Pacific leatherback sea turtles were listed as Critically Endangered by the IUCN in 2013 (Wallace et al, 2013), when it was affirmed that "under current status quo conditions the species will be extirpated in <60 yrs. if a reduction of adult mortality by ≥20% is not attained within the next 10-15 years, largely through the reduction of fishery-induced mortality". Expanded, sustained, coordinated, high-priority efforts among several entities working at multiple scales are required to ensure population stabilization and eventual increase (The Laud OPO Network, 2020).

However, leatherback sea turtles are not only the only species impacted by overfishing. At the turn of the current century scientists announced that global populations of large marine predators had declined by 90% since the 1950s due to overfishing (Myers and Worm, 2003). The incidental capture of other sea turtle species, as well as sharks and other marine megafauna in longline fishing gear has been reported to be a significant factor contributing to the current global decline of these groups (Lewison et al. 2004).

The resilience of sea turtles and sharks to these high rates of adult mortality is limited because they exhibit life history traits such as high adult survivorship, low fecundity, and late age of maturity, which implies intrinsic sensitivity to fishery-induced mortality (Lewison and Crowder, 2007). Thus, multi-species fisheries, such as Costa Rica's longline fishery, need to be tailored to the most sensitive, rather than the most robust species (Myers and Worm, 2003), which requires reductions in fishing effort, reduction in bycatch mortality and the protection of key areas to initiate recovery of severely depleted communities (Myers and Worm, 2004).

The priority for fishery managers however, given the political context and the limitations of most of the management authorities of the worlds' longline fisheries, has been to identify and institute the broad use of turtle avoidance strategies as well as handling and release practices to increase the survival prospects of captured turtles (Gillman et al, 2008). This approach requires the testing of such turtle avoidance strategies in individual fleets (since 'one size doesn't fit all'), as well as the evaluation of their impact on other sensitive marine species.

In this context, an independent Costa Rican longline fishery observer program led by myself since 1999 as the CEO of the Costa Rican non-governmental organization Sea Turtle Restoration Program (PRETOMA for its Spanish acronym) in collaboration with Papagayo Seafood, a longline company with a fleet of 12 medium scale vessels based in Playas de Coco, Guanacaste, Costa Rica, presented an opportunity to evaluate such turtle avoidance strategies in a relatively short-term, as a robust and significant statistical analysis was guaranteed due to the high reported sea turtle catch rate (Arauz et al, 2004a). Furthermore, the detailed taxonomic records kept of the total catch by the independent observers made it possible to evaluate the impact of the tested sea turtle avoidance strategies upon a broad spectrum of species, including sharks. Despite still being one of the main groups of species reported in the catch (Arauz et al, 2002), shark catch rates were estimated to have declined by 60% from 1991 to 2003, and by 90% when compared to experimental longline operations held in the 1950s (Arauz et al, 2004b).

The Joint Institute of Marine Science (JIMAR), a collaborative program between the National Oceanographic and Atmospheric Administration (NOAA) and the University of Hawaii, hired the Costa Rican non-profit Sea Turtle Restoration Program (PRETOMA), to conduct field research operations testing different turtle avoidance strategies during the ongoing independent longline observer program.

Our first collaborative research consisted of testing feeding behavior-based bait modifications as a turtle avoidance strategy in the field [PAPER 2; Swimmer, Arauz et al, (2005)]. Sea turtles are attracted to longline fishing gear by sight, detecting the white buoys, monofilament lines or bait from a distance in the blue background. Under laboratory conditions, loggerhead turtles (*Caretta caretta*) and Kemp ridley turtles (*Lepidochelys kempi*) clearly preferred untreated squid bait over blue-dyed or red-dyed squid bait. I directed the field experiments which were then held to test the efficacy of blue-dyed bait in reducing sea turtle bycatch in the Costa Rican mahimahi longline fishery, in which 108 olive ridley turtles (*Lepidochelys olivacea*) and 7 green turtles (*Chelonia mydas*) were caught. Despite the positive results for loggerhead and kemp ridley turtles under laboratory conditions, the use of blue-dyed squid bait in the field did not result in the reduction of olive ridley turtle by-catch. The results of this research acquired relevance because at the time, research in the field had only begun a few years earlier, most on-going experiments had small sample sizes, had been conducted over only a few seasons in a small number of fisheries, and the results of most studies had yet to be peer-reviewed (Gillman et al, 2005). In addition to directing the field work, I also contributed to the elaboration of the manuscript. This was the first peer-reviewed publication investigating the efficacy of turtle avoidance strategies in the longline fishery of the ETP and has served to mainstream the process of testing and adopting methods to reduce turtle bycatch in individual fleets, and has been widely cited by the scientific community [Google Scholar 84 citations; Research Gate 66 citations (*Research Interest = 38.5, higher than 94% of research items on Research Gate)]*, influencing subsequent research on turtle avoidance strategies.

Since feeding behavior-based bait modifications as a turtle avoidance strategy did not work in the field, our efforts then focused on reducing turtle bycatch and increasing post-hooking survivability by means of gear modifications, mainly the use of G-shaped hooks (also known as circle hooks) instead of traditional J-shaped hooks. The point on circle hooks is turned in toward the hook shank, the gap between the hook's point and shaft is smaller than J hooks, and the hook is wider at its base. Circle hooks may have the tip "offset" to different degrees, or non-offset, also called in-line hooks (Figure 3).

Experiments in the U.S. Atlantic swordfish fishery had shown that large circle hooks (size 18/0, 5.7 cm wide) effectively reduce sea turtle bycatch rates as well as the proportion of hard-shell turtles that swallow the hook versus hooked in the mouth when compared to smaller "J"-shaped hooks (size 9/0, 4.1cm wide), thus increasing post-release survivability. In contrast, no significant difference in turtle bycatch rates were found with smaller circle hooks (5.1 cm width) when compared to the same J hooks (Watson et al. 2004 and 2005 in Gillman et al, 2005).

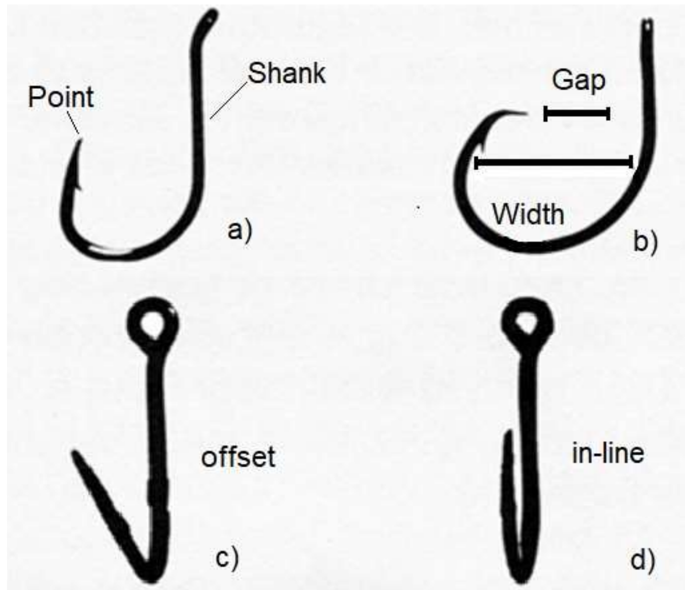

Figure 3. a) Traditional J hook, b) circle hook, c) offset hook, and d) in-line hook.

The incapacity of the smaller-sized circle hooks to reduce turtle bycatch rates was a concern, because the Costa Rican mahimahi longline fishery with its observed high turtle bycatch rate had already switched from J-style hooks to smaller-sized circle hooks (13/0, 2.79 cm wide and 14/0, 3.1 cm wide) by the time the observer program had begun in 1999 (personal observation). This hook type was widely accepted by the industry because, just as with turtles, circle hooks tend to hook target fish (mahimahi, tuna, billfish, sharks) lightly (in the mouth) rather than deeply (ingested), increasing fish quality over long periods of fishing gear soaking time. Thus, dealing with such high turtle bycatch rates in Costa Rica´s longline fishery, our first task was to determine post-release mortality following interactions with the smaller circle hooks.

We [PAPER 3; Swimmer, Arauz et al (2006)] deployed Pop-up Satellite Archival Tags (PSATs) on 14 olive ridley turtles and 1 green turtle between November 2001 and June 2003 during 5 longline fishing observation cruises. Nine of the olive ridleys and the green turtle were captured by longline fishing gear, and 5 free-swimming olive ridleys were hand-captured at the surface to serve as controls. Eight of the olive ridley turtles were hooked in the jaw or mouth, and the hooks were removed carefully with the assistance of dehooking devices prior to release, whereas only one olive ridley was hooked deeply (in the esophagus), because of which the hook was left in place as removal would have caused extensive injury. We concluded that most of the olive ridley turtles hooked using 14/0 circle hooks were done so lightly, and if handled properly survive as they generally behave normally following interactions with shallow-set longline gear, whereas the single turtle released after being deeply hooked did not follow normal dive patterns and behavior. I directed all the field work during this study and contributed with the elaboration of the manuscript together with researchers from JIMAR . The paper published from this research was the first published evidence on the post-hooking mortality of olive ridley turtles in the ETP when using smaller 14/0 circle hooks and led to the promotion of different sea turtle dehooking techniques and protocols to increase post-release survivability. This research has been highly cited [Google Scholar 108 citations; Research Gate 95 citations (*Research Interest = 53, higher than 96% of research items on Research Gate)].*

The Costa Rican mahimahi fishery has such a high catch rate of turtles that unfortunately, following protocols for their proper handling during release results in a nuisance to fishers, who may prefer to simply yank out the hooks or cut the lines, causing increased mortality either through physical damage or due to trailing fishing gear (personal observation). This situation led us to focus our attention on finding a modification to the 14/0 circle hooks used by the Costa Rican fleet that could lead to the reduction of sea turtle bycatch altogether. Studies held in the US Atlantic swordfish fishery had found that by offsetting large 18/0 circle hooks by 10° (when the hook point is turned out slightly from the eye of the hook) in combination with the use of mackerel bait, sea turtle catch rates could be reduced 88% when compared to conventional 9/0 J hooks using squid bait (Watson et al. 2004 and 2005 in Gillman et al, 2004).

Thus, we decided to perform field trials comparing the catch rates of mahimahi, sea turtles and other fish using 10° offset 14/0 circle hooks and 14/0 in-line circle hooks (with standardized squid bait) and recorded the anatomical location of hooking (mouth or esophagus) [PAPER 4; Swimmer, Arauz et al (2010)]. I was again in charge of directing the field work and contributed to the elaboration of the manuscript. The results indicated that mahimahi and sea turtle catches were similar between hook types with no differences detected between hook type and anatomical location. Thus, a 10°offset when using 14/0 circle hooks does not confer any selective advantage over hooks without an offset with respect to capture rates of mahimahi, sea turtles, sharks, or pelagic stingrays. This research has been well cited by researchers in the field since publication [Google Scholar 23 citations; Research Gate 28 citations (*Research Interest = 18.2, higher than 87% of research items on Research Gate)].*

In a further attempt to reduce sea turtle bycatch, we [PAPER 5; Swimmer, Suter, Arauz et al (2011)] compared the turtle avoidance performance of an appendage modification to in-line 14/0 circle hooks, which consists of the addition of a wire which projects posterior from the hook eye at an angle of approximately 45° to the shank, which is thought to form a physical barrier to ingestion by extending the hook's width dimension (Figure 4).

Figure 4. Circle hook modified with a wire appendage.

I again directed the field work comparing the avoidance performance of the appendage modification to in-line 14/0 circle hooks during five longline fishing trips held in Costa Rica´s EEZ targeting mahimahi, tunas, billfishes, and sharks from February to June 2007, for a total of 54 longline sets observed. The overall catch rate (number of specimens/1000 hooks) with control circle hooks was 47.8, 30% greater than with appendage hooks (33.2). The appendage hooks caught 52% fewer sea turtles, but also 23% fewer tuna and billfish than standard hooks, which represents a significant reduction in bycatch of endangered and commercial species alike. No differences were found in the anatomical location of hooking in sea turtles, suggesting the use of an appendage may not incur additional advantages regarding turtles' post-release survivorship. Thus, the adoption of circle hooks with an appendage designed to widen its dimension may be an effective conservation measure for sea turtles but is not commercially viable in maintaining target species catch rates, because of which it would not be acceptable to the fishing industry. This paper acquired relevance because at the time this turtle avoidance strategy was being tested in longline fisheries around the world, and at least in the ETP it wasn't working. This paper has been well cited [Google Scholar 40 citations; Research Gate 30 citations (*Research Interest = 22.2, higher than 89% of research items on Research Gate)].*

Taken together, my research (PAPERS 2-5) has provided the background and a methodological model for researchers in the region to perform comparative and verifiable studies on hook performance regarding turtle avoidance and impact on other sensitive species. For instance, Andraka et al, (2013) built upon my research to confirm that larger 18/0 circle hooks significantly reduced the catch of sea turtles when compared to "J" hooks in the Costa Rican Tuna, Billfish and Shark (TBS) longline fishery, although they also significantly increased the catch of endangered hammerhead sharks and vulnerable silky sharks. Slightly smaller 16/0 circle hooks had no impact on turtle catch when compared to "J" hooks, but they significantly increased hammerhead shark catch. A review of over 30 studies confirmed that using circle hooks instead of J-shaped hooks and fish instead of squid for bait, while benefitting sea turtles, odontocetes and possibly seabirds, exacerbates elasmobranch catch and injury (Gillman et al, 2016).

The next step in this process was the publication of our unique Costa Rican mahimahi longline fishery data sets, obtained by myself and independent observers from 1999 to 2008 (n=217 sets) working under my direction. Through a collaboration with Dalhousie University, Halifax, Nova Scotia, Canada, in which I provided all the field data and contributed to the elaboration of the manuscript, we published the first comprehensive description of the Costa Rican mahimahi longline fishery and quantified its impact on sea turtle and elasmobranch bycatch species [PAPER 6. Whoriskey, Arauz and Baum (2011)]. The total catch was dominated by mahimahi (53.14 ± 72.58 specimens /1000 hooks), followed by olive ridley sea turtles (9.05 ± 10.11 specimens /1000 hooks), pelagic rays (4.77 ± 6.10 specimens /1000 hooks) and silky sharks (2.96 ± 5.56 specimens /1000 hooks). Other commonly caught species included thresher sharks (1.12 ± 3.35 specimens /1000 hooks), green turtles (0.35 ± 0.81 specimens /1000 hooks) and scalloped hammerhead sharks (0.041 ± 0.279 specimens /1000 hooks). Generalized linear models (GLMs) of catch rates showed increases in olive ridley turtle catch rates and decreases in mahimahi and silky shark catch rates over the decade examined. GLMs also provide evidence that a closure of the mahimahi longline fishery from day 100 to day 300 of the year (April to October) when mahimahi catch rates seasonally decrease, would bring conservation benefits to sea turtles and sharks, the catch rates of which increase during this same period. Thus, such a seasonal closure could help minimize the fishery's impacts on threatened bycatch species while still maintaining a productive fishery (Figure 5).

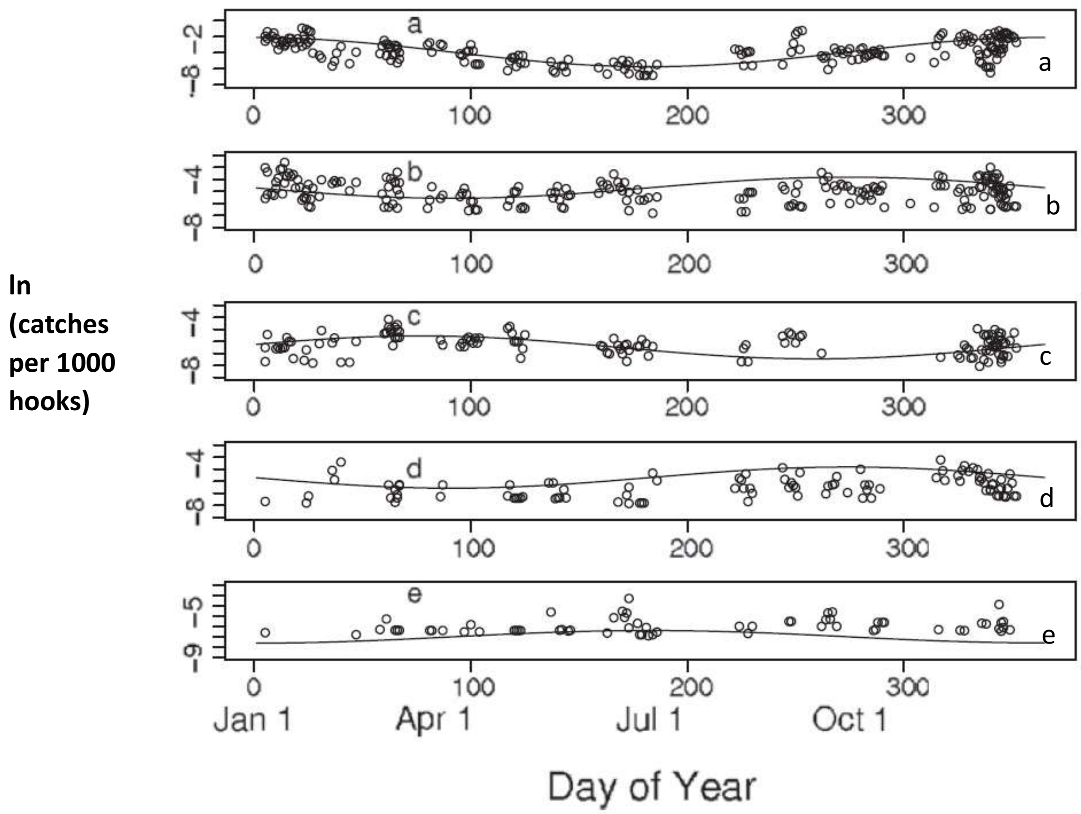

Figure 5. Seasonal variation in catch rates of: (a) mahimahi, (b) olive ridley turtle, (c) pelagic stingray, (d) silky shark, and (e) thresher shark in Costa Rica's mahimahi longline fishery: raw data plotted as ln (catches per 1000 hooks) (open circles) and predicted catch rates plotted using coefficients for sine and cos from the GLMs of best fit (black line) Whoriskey, Arauz & Baum 2011.

This study is unique for this type of work in that it describes the catch with so much detail, particularly in the ETP where observer programs on-board the longline fleet are rare, especially independent ones. Other than directing the field work and providing the data, I worked closely with researchers from Dalhousie University reviewing the manuscript. The paper has been highly cited [Google Scholar 51 citations; Research Gate 40 citations (*Research Interest = 27.5, higher than 92% of research items on Research Gate)].*

I followed up and published a second paper on the Costa Rican mahi-mahi longline fishery, this time in collaboration with Drexel University, Philadelphia, Pennsylvania [PAPER 7; Dapp, *Arauz* et al (2013)]. In this second analysis we included additional data sets to the previous analysis that were obtained from 1999 to 2010 during the independent longline observer program I was directing, for a total of 466 sets, and incorporated a sea turtle and shark body length frequency analysis. In total, 62 species of fish, three species of sea turtles and an unidentified dolphin (mammal) were recorded in the catch. We estimated that Costa Rican longline fisheries had caught 699,600 olive ridley sea turtles from 1999 to 2010. A statistically significant size decrease was detected in mature olive ridley turtles and in silky sharks. Mean Curved Carapace Length (CCL) of olive ridley turtles decreased from 68.5 cm in 1999 to 66.6 cm in 2010 ($F = 6.983$, $df = 10, 741$, $p < 0.0001$). Of the 2,562 silky sharks examined, only 375 (14.6%) had a Fork Length (FL) greater than 144 cm, the smallest mature silky shark observed. Statistically significant decreases in FL of silky sharks ($F = 9.684$, $df = 7, 2554$, $p < 0.0001$) were detected from 2004 to 2009, with average FL decreasing to 97.3 cm in 2010 (Figure 6). Pelagic thresher sharks were small and fluctuated in size over the study period. Geospatial analysis indicated that mahimahi abundance fluctuated on a temporal scale, but fishing effort did not, suggesting the seasonal targeting of sharks. We confirmed the mahi-mahi longline fishery's impact on sea turtles and sharks and concluded that marine protected areas and/or time area closures are needed as a conservation strategy to reduce its impact. This article has been highly cited since its publication [Google Scholar 63 citations; Research Gate 49 citations (*Research Interest = 37.9, higher than 94% of research items on Research Gate)].*

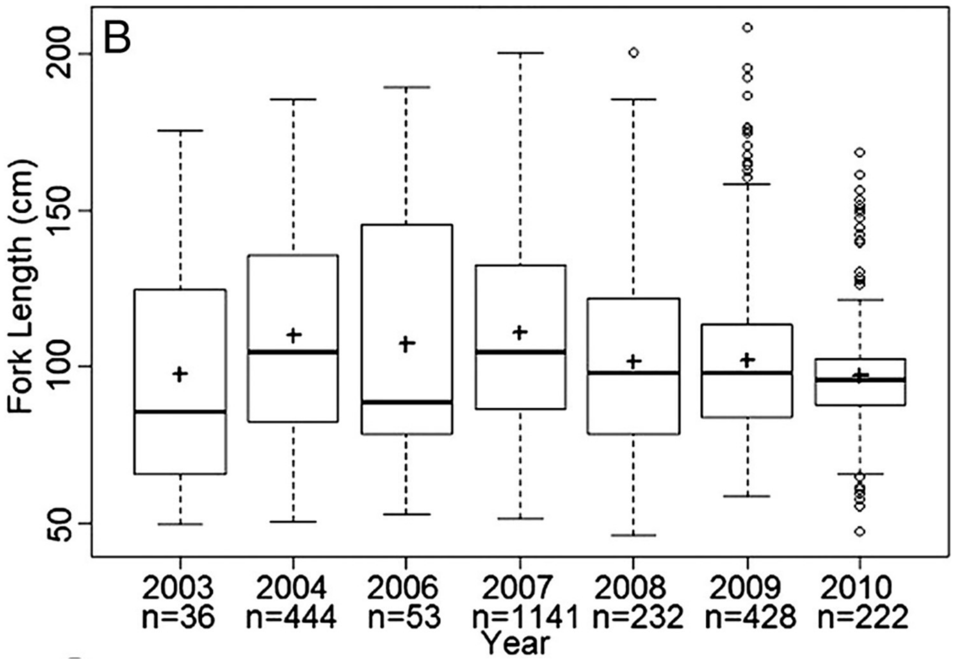

Figure 6. Observed fork lengths of silky sharks from 2003 to 2010. The cross symbol represents the mean size for each year. The box plots display the median as a thick black line, extreme lower whisker, lower hinge (median of the lower half of the numbers), upper hinge (median of the larger half of the numbers) and extreme upper whisker. The extreme upper and lower whiskers are defined as the most extreme data points within 1.5* the interquartile range of the first and third quartiles. Circles represent outliers in the data. The 2003 data set was excluded from the regression analysis due to a misidentification with black tip sharks (*C. limbatus*) (Dapp, Arauz et al, 2013).

Taken together. PAPER 6 and PAPER 7 constitute the best justification up to date for the implementation of a seasonal closure of the mahi-mahi longline fishery in the ETP.

As a result of my research activities, I was invited to participate in a "big data" paper, a highly collaborative and data-intensive ecological study regarding global fish and fishery interactions, by providing our unique fisheries observer datasets that reveal the operating patterns of Costa Rica's mahimahi longline fishery, and eventually contributing to the final version of the manuscript. Results show that globally important habitat areas for threatened pelagic sharks overlap considerably with industrial fishing activity, in both space and time, with high levels of industrial fishing effort centered on ecologically important hotspots of space use for oceanic sharks [PAPER 8; Queiroz, Humphries…Arauz, et al (2019)]. High risk was evident for shark species listed under the appendixes of the Convention on International Trade in Endangered Species of Wild

Fauna and Flora (CITES) or protected by Regional Fisheries Management Organization (RFMO) regulations. The designation of large-scale marine protected areas around ecologically important space-use hotspots for threatened shark species is needed to enhance their recovery, notwithstanding the need for more-complete reporting of catch data, with enforcement to support stricter conventional management bycatch prohibitions, quotas, or minimum sizes. Although only published in 2019, this paper has been very highly cited [Google Scholar 168 citations; Research Gate 163 citations (*Research Interest = 233.4, higher than 99% of research items on Research Gate)].*

Over the last two decades, I have studied the Costa Rican longline fishery as well as the efficiency of turtle avoidance strategies and impact on other sensitive species, providing some of the first peer-reviewed published results of fisheries observer work in the region, thus setting a methodological standard, and establishing the direction of new research. It is evident that the sea turtle avoidance strategies tested thus far have not been efficient at reducing the high turtle catch rates that occur in the Costa Rican longline fishery. The number of nesting leatherback turtles in the ETP continues to decrease, with local extirpations currently occurring on previously categorized secondary beaches (Santidrián et al, 2017). Furthermore, tested sea turtle avoidance strategies may increase risk to threatened shark species. However important more-complete reporting of catch data and enforcement to support stricter conventional management bycatch prohibitions, quotas, or minimum sizes may be, time is running out, particularly for threatened sharks, and the only efficient approach to halt the extinction trends displayed by their populations is to reduce fishery-induced mortality. Unfortunately, thus far, fishery policy has not addressed the conservation needs of threatened marine species.

The scalloped hammerhead shark (*Sphyrna lewini)* was listed as Endangered by the International Union for the Conservation of Nature´s (IUCN) Red List of Threatened Species in 2008, and despite their listing under Appendix II of CITES in 2013, which should have guaranteed the continued extraction of the species under criteria of sustainability, the species' continued detriment due to overfishing warranted its listing as Critically Endangered in 2019. The silky shark and pelagic thresher shark were both listed under Appendix II of CITES in 2016 and catalogued as vulnerable and endangered by the IUCN in 2017 (Rigby et al, 2021 a) and 2018 (Rigby et al, 2019) respectively, with overfishing pointed out as the main cause for the listings.

Amidst this overfishing process, the Inter-American Tropical Tuna Commission (IATTC), the jurisdictional Regional Fisheries Management Organization (RFMO), requires owners/operators/vessel crew to promptly release all sea turtles, to use trained personnel and proper gear to do so, to strive to implement or enhance observer programs to obtain better information, and to use only large circle hooks baited solely with finfish, or another mitigation measure to reduce sea turtle bycatch that has been duly approved by the IATTC (IATTC, C-19-04 - 2019), completely disregarding the impact of these measures on threatened sharks. Furthermore, even though yellow fin tuna populations are recovering thanks to the establishment of regional fishery quotas during the last decade, meriting the down listing of the species from a "Near Threatened" category to a "Least Concern" category in 2021 (Collete et al, 2021), these same measures have failed to translate into conservation benefits for sharks, with 37% of all shark and ray species listed under a threatened category (vulnerable, endangered, critically endangered) in the most recent version of the IUCN's Red List of Threatened Species (https://www.iucnredlist.org).

The establishment of area closures has been possible in Costa Rica, but only applicable to the tuna purse seine fishery. Three areas were created in 2014 to manage tuna fisheries that restrict the operation of tuna purse seiners: a) a coastal area running parallel to and beyond the 12 nm (22 km) limit of territorial waters, reaching out to 40 nm (75 km), including an additional 5 nm (9.3 km) buffer zone, b) an oceanic rectangle, and c) a tuna recruitment area in the southern area of Costa Rica's EEZ that borders Ecuador's EEZ (La Gaceta, 2014) (Figure 7). Longline fishing, however, is allowed to continue unabated in the tuna management areas, despite being globally well known as the type of gear that catches the most pelagic sharks (Oliver et al, 2015).

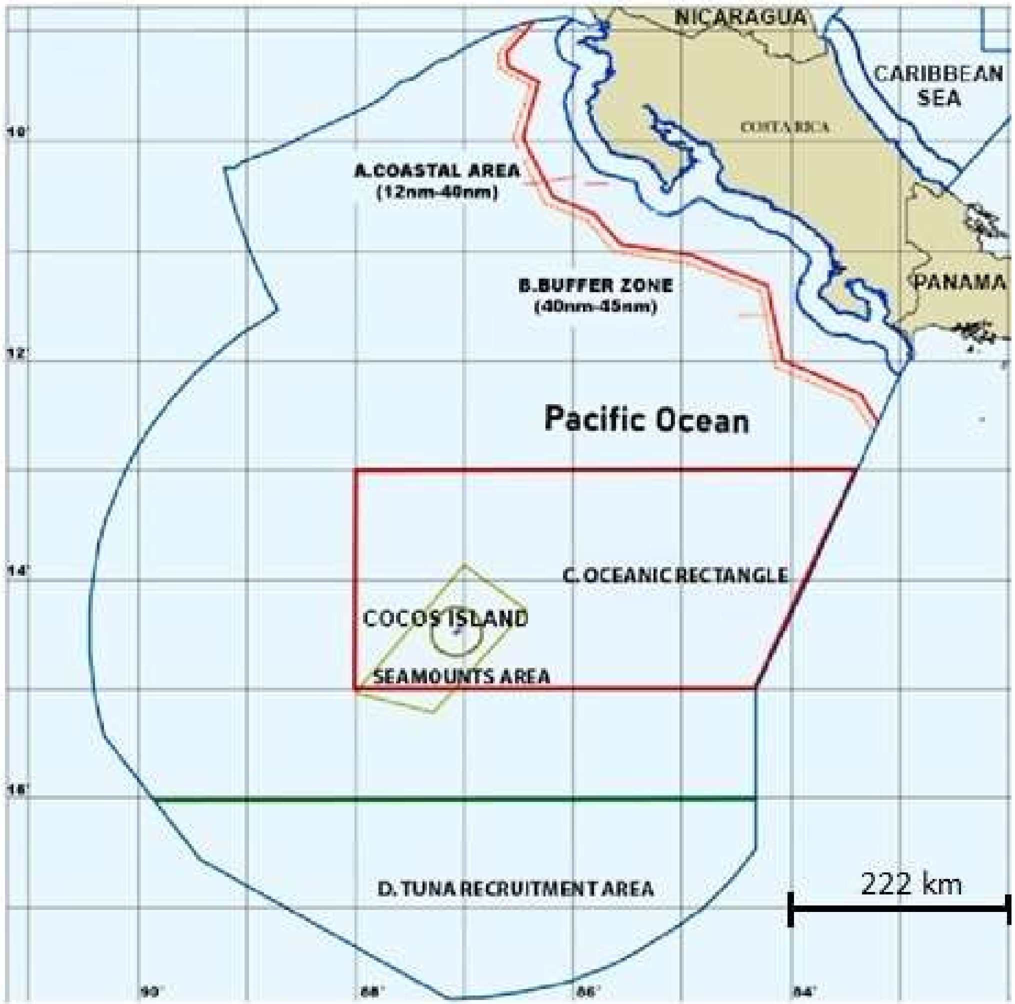

Figure 7. Three tuna management areas: a) the coastal area from 12 to 40 nm from the coastline including an additional 5 nm buffer zone, b) an oceanic area, and c) the tuna recruitment area to the south. Decreto N° 38681, La Gaceta № 213, 5/11/2014.

Acknowledging the current dire situation of critically endangered hammerhead sharks, Costa Rican longline fishers recently announced that they would free all hammerhead sharks caught as a conservation strategy (LaRepublica.net, 2021). However, this measure is not efficient for hammerhead sharks, as this species in particular ranks among the most vulnerable to longline fisheries, with high post-hooking and release mortality, because of which the best conservation policy is to avoid its interaction with fisheries in the first place (Gallagher et al, 2014).

Clearly, overfishing in the ETP is not a sea turtle problem, nor a shark problem – it is an overfishing problem with global ecosystem impacts that will not be solved with monospecific solutions for endangered or commercial species. Currently, the only ecosystem solution to overfishing by the regional longline fishery is to tailor management to the needs of the most sensitive species (turtles and sharks), requiring the reduction of fishing effort and thus of fishery-induced mortality. This can be attained implementing a seasonal closure of the longline fishery when sea turtle and shark occurrence in the catch is at its highest, or by creating large fully protected marine protected areas at essential habitats for endangered species and marine biodiversity hotspots, as well as along migratory biological corridors.

Chapter 3. Migratory movements of threatened sea turtles and sharks in the Eastern Tropical Pacific.

Highly migratory marine species are not randomly dispersed throughout the ocean, but rather tend to aggregate at specific geographical features such as oceanic islands and seamounts, called hot spots of biodiversity, and may follow migratory routes between these sites during seasonal migrations (Klimley et al, 2005). The existence of a migratory corridor between Cocos Island and Galapagos Islands was first hypothesized by Morreale et al, (1996) after satellite tracking the post-nesting movements of 8 leatherback sea turtles tagged in Playa Grande, Costa Rica, from 1991 to 1995. All animals headed to the South Pacific Gyre in international waters following a southwestward corridor conservatively estimated to be 500 km wide (Figure 8), which could be influenced by environmental factors such as ocean fronts, bathymetric features, currents, or geomagnetic cues. The authors speculated that the migratory corridor observed may be representative of the migration route of all Pacific leatherbacks in the vicinity, and possibly in the entire Central American region, and that protection of world stocks could be facilitated by simply restricting potentially harmful activities within the spatial and temporal corridor.

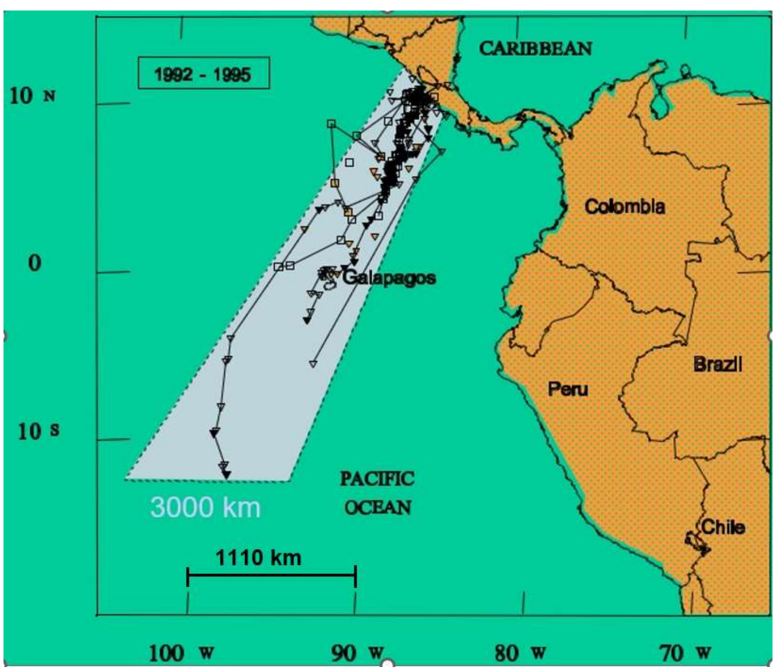

Figure 8. Post-nesting movements of 8 leatherback turtles tagged with satellite transmitters in Playa Grande, Costa Rica, from 1991 to 1995 (Morreale et al, 1996),

The Submerged Cocos Ridge (SCR), the dominant bathymetric feature in the region , stretches southwest from the Osa Peninsula of Costa Rica to the Galapagos Archipelago of Ecuador, covering over 1,000-km in length and 250–500 km in breadth, and a depth of about 2 km shallower than the adjacent basin (Walther, 2003). Since the migration tracks of the leatherback turtles recorded by Morreale et al (1996) overlapped the SCR, it was assumed that the migratory corridor was somehow related to this bathymetric feature.

A further analysis of 46 leatherback turtle satellite tracking datasets from 2004 to 2007 confirmed the existence of a persistent post-nesting southwestward migration corridor for leatherbacks tagged in Playa Grande, Costa Rica, spanning from the Pacific coast of Costa Rica to the Equator and into the South Pacific (Shillinger et al, 2008). The authors found no correlation however, between the southward turtle movements and the most prominent frontal feature in the region, the North Equatorial Countercurrent (NECC), nor the SCR. Instead, turtles were found to head in a southwestward direction toward the south Pacific gyre, but the current strength off the southern edge of the Costa Rica Dome (CRD) deflects them southeast over the SCR. Once the influence of the current was removed, it became evident that the observed southeast turn was current induced, as turtles "corrected" their southwestward direction. The authors concluded that leatherback navigation through the complex and highly energetic equatorial region supports the existence of a compass sense, possibly guided by the geomagnetic map (Shillinger et al. 2008). These data elucidate potential areas for mitigating fisheries bycatch interactions by providing immediate regions in the migration corridor where conservation can be implemented. (Figure 9).

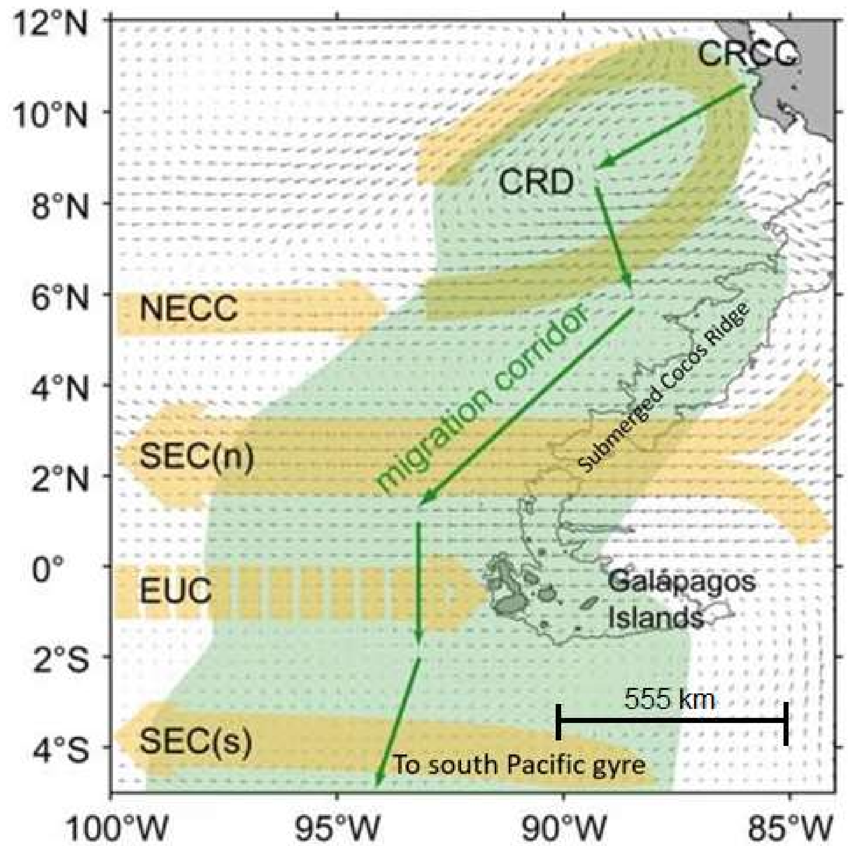

Figure 9. Schematic of turtle migration corridor through the equatorial current system based on the 75% home range utilization distribution contour (current abbreviations are given in text, except EUC, Equatorial Undercurrent). Shillinger et al, 2008.

Guidance by magnetic fields was also described for scalloped hammerhead sharks (*Sphyrna lewini*) that congregate at Bajo Espiritu Santo, Gulf of Mexico, Mexico (Klimley at al, 2005). As demonstrated in this early study, hammerhead sharks do not congregate at the seamount to feed, as their main food item, squid, lives in much deeper water. Hammerhead sharks display a pattern of dusk departure to deeper waters over 20 km away, and predawn return to the seamount following the same path. By comparing the routes to a geomagnetic survey of the sea bottom, the authors showed that the hammerheads, with their ability to perceive faint magnetic fields, were using Bajo Espiritu Santo Seamount as a sort of 'transit hub', following the geomagnetic signatures of old basaltic lava flows to reach preferred feeding grounds. Thus, rather than aggregating at the seamount because it is a biotic hotspot, the site provides a network of "paths" or signposts, that enables hammerhead sharks to find productive feeding grounds in surrounding waters.

Based on this information, I was one of the first researchers to initiate studies on the migratory movements of hammerhead sharks in the Eastern Tropical Pacific in 2004 (Cocos Island Marine Conservation Area, Research Permit 002-004-2004). Since well-known ETP biodiversity hotspots Cocos Island, Malpelo Island, Coiba Island and the Galapagos Archipelago are actually the summits of aseismic volcanic ridges in the Panama Basin (SCR, Malpelo Ridge, Carnegie Ridge, and Coiba Ridge, respectively), with associated magnetic anomalies (Walther, 2003), I hypothesized that hammerhead sharks were moving from one aggregation site to another, and possibly to coastal breeding habitats, following the geomagnetic signature of these ridges.

Until the early 2000s, little was known regarding how these populations related to each other (i.e., the degree of connectivity), knowledge that has important implications for the establishment of marine conservation policy. If these populations are independent from each other, then each country is responsible for their conservation, but if we are dealing with a shared population, with animals moving from one island or national jurisdiction to another, then regional coordination is required for the efficient implementation of conservation policy.

In 2005, three hammerhead shark tagging projects were established simultaneously yet independently from each other in the ETP, led by researchers working in CINP, Costa Rica (myself), in Colombia's MSFF (Sandra Bessudo) and in Ecuador's GMR (Alex Hearn and James Ketchum). Early on, we agreed to collaborate on the standardization of telemetry research methods and the joint evaluation of migratory movements to provide evidential data for the establishment of effective conservation policy for highly migratory marine species in the ETP. As of 2006 we started calling ourselves Migramar. Currently, the organization consists of a network of 22 researchers belonging to universities, government agencies and non-profit organizations from different parts of the American continent, and in 2017 it formally constituted as a non-profit organization in the United States, Mexico, and Costa Rica. The scope of our studies, which currently includes an array of elasmobranch species (tiger sharks, whale sharks, galapagos sharks, silky sharks, silvertip sharks, blacktip sharks, manta rays), sea turtles (leatherbacks, green turtles hawksbill turtles) and cetaceans, as well as our published results in peer reviewed journals, has earned Migramar a place as a scientific authority and advisor to local, national, and regional intergovernmental authorities (https://www.migramar.org).

The first and still most common tracking methodology used by Migramar entails placing coded ultrasonic beacons on sharks and detecting their presence with stand-alone receivers deployed at known congregation sites, to determine presence or absence of tagged specimens at these sites and identify movements between them. Sharks are fitted with coded ultrasonic tags (Innova-Sea Systems Inc., Nova Scotia, Canada, V16-6H or-6L) which produce a coded signal at a frequency of 69 kHz. Tags are attached either externally or internally. External attachment requires free diving or scuba diving to the proximity of a shark and attaching the tag by inserting a dart at the end of pole spear into the shark's dorsum with a tether leading to the transmitter. Internal implantation involves capturing the shark by hook and line, lifting the shark on the deck of the boat, irrigating its gills with water, or keeping the shark by the side of the boat, while making an incision, inserting the tag into the body cavity, closing the opening with sutures, and releasing the shark into the ocean (Klimley et al, 2022). Internal tagging is preferred over external tagging, because there is no loss of data due to poor tag retention, which may occur when sharks are tagged externally, but internal tagging is more time consuming, labor intensive, and invasive.

This collaboration with Migramar rendered the first scientific evidence confirming the movements of hammerhead sharks between Malpelo Island, Cocos Island, and the Galapagos Islands [PAPER 9; Bessudo, Soler…and Arauz (2011)]. I provided the hammerhead shark acoustic tracking data that I had complied in CINP for over 5 years (2005 – 2010) and assisted with the elaboration of the manuscript. Of sixty-nine hammerhead sharks tagged with ultrasonic transmitters in Malpelo Island throughout 2006 to 2008, five visited Cocos Island, one of which also visited the Galapagos Archipelago. Although connectivity between these sites was confirmed, the frequency of interisland movements appeared to be relatively low (<7% of the tagged sharks). This was the first paper of a series co-authored with Migramar members confirming that the hammerhead sharks of Cocos Island, Malpelo Island and the Galapagos Archipelago constitute a shared population and is one of my most cited papers [Google Scholar 143 citations; Research

Gate 80 citations (*Research Interest = 50.3, higher than 96% of research items on Research Gate)*].

The next step was publishing the results of the movements of 134 scalloped hammerhead sharks tagged with ultrasonic transmitters at Darwin and Wolf and islands, 35 km apart from each other and 175 km northwest of the main Galapagos Islands [PAPER 10; Ketchum, Hearn…and Arauz (2014)]. I provided my hammerhead shark acoustic tracking data from Cocos Island and assisted with the elaboration of the manuscript. We determined that hammerhead sharks tagged in Darwin and Wolf Islands made constant short distance back and forth movements (<50 km) between each other, a situation described as 'hotspots in a hotspot' (Hearn et al, 2010) Only 5 of the tagged hammerhead sharks were detected at other sites: 1 medium distance movement (50 – 300 km) to Seymour Island (one of the main Galapagos Islands), and 3 long distance movements (>300 km), 2 to Cocos Island and 1 to Malpelo Island. Despite the low observed frequency of inter-island movement (3% of tagged sharks), our results show a seasonal migratory pattern occurring from December to February, when fewer hammerheads are observed in the Galapagos Islands and the long-distance movement to other islands occurs. These findings provide important information, such as movement modes, connectivity between islands and possible movement corridors, seasonality and environmental factors, all of which should assist decision makers in developing management strategies for hammerheads within the GMR and in the open sea beyond the limits of the marine protected area, and has been widely cited by the scientific community [Google Scholar 100 citations; Research Gate 78 citations (*Research Interest = 52.6, higher than 96% of research items on Research Gate*)]

We completed this process with the publication of the movements of 84 scalloped hammerhead sharks tagged with ultrasonic transmitters at Cocos Island between 2005 – 2013 [PAPER 11. Nalesso, Hearn…and Arauz, (2019)]. I directed all field operations over the 8-year duration of the study and compiled all the data sets. I also contributed to data analysis and elaboration of the manuscript. Only one of the tagged sharks made an inter-island movement to the Galapagos Islands. However, more movement seemed to be detected in the opposite direction, with 9 hammerheads tagged in the Galapagos Archipelago and one tagged in Malpelo Island visiting Cocos Island. Sharks tagged in Cocos Island were strongly associated to the island, contrary to sharks tagged elsewhere, suggesting that hammerhead sharks from Malpelo Island and the Galapagos Archipelago may use Cocos Island as a navigational waypoint or stopover during seasonal migrations to coastal Central and South America. Cocos Island presented the lowest frequency of inter-island movements of animals tagged at any site when compared to Malpelo Island and the Galapagos Archipelago. Despite being a relatively recent paper, it has already been cited widely [Google Scholar 33 citations; Research Gate 29 citations, (*Research Interest = 31.9, higher than 93% of research items on Research Gate*)].

Thus, my research has confirmed the existence of biological connectivity between Cocos Island, Malpelo Island, and the Galapagos Archipelago through the movements of hammerhead sharks. Abundance patterns suggest the seasonal movements of hammerhead sharks (December to February) from Malpelo Island and the Galapagos Archipelago to Cocos Island, after which they possibly migrate to the coastal mangroves of Central America to give birth. Inter-island frequency movement however is low, which can have several explanations. Tag retention may be an issue when animals are tagged externally during free diving or scuba diving, or sharks may be moving to other aggregation sites where there are no receivers. The proximity of Las Gemelas seamount to Cocos Island, only 40 nm southwest, led me to hypothesize that hammerhead sharks tagged in Cocos Island could be doing constant short distance back and forth movements between these sites, just as the ones previously described by Hearn et al (2010) and Ketchum et al (2014) at Darwin and Wolf Islands in the GMR. The well-known biodiversity hotspot status of Las Gemelas seamount which warranted its strict protection under the proposed SMMA Management Plan, strengthened this hypothesis.

To address this, I coordinated the deployment of two acoustic receivers upon separate summits of Las Gemelas seamount at 180 m depth in May of 2015 using a submersible. During this expedition, we tagged a hammerhead shark in Cocos Island externally with an ultrasonic tag using a pole spear during scuba operations at a dive site known as Dirty Rock, as well as a pelagic thresher shark (*Alopias pelagicus*) into which we surgically implanted an ultrasonic tag after being caught during an experimental fishing operation at Las Gemelas seamount. When the data from Cocos Island and Las Gemelas seamount receivers were downloaded in September of 2016, we found that the hammerhead shark tagged at Dirty Rock had performed three short distance back and forth movements to Las Gemelas (Figure 10) [PAPER 12. Chávez, Arauz et al (2020)].

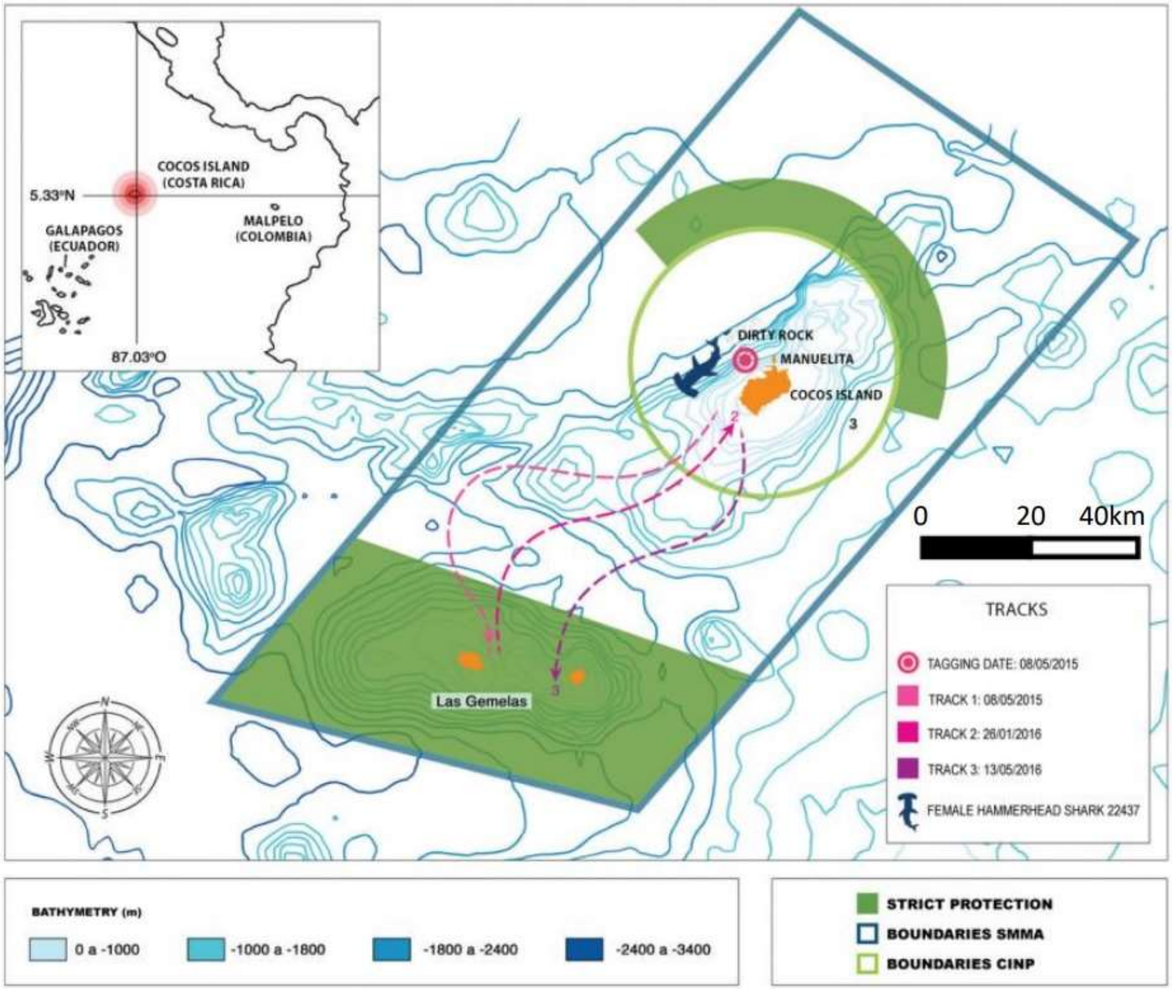

Figure 10. Movements of a scalloped hammerhead shark between Cocos Island National Park (CINP) and Las Gemelas Seamount in the Seamounts Marine Management Area (SMMA) from May 2015 to May 2016. Dotted lines suggest the shark's potential trajectory. Chávez et al, 2020).

These results strengthen the hypothesis that the seamounts along the Cocos Ridge are not only hotspots of biodiversity, but that they also act as 'steppingstones', between Cocos Island and the Galapagos Archipelago, and that hammerhead sharks move from one steppingstone to another, not necessarily in a unidirectional fashion. Furthermore, these results expose the inadequacy of the SMMA's proposed Management Plan which allowed longline fishing between CINP and the no-take area of the SMMA where Las Gemelas occurs, leaving hammerhead sharks exposed to fisheries when performing these back-and-forth movements, underscoring the need for a no-take policy in the entire area. This paper significantly advances our understanding of the movement ecology of hammerhead sharks in the ETP and although only published in 2020, it has already drawn the interest of researchers in the region [Paper 12; Google Scholar 6 citations; Research Gate 2 citations (*Research Interest = 6.1, higher than 69% of research items on Research Gate)].*

Migramar introduced the concept of a Swimway between Cocos Island and the Galapagos Archipelago in 2018 and defined it as a single interconnected ecosystem in the region along the Cocos Ridge, which consists of a system of seamounts that harbor and concentrate significant marine migratory activity, which can clearly be appreciated upon superimposing satellite tracking information of 389 individuals of 15 threatened vertebrate marine species (Peñaherrera-Palma et al, 2018). After synthesizing the technical information up to date, the authors recommended the implementation a no-take regime covering a 40 nm radius (74 km) around each connectivity hotspot or seamount, such as the criteria used for the creation of Mexico's Revillagigedo National Park (Ketchum, 2011), including a defined buffer zone unifying the coverage area of each connection (Figure 11). The official protection of this 239,502 km^2 area, which Migramar is calling The Cocos - Galapagos Swimway, would protect the integrity of marine ecosystems in CINP, the SMMA, and the GMR, ensuring spatial redundancy that promotes ecosystem resilience in all three MPAs.

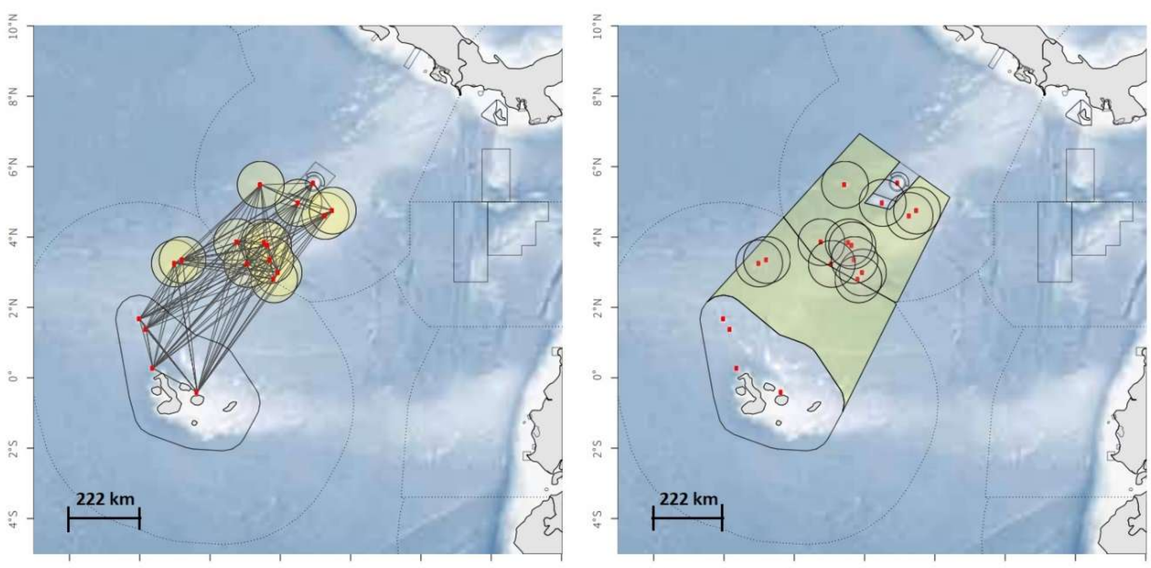

Figure 11. Proposed design of the Cocos – Galapagos Swimway. Left, network analysis of the connectivity hotspots and seamounts along the Cocos Ridge. Right, buffer area unification from connecting each network node. Peñaherrera-Palma et al, 2018.

Drifting-pelagic baited remote underwater video stations (BRUVS) were used by the University of Costa Rica's Center for Marine Research (CIMAR for its Spanish acronym) to investigate the distribution and relative abundance of Large Pelagic Species (LPS) along 9 seamounts of the Cocos Ridge from April 3rd to 11th, 2018 (Figure 12) (Cambra et al, 2021b).

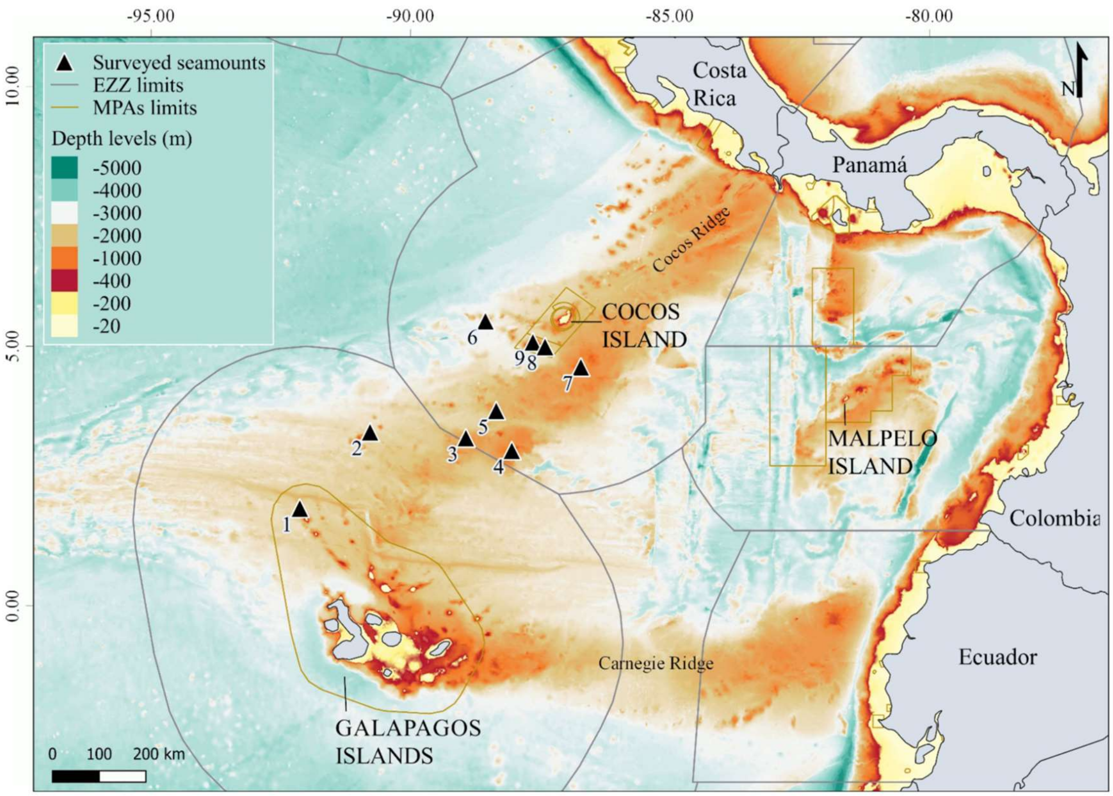

Fig 12. Location of seamounts surveyed along the Cocos Ridge between Cocos Island and the Galapagos Archipelago. Numbers indicate surveyed seamounts: (1) NW Darwin; (2) Paramount; (3) Medina 1; (4) Medina 2; (5) Medina 3; (6) West Cocos; (7) East Cocos; (8) Las Gemelas 1; (9) Las Gemelas 2. Cambra et al, 2021b.

Depth of seamount summit was the most significant driver for LPS richness and abundance, both of which were significantly higher at shallower seamounts (< 400 m) when compared to deeper ones (> 400m). Distance to nearest MPA was also a significant predictor for LPS abundance, which increased at increasing distances from the nearest MPA. Cambra and colleagues suggest that the Cocos Ridge seamounts, specifically West Cocos and Paramount which had the highest LPS richness and abundance of all 9 seamounts surveyed, are important aggregation sites for LPS in the ETP (Cambra et al, 2021b).

To summarize the 'state of the art' knowledge on movement patterns of large pelagic sharks based on telemetry, and to provide the evidence base to justify the expansion of marine protected areas in the Eastern Pacific, we published a review paper in 2022 [PAPER 13; Klimley, Arauz et al, (2022)]. In this paper we describe the movement ecology of 9 species of sharks tagged at Cocos Island, Malpelo Island, Galapagos Archipelago and Revillagigedo Archipelago, using two tracking technologies: ultrasonic tags and satellite tags that communicate with the global ARGOS system. This information has enabled Mexico, Colombia, Panama, and Costa Rica to recently expand their own no-take and multiple-use MPAs in the region.

Taken together, papers 9 to 13 provide some of the first hard evidence of biological connectivity between the oceanic islands of the Eastern Tropical Pacific through the migratory movements of hammerhead sharks, and underscore not only the high quality of the research held in Costa Rica, but also how efficiently Migramar works as a team. These collaborative studies showing the association of hammerhead sharks to Las Gemelas seamount, coupled with the results of Cambra et al (2021 b) prioritize the need to not only protect a 40 nm radius around West Cocos and Paramount Seamounts (in the Ecuadorean EEZ), but to fully protect the waters in between them to safeguard hammerhead sharks during their regular migratory movements.

Chapter 4. The recent process to expand Costa Rica's MPAs in the Eastern Tropical Pacific.

On December 19, 2017, a process was initiated within the National System of Protected Areas (SINAC for its Spanish acronym) to compile the best scientific information available to strengthen a proposal exploring the viability of expanding CINP and the SMMA (Res. R-001-D-ACMC-2017).

Over the next 18 months, SINAC compiled all scientific, social, financial, and legal information pertaining to the viability of changing or modifying the boundaries of CINP and the SMMA, and then proceeded to use the spatial prioritization tool Marxan, a software program to help design optimal reserve networks, to design the proposed expansions of CINP and the SMMA. By incorporating data on species, habitats, and other biodiversity features, the software can identify networks of reserve sites that would meet biodiversity targets while minimizing costs to resource users, such as fishers. Marxan is not meant to replace decision-making, as it is then up to planners to decide which of the possible networks would be preferable, or to modify the networks by addressing specific stakeholder concerns or incorporating other data (Davis, 2004). The following information was compiled and included in the Marxan analysis: habitats (geomorphological formations such as seamounts, oceanic trenches, upwelling areas, hydrothermal vents, coral reefs), biodiversity (9 species of cetaceans and 27 pelagic species of commercial and conservation interest caught by tuna purse-seiners and longliners) (SINAC, 2018).

SINAC then designed a participatory platform to submit the proposal to all social actors and stakeholders, consisting of 3 separate participatory workshops with a) Government institutions, b) Non-Governmental Organizations (NGOs) and academia, and c) economic sectors (fisheries and tourism), allowing for the determination of common ground, listen to proposals and obtain input for proposal improvement (SINAC, 2021a).

The first NGO – academia consultative workshop was held on July 21, 2021, where we were presented with SINAC's first proposed boundaries for the expansion of CINP and the SMMA (SINAC, 2021a).

Based on the identification of priority conservation sites as determined by the results of the Marxan analysis, SINAC proposed to expand CINP from a 12 nm no-take radius to a 50nm no-take radius, covering 28,819 km^2, surrounded by an expanded SMMA in the shape of a rectangle that would cover 135,996 km^2, superseding most of the oceanic rectangle tuna management area. Together, these two expanded MPAs would cover 31% of Costa Rica's EEZ (Figure 13). The design of the SMMA's Management Plan, however, would be left pending for the new government administration to deal with (initiating May 3, 2022).

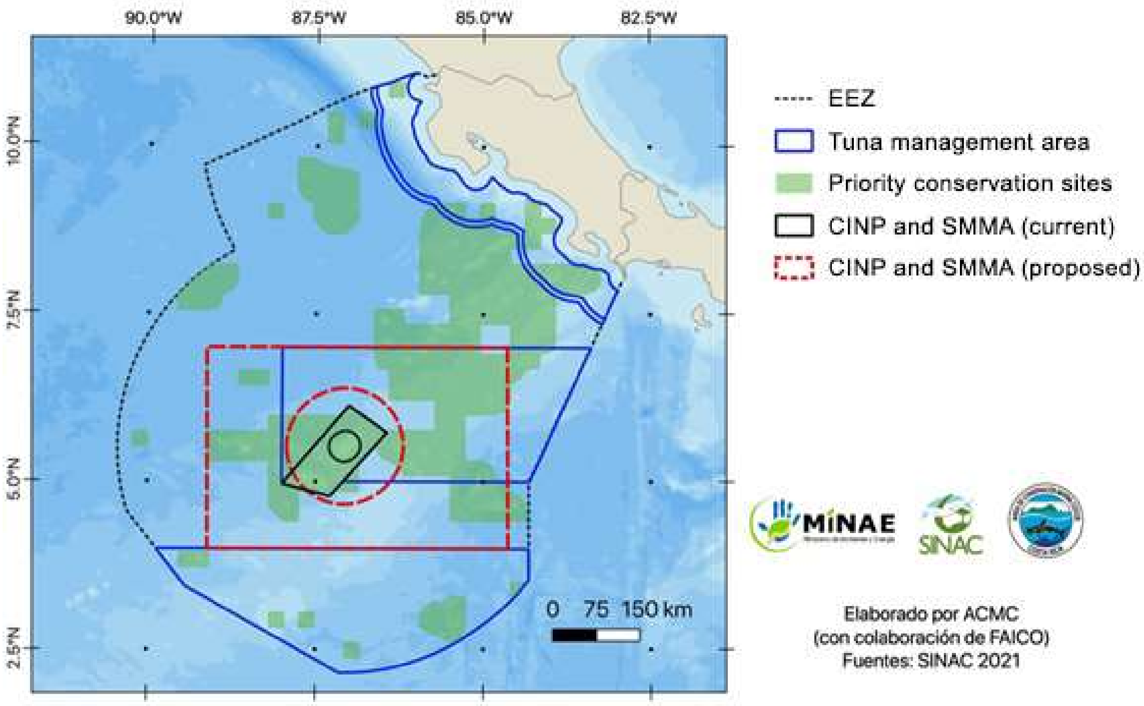

Figure 13. SINAC's proposal to expand CINP to a 50nm no-take radius covering 28,819 km^2 and expand the SMMA to a rectangle covering 135,966 km^2. Green areas represent priority areas as determined by the Marxan analysis. SINAC 2021a.

To receive input from NGO - academia workshop participants (University of Costa Rica, National University, Conservation International, Costa Rica Forever, Turtle Island Restoration Network, Fins Attached Marine Research and Conservation, Migramar, Friends of Cocos Island Foundation, Misión Tiburón, MarViva), SINAC facilitators formed 4 working groups, and allowed 2 hours for them to discuss the proposal internally and provide not only their opinion but also their recommendations for its strengthening during a final plenary session. Although there was a consensus in that the expansion of CINP was right, concerns were expressed regarding not only the orientation of the SMMA, which did not coincide with the seamounts of the SCR, but also its reach, not encompassing waters all the way to the limit of Costa Rica's EEZ with Ecuador´s (SINAC, 2021a), thus failing to provide an opportunity to design policy that secures biological connectivity between these biological hotspots.

A second NGO – academia consultative workshop was held on August 20, 2021, to present the new proposed modifications to the boundaries of CINP and the SMMA, based on the results of the latest Marxan conservation priority analysis, which now included partial longline vessel operation GPS coordinates from 2015 to 2019 (INCOPESCA-PE-958-2021), as well as longline vessel fishing effort from 2017 to 2021 provided by the Tracking, Control, and Surveillance Center of the Costa Rican Fisheries Institute (INCOPESCA) (SINAC, 2021b) (Figure 14).

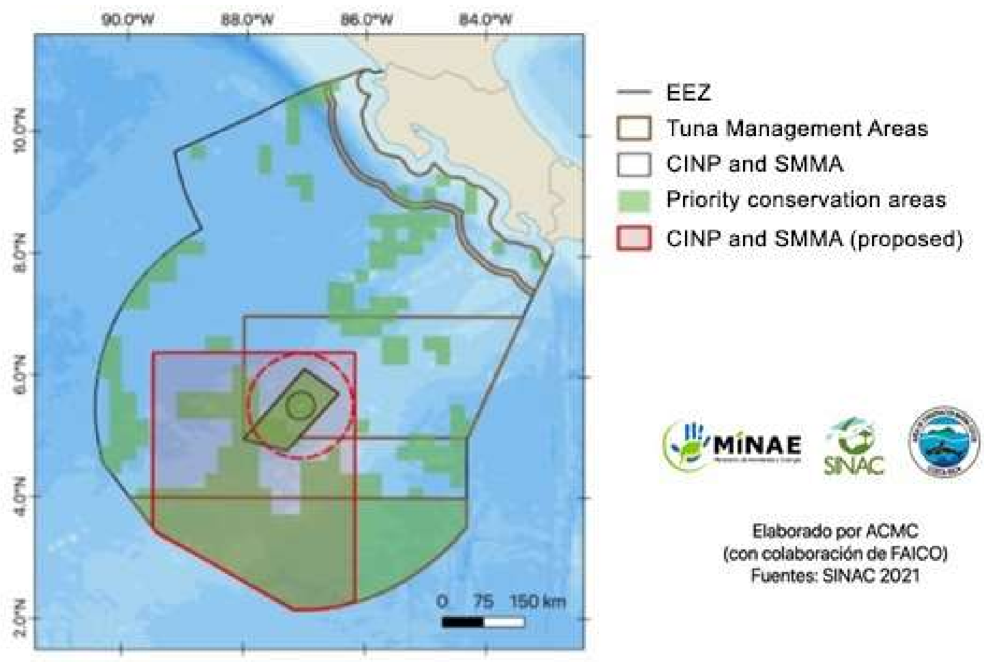

Figure 14. Second official proposal to expand CINP and the SMMA. CINP remains the same, but the SMMA is now extended to reach the border of the EEZ that limits with Ecuador, covering 125,603 km^2, responding to the new priority areas to the south of CINP as established by the latest Marxan analysis.

NGO participants expressed satisfaction with the new proposed boundaries for the SMMA during the plenary session, now reaching Ecuador´s EEZ. However, concern was raised regarding the intention of creating such a large MPA without an officially approved management plan, impeding the immediate implementation of conservation policy such as the adoption of a no-take policy in a 40nm radius around the seamounts of the SCR, and the eventual political fate of the fragmented tuna management areas currently under the governing body of INCOPESCA (SINAC, 2021b). This is relevant in a regional context, because the establishment of efficient transboundary marine conservation policy is expected to be more feasible to attain if conversations and agreements are held through each country's respective Ministry of Environment, as entities that respond to the regional and global conservation needs of threatened marine species through conventions such as the United Nations Convention on the Law of the Sea (UNCLOS), CITES, the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and regional intergovernmental marine conservation agreements such as the Marine Conservation Corridor of the Eastern Tropical Pacific (CMAR for its Spanish acronym). Given that this is the case, and the governing body over the proposed MPA expansions by Costa Rica, Ecuador, and Colombia is each country's respective Ministry of Environment, then INCOPESCA's governing body status in the fragmented tuna management areas, with its mandate to foster fisheries, could impede the adoption of transboundary policy that takes the conservation needs of the most threatened species into consideration.

As part of the official consultative process, I coordinated the drafting and submission of the following technical proposal from Migramar to the Minister of Environment, Andrea Meza Murillo on September 2nd, 2021, regarding the expansion of CINP and the SMMA.

According to our criteria, the expansion of CINP should consist of a square shape covering 48,978.0 km^2 (9.2% of the EEZ), instead of a circle, to facilitate surveillance operations. The proposed expanded SMMA should consist of two zones: a no-take or absolute protection zone to the southwest (red shaded) covering 106,994.7 km^2 (20.2% of the EEZ) and reaching out to the border of the EEZ with Ecuador´s BMR, and a fishery management zone (red lines) covering 65,104.95 km^2 (12.3% of the EEZ), superseding the oceanic tuna management area and reaching out to the border of the EEZ with Panama's Coiba Ridge Managed Resources Area (CRMRA) (Figure 15).

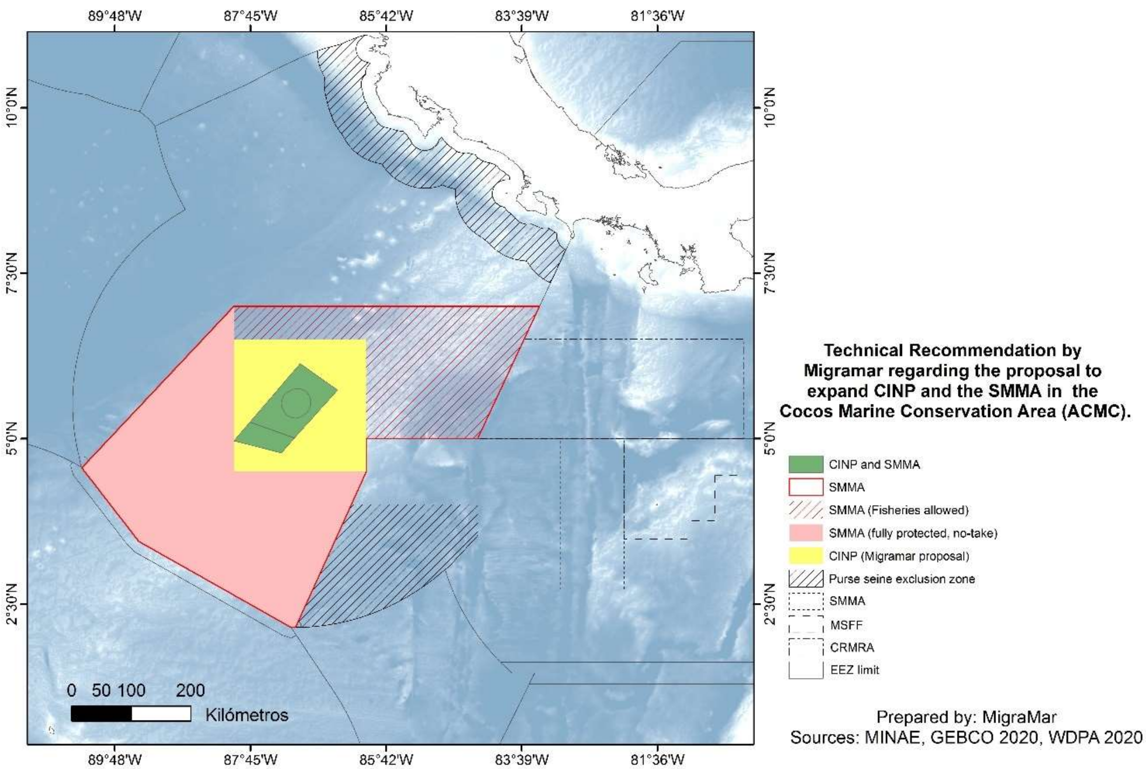

Figure 15. Migramar's CINP and the SMMA expansion proposal. CINP corresponds to a 48,978.0 km^2 square, imbedded within a SMMA that is now zoned, with a no-take 106,994.7 km^2 encompassing the Cocos-Galapagos Swimway, and a 65,104.95 km^2 fishery management zone connecting with Panama's Coiba Ridge Managed Resources Area (CRMRA). Map by Migramar, 2021.

This proposal for the expansion of the SMMA is consistent with the International Union for the Conservation of Nature's (IUCN) Protected Area Management Category VI, defined as protected areas with sustainable use of natural resources, and described as areas that conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems, which are generally large, with most of the area in a natural condition, and where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area (Day et al, 2019). Given that 75% of the protected area should apply to fulfil the primary objective (conserve ecosystems and habitats), the remaining 25% can be managed for other essential purposes so long as these uses are compatible with the definition of a protected area and the management category it is being assigned to (Day et al, 2019).

Migramar's design for the proposed expansion of CINP and the SMMA allows for the strict protection (implementation of a no-take regime) of the seamounts along the SCR, throughout Costa Rica's EEZ to the border of Ecuador's EEZ, consisting of 62.2% of the proposed expanded SMMA, and allows certain fisheries operations to occur in the other 37.8%, which would supersede the oceanic rectangle tuna management zone that reaches the border of Panama's CRMRA. Under this design, the establishment of transboundary marine conservation and resource management will be facilitated through direct communications between the environment authorities of Costa Rica, Ecuador, Panama and Colombia through CMAR, the regional body established precisely for this purpose.

On October 7, 2021, the authorities of the Ministry of Environment shared the third official and latest version of the proposed boundaries of CINP and the SMMA with the NGO - academia sector. In this version, CINP is expanded to a 54,844 km^2 rectangle surrounding Cocos Island and including important seamounts, which was viewed as a very positive outcome. Nonetheless, the government was reluctant to change the orientation of the SMMA, which now covers 106,285.56 km^2, as well as to expand it to encompass the oceanic tuna management area (Figure 16).

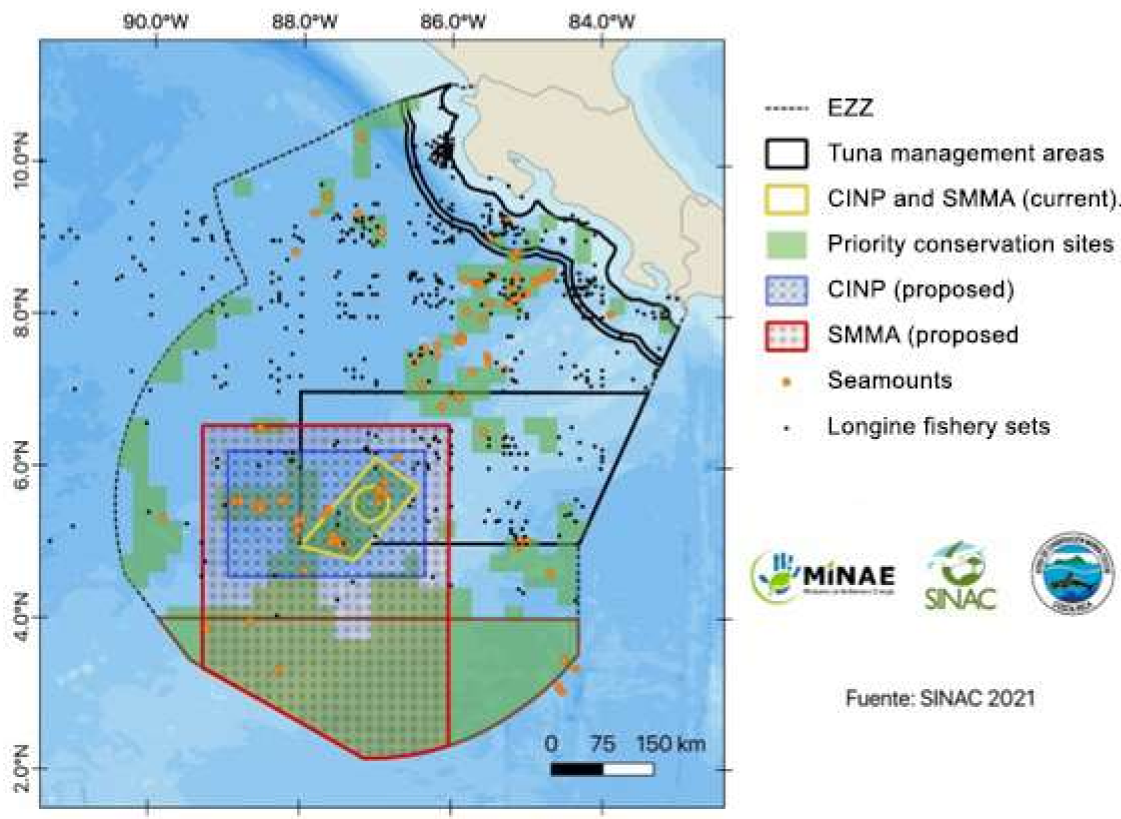

Figure 16. Third official version of proposed boundaries for CINP and the SMMA. CINP now consists of a 54,844 km^2 rectangle, and the SMMA of a 106,285.56 km^2 rectangle that reaches the limit of the Costa Rican EEZ that borders Ecuador. Source: SINAC, 2021.

The authorities then announced that 6 more consultative working sessions would be held with the fishery sector over the next 6 Fridays, to which the Minister of Environment personally requested my attendance. The intention was to complete this process by late December 2021 (Minister of Environment Andrea Meza Murillo, personal communication).

On November 12, 2021, the Ministry of Environment announced that the proposal to expand CINP and the SMMA would be submitted to a 5-day public consultation to receive inputs and observations, ending Friday November 19, 2021.

To assist the public during this process, the official proposal was posted on CREMA's website (a domestic NGO) explaining the issues to the public, including a recommended position statement calling for the orientation of the SMMA to be corrected and thus allow for the strict protection of the Cocos – Galapagos Swimway.

https://www.cremacr.org/en/help-conserve-the-biodiversity-of-cocos-island/

After the 6 working sessions with the fishery sector and the inputs and observations from the public were received, the government of Costa Rica announced the official expansion of CINP and the SMMA on December 17th , 2021, exactly as it had been announced on October 7th. Unfortunately, the calls and recommendations to change the orientation of the BMMA and expand it to encompass the oceanic rectangle tuna management area went unheard.

In a separate political process beyond the scope of this review, the government of Ecuador announced the creation of the Brotherhood Marine Reserve (BMR) on January 14, 2021 (Executive Decree N° 319), which reaches the limit of the Ecuadorean EEZ that borders Costa Rica's BMMA (Figure 17).

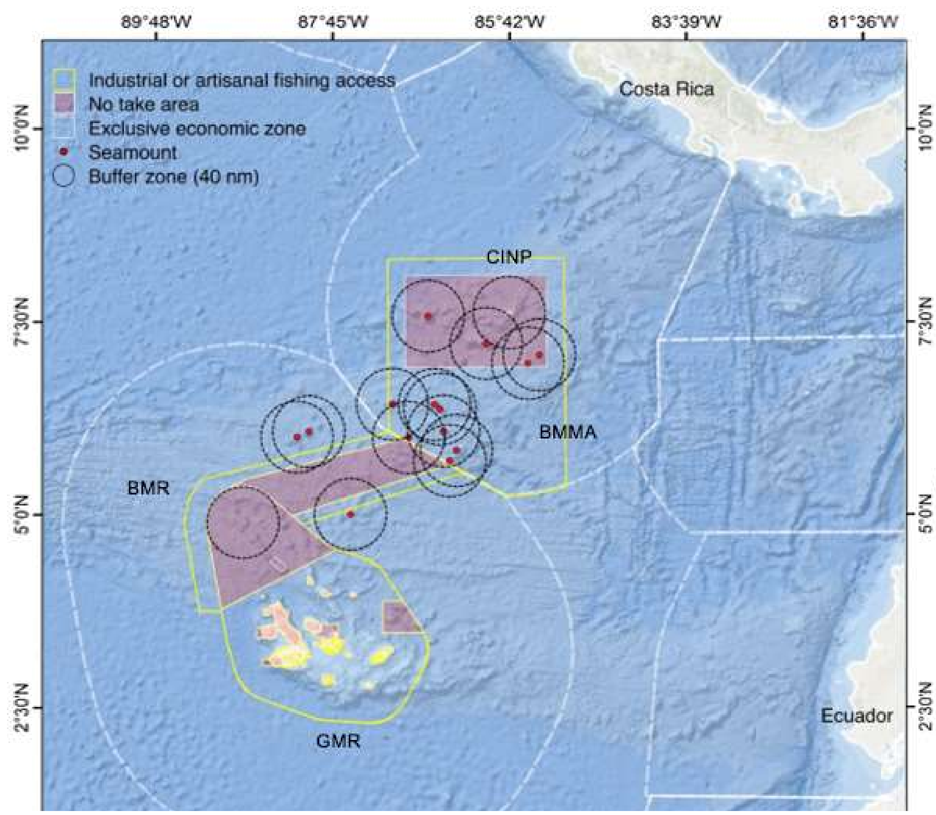

Figure 17. Recent expansion of MPAs in the EEZ´s of Costa Rica and Ecuador. Yellow line borders the expanded BMMA and the BMR, red areas within are no-take areas (CINP and BMR no-take area, respectively), black dots represent seamounts with corresponding recommended 40 nm no-take radius. Map by Migramar, 2022

This joint output does not, unfortunately, respond to the best science available regarding biological connectivity nor to the conservation needs of threatened marine species in the ETP. It positively includes the much-needed expansion of CINP's former no-take area from a 2,000 km^2 radius to the current 54,844 km^2 no-take rectangle, covering critical habitats such as Las Gemelas and West Cocos seamounts. The joint design of the Costa Rica's 106,285.56 km^2 BMMA and Ecuador's 60,000 km^2 BMR however, is flawed, as it does not protect the recommended 40 nm no-take radius around all of the shallow seamounts (less than 400 m) along the SCR and that constitute the Cocos - Galapagos Swimway, nor the buffer zone between its three most important seamounts regarding LPS richness and abundance: the fully protected West Cocos seamount in CINP, the fully protected Darwin and Wolf Islands in the GMR, and the unprotected Paramount seamount in the EEZ of Ecuador. As a result, sensitive species such as critically endangered hammerhead sharks are vulnerable while performing their regular back and forth movements from hotspot to hotspot . This outcome also fails to address the calls made by Costa Rica's NGOs, academia, and business sectors (fisheries and tourism) during the public consultation process, not only for the orientation of the BMMA to coincide with the seamounts of the Cocos Ridge, but for it to supersede the oceanic rectangle tuna management area and reach the border of the EZZ with Panama's CRMRA.

These flaws may hinder efforts to design an efficient Management Plan for the BMMA. If the orientation of the management area is not corrected to coincide with the seamounts of the Cocos Ridge prior to discussing further conservation policy, then critical areas of the Cocos-Galapagos Swimway on both Costa Rica's and Ecuador's sides will be beyond the governing body of their respective Ministries of Environment and thus, open to fisheries. Furthermore, a BMMA that connects with the CRMRA of Panama could have offered a unique opportunity for both countries to consolidate marine conservation policy directly through their corresponding Ministries of Environment and under the framework of CMAR.

Now that Costa Rica is about to initiate the process to design the Management Plan for the BMMA, it is critical that it responds to the conservation needs of the threatened marine species of the ETP, especially endangered and critically endangered species. Here, I present the following considerations to domestic marine conservation policy planners, and then proceed to recommend two possible political scenarios under my personal vision that lead to efficient marine conservation in Cocos – Galapagos Swimway.

First and foremost, the boundaries of the BMMA must be modified at a very early stage of the design of its Management Plan with a southeast-northwest -inclination, to coincide with the seamounts of the SCR, thus allowing for the adoption of transboundary policy that guarantees the conservation of biological connectivity throughout the Cocos – Galapagos Swimway. Given that this modification does not imply a reduction in marine protected area coverage, it can be adopted through an Executive Decree (Artículo 38, Ley Orgánica del Ambiente 7554; Artículo 58, Ley de Biodiversidad 7788). Discussions must be held simultaneously with the authorities of the Ministry of Environment of Ecuador, for this modification to be congruent with a modified BMR that fully protects Paramount seamount, which should be discussed and executed in the framework of the CMAR.

Once the boundaries of the BMMA are modified, then policy must be designed regarding the type of fisheries that will be allowed, which must be low-level non-industrial use and compatible with nature conservation, as well as time and area restrictions.

In this regard, tuna purse seine fisheries must be excluded from operating in the BMMA. The operation of tuna purse seiners had already been restricted from operating in large swaths of Costa Rica's EEZ with the creation of the tuna management zones since 2014, and the SMMA's Management Plan also excluded tuna purse seiners. The current 20% spike in tuna catches recorded over the last 5 years in the ETP (IATTC, 2023) is attributed in part to the exclusion of the tuna purse seiner fleet from the tuna management areas (Chinacalle, 2023).

The SMMA Management Plan banned longline fishery operations in the southern portion of the area that covered Las Gemelas Seamount but allowed longline operations with restrictions (shorter longlines with fewer hooks and use of circle hooks) in the rest. Since allowable fisheries in the BMMA will be discussed during the public consultation process, I will proceed to discuss certain limitations that could be imposed on the longline fishery to allow its operation in the BMMA, and their compatibility with nature conservation.

Allow longlining in the entire BMMA with restrictions. The same restrictions imposed in the SMMA's Management Plan could be considered for the BMMA, as well as additional restrictions such as reduced soaking time and use of monofilament instead of steel for the leaders (the line that connects the hook to the mother line). The Costa Rican longline fishery, however, has one of the highest global catch rates of sea turtles in the world, mainly vulnerable olive ridley sea turtles but including endangered green turtles and critically endangered leatherback sea turtles (Dapp et al, 2013). Furthermore, the fishery is heavily dependent on threatened shark species, which constituted slightly over 40% of its total catch (by specimens) from 2015 to 2021 (Arauz y Madrigal, 2022). Thus, reduced soaking time and shorter longlines with fewer hooks in the BMMA still implies the capture and mortality of threatened sea turtles and sharks, particularly critically endangered leatherback sea turtles and hammerhead sharks, during their respective post nesting migration to the southern hemisphere (Shillinger et al 2008) and regular interisland (Bessudo et al, 2011; Ketchum et al, 2014; Nalesso et al, 2019), and seamount (Chávez et al, 2020) migratory movements. The preferred use of smaller circle hooks by the domestic longline industry implies no reduction of turtle catch rates (Dapp, 2013), whereas the use of larger circle hooks, if mandated, could potentially reduce turtle catch rates, but at the same time increase the catch rates of threatened silky sharks and critically endangered hammerhead sharks (Andraka et al, 2013). A ban on the use of steel leaders would reduce shark catch rates, as sharks are able to use their sharp teeth to bite through commonly used monofilament fishing material and escape (Ward et al, 2008), but would bring no benefit to turtles.

Implement spatial and seasonal closures to the longline fishery in the BMMA. A no-take 40nm radius around the seamounts of the Cocos Ridge, particularly the ones with the highest diversity of LPS can be considered, while allowing fisheries in the buffer zone between them. This model can help protect highly migratory species during periods where they spend time at the sites, such as juvenile green turtles (Heidemeyer, 2015) and scalloped hammerhead sharks (Nalesso et al, 2019) but does not protect these species as they move from one seamount to another along the SCR. A total seasonal closure of the BMMA could be considered from March to April to protect post nesting leatherback sea turtles as they migrate from nesting beaches in Costa Rica towards the Galapagos Archipelago and then the gyres of southern hemisphere to feed (Shillinger et al, 2023), and from May to October to protect threatened sharks and sea turtles, corresponding to the months when mahimahi is less abundant and the longline fishery targets threatened sharks with high sea turtle bycatch rates (Dapp, 2013). Allowing restricted longlining activities in the BMMA for the other 4 months of the year, however, implies the catch and mortality of an array of threatened marine species, regardless of the implementation of a 40nm no-take radius around the seamounts.

Allow green stick fishing to target tuna in the BBMA. The Code of Federal Registrations of the United States (50 CFR § 635.2) defines green stick fishing gear as an actively trolled mainline attached to a vessel and elevated or suspended above the surface of the water with no more than 10 hooks or gangeons attached to the mainline. The mainline is attached to the vessel by means of an 11 to 15 m bamboo or fiberglass pole, and the gangeons are equipped with lures that dangle on the surface (Blankinship & McLaughlin, 2008, in Ross 2014). Due to its high selectivity towards tunas, the environmental impact is not as severe as other fishing arts like purse seining and longlining, while providing other benefits such as higher quality of fish, greater employment opportunities, reduced fuel combustion and protection of threatened sea turtles and sharks (Ross, 2014).

Green stick field trails held in 2017 and 2018 in Costa Rica's EEZ resulted in a highly selective catch (98.5%) of yellow fin tuna (*Thunnus albacares*), with greater catches of smaller specimens (90% of the total catch during the study) occurring in coastal waters in association with spinner dolphins (*Stenella longirostris),* and the identification of three potential areas where high quality tuna could be caught, one near Caño Island Biological Reserve (16 km from the coast of the Osa Peninsula) and two others in the oceanic rectangle tuna management area (Marín et al, 2019).

The combined effect of adopting a 40nm no-take radius around the seamounts of the BMMA, while allowing tuna green stick fishing in the buffer areas, could provide an alternative fishing activity for longliners if a seasonal longline closure were to be adopted, especially if such a closure were to be adopted throughout the EEZ.

Ban longline and tuna purse seiner fishing in the BMMA. Contrary to common concerns expressed by the fishing industry in the sense that large no-take marine protected areas just displace fishing effort and threatens their businesses and livelihoods, MPAs where fishing is prohibited benefit ocean biodiversity, help improve nearby fisheries, and mitigate climate change (Sala et al, 2021). For instance, 10 years after the creation of the GMR, it was found that fishing productivity increased in both the Galapagos EEZ surrounding the GMR, as well as inside the marine reserve (Bucarem et al. 2018). Likewise, the Hawaii longline fleet is reporting higher catch and catch per unit of effort since the creation of two U.S. National Monuments in the Pacific, which constitute two of the largest protected areas on Earth (Lynham et al, 2020), with clear evidence found that the protections afforded to two migratory species, bigeye and yellowfin tuna, led to spillover effects previously only seen for resident fish populations (Medoff et al, 2022). Similarly, an assessment of behavior and productivity of the Mexican industrial fishing fleet (purse seiners and longliners) before and after the implementation of the largest fully protected MPA in North America (the 147,000 km^2 Revillagigedo National Park), found no decrease in catches and no causal link between the variation of the spatial footprint of the industrial fleet and the implementation of the MPA (Favoretto et al, 2023).

Finally, a total ban of fisheries operations in the BMMA would have a minor impact on longline and tuna purse seine fisheries, as both concentrate most of their fishing effort in the northwestern area of Costa Rica's EZZ (Chinacalle et al, 2021).

Based on these considerations and different restrictions that could be imposed on the tuna purse seiner and longliner fisheries that currently operate in the area of interest, I hereby offer two scenarios to be considered by the authorities of Costa Rica and Ecuador, for the design of the future BMMA's Management Plan and the modification of the BMR to guarantee biological connectivity along the seamounts of the SCR, or the Cocos-Galapagos Swimway, as well as transboundary marine conservation policies that are compatible with marine conservation.

Scenario 1 (Figure 18) implies fewer changes to the current boundaries and guarantees protection to the most important seamounts of the SCR. The orientation of both the BMMA and the BMR must be modified to, at the very least, offer the opportunity to provide strict protection in the 40nm radius surrounding the seamounts with the highest abundance of LPS, West Cocos in Costa Rica and Paramount seamount in Ecuador, along with the buffer areas that join them to Ecuador's fully protected Darwin and Wolf Islands, precisely the area that constitutes the Cocos – Galapagos Swimway. Once this change in orientation has been attained, and in correspondence with an IUCN protected area management category VI, I propose the following zoning for the BMR: a 40-mile-wide strip of no-take waters from Darwin and Wolf Islands to Paramount Seamount, and from there to the border of the EEZ with Costa Rica, including an additional 20nm wide strip along the eastern flank of the BMR in which fisheries may have access. Furthermore, I propose the following zoning for the BMMA: a no-take policy from Costa Rica's border with Ecuador along the EEZ that limits the modified GMR, to CINP, leaving a triangle in the southeastern flank of the BMMA in which fisheries have access, as well as along the eastern and northern flanks of CINP. I propose that tuna green stick fishing may be allowed in these areas.

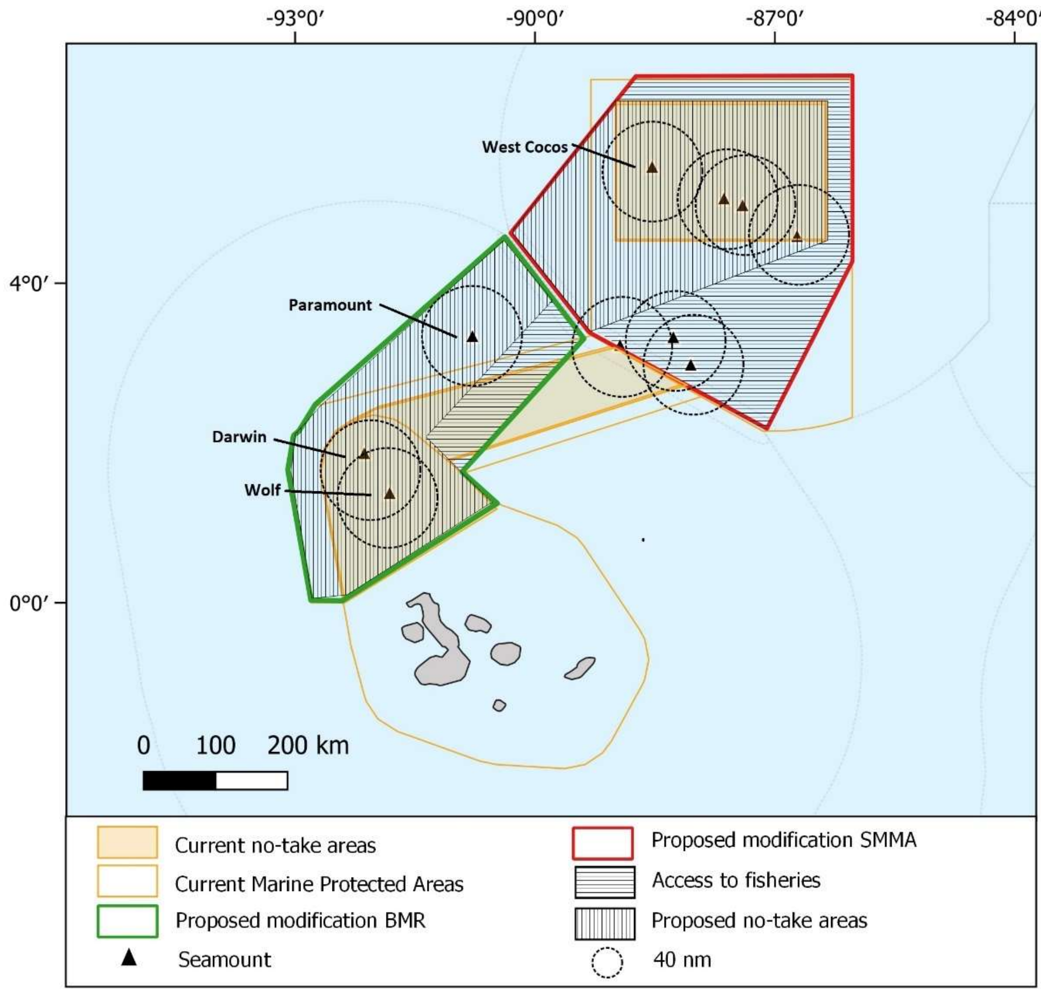

Figure 18. Scenario 1. Proposed modifications to the BMR and SMMA, including proposed zoning where no-take policy must be adopted and where fisheries may be granted access. Map by Migramar, 2022.

Furthermore, discussions are encouraged between the governments of Costa Rica and Ecuador to reach a consensus on the types of fisheries that should be allowed in the

BMMA and BMR. Currently, Ecuador has banned the use of longlines in the BMR, while allowing tuna purse seiners to operate with area restrictions, whereas Costa Rica is considering banning tuna purse seines in the BMMA, just as it had been in the former SMMA Management Plan yet is considering the allowance of longlining operations with area and gear restrictions. Transboundary marine conservation policy must be congruent between both nations.

Scenario 2 (Figure 19) is far more complete. It implies the protection of the entire Cocos-Galapagos Swimway under the authority of the Ministries of Environment of Costa Rica and Ecuador. The BMR would encompass the entire area described as the Cocos – Galapagos Swimway by Migramar in Ecuador's EEZ, where a no-take policy should be adopted in the 40nm radius surrounding the seamounts of the Cocos Ridge, whereas access could be granted to fisheries on the eastern side, where seamounts do not occur. The BMMA should be expanded to supersede the oceanic rectangle tuna management area, and zoned in such a way that fisheries are banned in the area corresponding to the Cocos – Galapagos Swimway in Costa Rica's EEZ, protecting the 40nm radius surrounding the seamounts as well as the buffer area that joins them, yet allowing fishing activities, such as tuna green stick fishing in the area that formerly belonged to the oceanic rectangle tuna management area and that borders the CRMRA of Panama, allowing for the design of transboundary marine conservation policy between the respective environment authorities of each country.

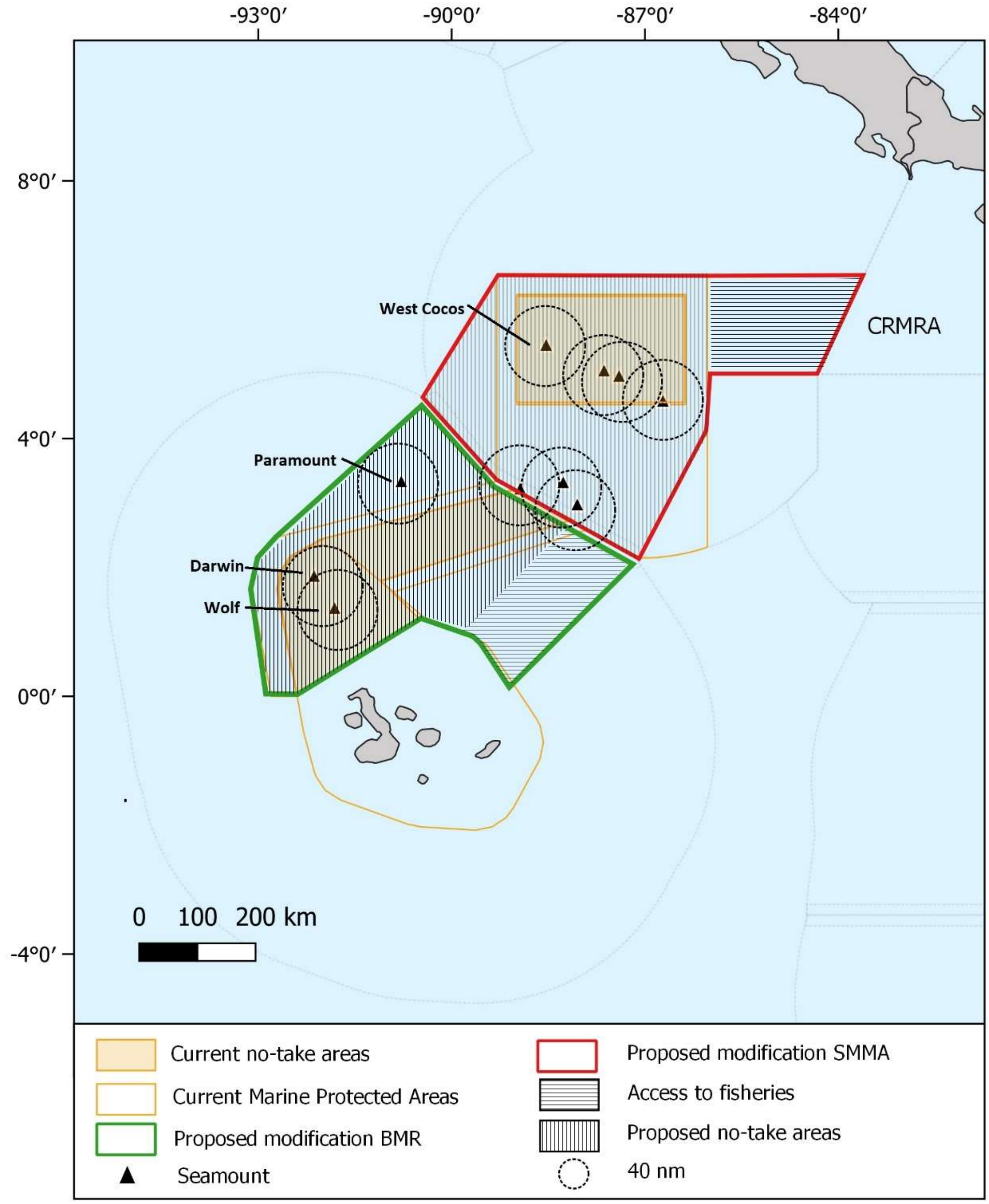

Figure 19. Scenario 2. Proposed modifications to the BMR and CINP, including proposed zoning where no-take policy must be adopted and where fisheries are granted access. Map by Migramar, 2022.

The efficient adoption of marine conservation policy can only be attained through the respective authorities of the ministry of environment of the region, working under close collaboration and considering the best available science for the establishment of policy, under the framework of domestic wildlife conservation laws and wildlife conservation conventions. It must be underscored that conservation of threatened highly migratory species cannot be attained by creating marine protected areas alone. Fisheries policy must also be established outside of marine protected areas by domestic fisheries authorities that favors the conservation of threatened marine species, such as a regional ban on the catch, retention, and commercialization of endangered and critically endangered species, as well as the adoption of a region-wide seasonal longline closure.

I will continue playing an active role in the design of effective marine conservation in the region. Through my affiliation with Migramar I will continue performing high-quality cutting-edge research on the migratory movements of highly migratory marine threatened species in the Eastern Tropical Pacific. Furthermore, through my membership in the IUCN's Species Survival Commission (SSC), the Marine Turtle Specialist Group (MTSG) and the Connectivity Conservation Specialist Group (CCSG), I will continue to use the best available science to influence marine conservation policy in domestic, regional, and global marine conservation forums.

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