Western and Central Pacific Fisheries Commission

SCIENTIFIC COMMITTEE
TWENTIETH REGULAR SESSION

Manila, Philippines
14 – 21 August 2024

Leatherback Sea Turtle Interactions in Western and Central Pacific Deep-Set Longline Fisheries

WCPFC-SC20-2024/EB-IP-09 (Rev.01)
6 August 2024

Irene K. Kelly[1], Melissa Snover[1], and Rob Ahrens[2]

[1] NOAA Fisheries Pacific Islands Regional Office
[2] NOAA Fisheries Pacific Islands Fisheries Science Center

Abstract

Pacific leatherback sea turtle (*Dermochelys coriacea*) populations continue to decline at alarming rates and fishery bycatch is considered a primary threat. Incidental capture, or bycatch, in deep-set fisheries targeting tuna are especially concerning because ~ 79% of longline fisheries operating in the Western and Central Pacific Ocean (WCPO) are deep-set fisheries that do not have sea-turtle specific required conservation and management measures (CMMs). This report compiles leatherback turtle bycatch and mortality estimates using data from the Western and Central Pacific Fisheries Commission (WCPFC), and also focuses on a subset of this larger data set by analyzing leatherback turtle interactions and estimated mortality from the Hawaii longline fisheries. Leatherback interaction rates are 0.0055 and 0.00026 per 1,000 hooks in Hawaii's shallow-set (<15 hooks between floats) and deep-set (=> 15 hooks between floats) fisheries, which have 100% and ~20% fisheries observer coverage, respectively. Despite a lower rate of interaction in the deep-set fishery, its effort represents ~ 97% of total longline fishing effort (per number of hooks set), and thus results in a much higher number of estimated interactions and mortalities. Therefore, we report that in Hawaii's fisheries, there are more interactions and mortalities of leatherback turtles in deep-set fisheries as compared to shallow-set.

Previous estimates of fisheries interactions and impacts to sea turtle populations in the WCPFC Convention Area indicate a trend of both increased effort in deep-set longline fisheries as well as an associated increased interaction rate and potential impacts to Pacific leatherback turtles (Peatman et al. 2019). However, fisheries interaction data reported by the WCPFC are derived from fleets with low observer coverage (1 to 3%) and spatially limited coverage (Peatman et al. 2019), thereby limiting abilities to understand the impacts of these trends on leatherback populations. Data from Hawaii's longline fleets, which have ~20% (deep-set) and 100% (shallow-set) observer coverage, could be useful in providing a more accurate understanding of the impacts of deep-set longline fishing on leatherback populations in the Pacific Ocean.

In this paper, we apply mortality rates based on data obtained from Hawaii's deep-set longline fishery to better understand the potential impacts to leatherback turtles from fisheries interactions in the WCPFC Convention Area. Previous work (Peatman et al. 2019) estimates an annual interaction of ~ 257 leatherbacks per year, which we estimate to result in 90 mortalities using the mortality rate from Hawaii's deep-set longline fishery. We also report on an alternative approach to estimate leatherback interactions in the WCPFC using interaction rates derived from Hawaii's longline fishery, for which there is relatively high (~20%) observer coverage. Given concerns regarding the population decline of Pacific leatherback turtles, our data indicate a high conservation value if the current WCPFC Sea Turtle CMM (2018-04) were expanded to include measures to address deep-set longline fisheries. Additionally, our findings highlight the importance of increasing observer coverage levels in order to improve accuracy of estimates of bycatch and mortality, thereby improving the Commission's ability to sustainably manage fisheries and resources within the WCPO.

1 Introduction

Bycatch in pelagic longline fisheries continues to threaten the recovery of vulnerable and protected species, such as sea turtles. The most critical of these species is the leatherback sea turtle (*Dermochelys coriacea*) whose already perilous Pacific Ocean populations continue to decline by at least 6% per year (Benson et al. 2015; Martin et al. 2020; Tapilatu et al. 2013; Tiwari et al. 2013; Wallace et al. 2013a). The recovery and conservation of the species is dependent upon the cooperation and engagement of the international community including nations with fisheries operating throughout the Western and Central Pacific Ocean (WCPO).

The reduction of pelagic fishery bycatch and mortality is a high priority recovery need (Lewison et al. 2014; NMFS and USFWS 1998; NMFS and USFWS 2020; Roe et al. 2014; Tiwari et al. 2013; Wallace et al. 2011, 2013b), yet conservation and management measures for all longline fisheries operating within the WCPO are lacking (Clarke 2017). Of Pacific leatherback turtles, the West Pacific component of the population as it is most relevant to the management jurisdiction of the Western and Central Pacific Fisheries Commission (WCPFC). This report does not include solutions to mitigate interactions, but aims to present data and information to raise awareness of the impacts of deep-set pelagic longline fisheries on leatherback turtles; the mitigation of which remains an important conservation gap and recovery need.

2 Pacific Leatherback Sea Turtle Background

Leatherback sea turtles are distributed throughout the oceans of the world from the equator to subpolar regions in both hemispheres. There are two populations occurring within the Pacific Ocean basin: the West Pacific and East Pacific populations. West Pacific leatherback turtles primarily nest in Indonesia, the Solomon Islands and Papua New Guinea, and East Pacific leatherback turtles primarily nest in Mexico and Costa Rica (Benson et al. 2015; Eckert et al. 2012; Tiwari et al. 2013; Wallace et al. 2013a).

2.1 Status and Pelagic Habitats

Leatherback turtles are listed under the IUCN Red List as “critically endangered” in the Pacific Ocean (IUCN 2024). In the United States (US), leatherback turtles are listed under the Endangered Species Act as endangered throughout their global range. The West Pacific population has been estimated to have declined by 83% during the past three generations (30 years), with an estimated long-term decline of 6% per year (Martin et al. 2020; Tapilatu et al. 2013; Tiwari et al. 2013). In 2017, an estimated 790 females nested at the primary Indonesian beaches, with 1,054 total females (95% CI: 888 to 1,256) in the population at that time, with an estimated total of 1,443 mature adults (i.e., males and females, Martin et al. 2020). The East Pacific population has declined by more than 97% over three generations with currently less than 140 nesting females per year (Wallace et al. 2013a). Given the management jurisdiction of the WCPFC, this report will focus on the West Pacific leatherback population as fishery interactions are most likely to be with this component of the Pacific population (e.g., 96% of leatherback turtle interactions in the Hawaii longline fishery is with the West Pacific population; NMFS 2024).

West Pacific leatherback turtles migrate to and from nesting beaches and foraging habitats, spanning much of the Pacific rim (Benson et al. 2011; Figure 1). Additionally, there is clear geographic separation of migratory and foraging destinations based on nesting season (Eckert et al. 2012; Benson et al. 2011; Benson et al. 2015; Tiwari et al. 2013). Summer (mid-year) nesting females primarily from Indonesia and Solomon Islands migrate through the Northern Hemisphere foraging throughout Asia and the North Pacific Ocean, while winter (end-of-year) nesting females primarily from Papua New Guinea and the Solomon Islands migrate to tropical waters of the Southern Hemisphere in the South Pacific Ocean (Benson et al. 2011; Harrison et al. 2018). In addition to pelagic habitats, there are important coastal foraging habitat that have been identified, including the west coast of California (Benson et al. 2007, 2020), the Maluku region of the Kei Islands, Indonesia (Benson et al. 2011; Suarez and Starbird 1996), southeast Australia (Dunn et al. 2023), and the northeast coast of New Zealand (Bay of Plenty, North Island; Hays et al. 2023).

Additionally, genetic analyses of leatherback turtles caught in fisheries off Peru and Chile indicate that approximately 15% of sampled individuals originate from the West Pacific, likely end-of-year (winter) nesting females that have migrated across the Southern Hemisphere to the productive waters off South America (Donoso and Dutton, 2010).

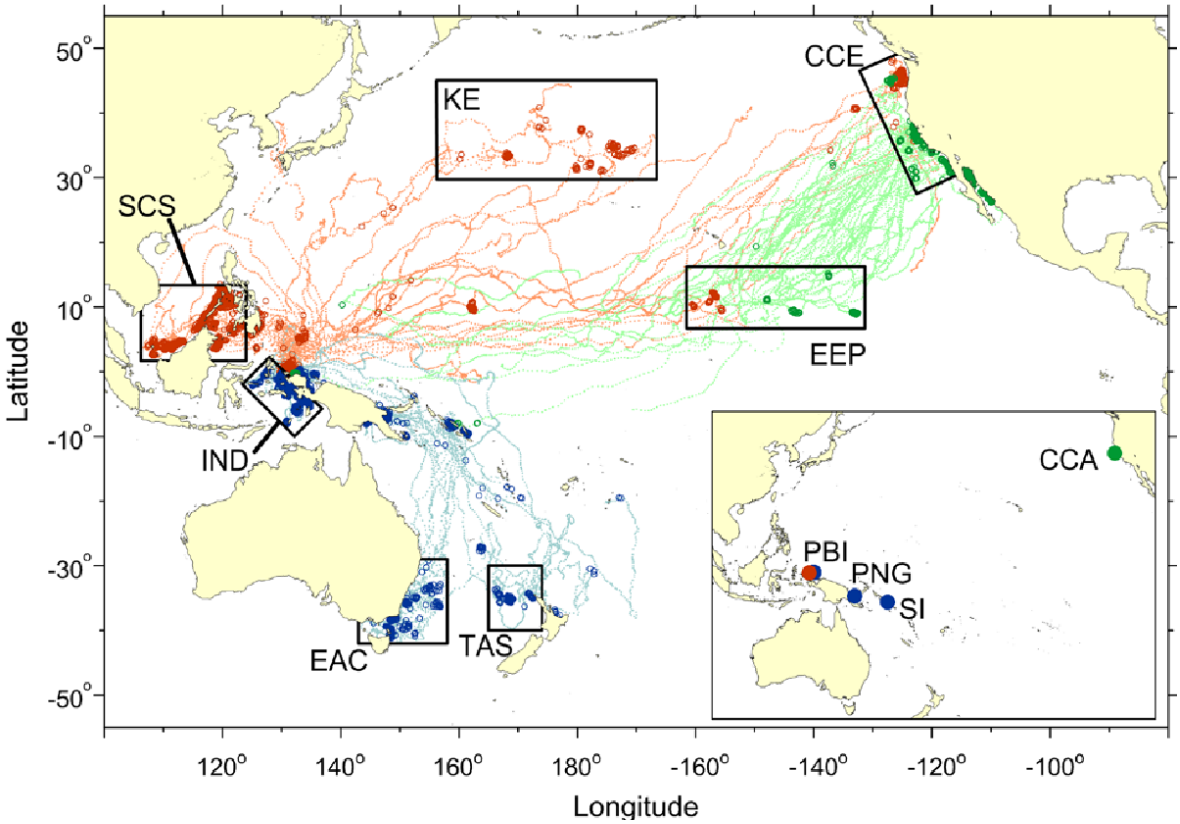

Figure 1. West Pacific leatherback turtles, satellite tracked from nesting beaches or at sea. (Figure 1 from Benson et al. (2011), used with permission), showing 126 satellite tag deployments presented as probability of transit. Large, darker circles indicate Area Restricted Search behavior; small, lighter dots indicate transiting behavior. Color of track indicates deployment season: red = summer nesting

females, blue = winter nesting females, green = deployments at central California foraging grounds. Inset shows deployment locations: PBI = Papua Barat, Indonesia, PNG = Papua New Guinea, SI = Solomon Islands, CCA = central California. Black boxes represent ecoregions for which habitat associations were quantitatively examined: SCS = South China, Sulu and Sulawesi Seas, IND = Indonesian Seas, EAC = East Australia Current Extension, TAS = Tasman Front, KE = Kuroshio Extension, EEP = equatorial eastern Pacific, and CCE = California Current Ecosystem.

2.2 Fishery Bycatch - Primary Marine Threat

In the open ocean, leatherback turtles are exposed to fishery bycatch, pollution and entanglement in (or ingestion of) marine debris, climate change, vessel strikes, and direct human take (Benson et al. 2015; Eckert et al. 2012; Hitipeuw et al. 2007; NMFS and USFWS 2020; Tiwari et al. 2013; Wallace et al. 2013a,b). Pacific leatherback populations are exposed to fishery bycatch throughout their extensive pan-Pacific marine foraging and migratory range. While little is known about the total magnitude or full geographic extent of mortality, the information that does exist identifies fishery bycatch as the primary marine threat to leatherback sea turtles (Benson et al. 2011, 2015; Beverly and Chapman 2007**;** Clarke 2017; Eckert et al. 2012; Lewison et al. 2014; NMFS and USFWS 2020; NMFS and USFWS 2021; Peatman et al. 2019; Tiwari et al. 2013; Wallace et al. 2013a,b).

For the West Pacific leatherback population, several areas of high fishery bycatch risk exist in the WCPO, with the greatest risk adjacent to primary nesting beaches in tropical seas of Indo-Pacific islands, in the Sulu, Sulawesi, and South China Seas (Benson et al. 2011; Lewison et al. 2014; Roe et al. 2014; Wallace et al. 2013b). Additionally, the summer nesting component of the West Pacific leatherback population exhibits strong site fidelity to the central California foraging area (Benson et al. 2007, 2011, 2020), which puts migrating leatherbacks at risk of interacting with pelagic longline fleets operating throughout the central and north Pacific Ocean.

Clarke (2017) analyzed fishery observer data collected between 1989 and 2015 of 34 purse seine and longline fleets across the Pacific that documented a total of 2,323 sea turtle interactions, of which 331 were leatherback turtles. Two bycatch hotspot areas were identified: one in the central North Pacific (which reflected the 100 percent observer coverage in the Hawaii shallow-set longline fishery) and a second hotspot near eastern Australia (Clarke 2017), yet the author indicates these data are unlikely to be representative of all bycatch hotspots as the data are obtained by fishery observer programs, which are not extensive and are concentrated in certain nations fishing fleets. Recent studies report on leatherback bycatch and stranding data from New Zealand and Australia that provides insights into fishery-induced impacts in the data poor region of the South Pacific (Dunn et al. 2023; Hays et al. 2023). In New Zealand's shallow-set longline fishery, observers have documented an increase in leatherback captures from one turtle in 2008 to 50 in 2022, with an average of 15.5 captures per year (Dunn et al. 2023).

3 WCPFC Sea Turtle Conservation and Management Measure

In 2008, the WCPFC adopted a Sea Turtle Conservation and Management measure (CMM 2008-03) to mitigate the impacts on sea turtles in shallow-set longline swordfish fisheries operating in the WCPO. This measure applied to fleets targeting swordfish fishing in a shallow-set manner, but fleets

were allowed to formulate their own definition of "shallow-set". Such shallow-set swordfish fleets were required to use large circle hooks with offsets of 10 degrees or use whole finfish for bait (among other measures).

A workshop convened in 2016 to assess the effectiveness of the CMM 2008-03 found limited reductions in interactions and mortalities, and concluded that the overall conservation benefits would have been greater had mitigation measures been applied to deep-set gear and not just shallow-set fisheries alone (Clarke 2017). Notably, Clarke's (2017) analysis was based on limited observer data (<1 %) with the exception of the Hawaii shallow-set longline fishery.

In 2018, the WCPFC expanded the sea turtle CMM by adopting CMM 2018-04 to ensure the safe handling, release, and reporting of captured sea turtles for shallow-set vessels and purse seine fisheries, and to require large circle hooks or finfish bait for ALL shallow-set longline vessels fishing at depth shallower than 100 meters. There was no agreement at that time to expand the measure to apply to deep-set longline fisheries, which constitute a significant proportion (approximately 80%) of the WCPO longline effort (Clarke 2017; Peatman et al. 2019); however, the following language was included in the revised measure (CMM 2018-04, para. 12):

> *12. This measure will be reviewed by the Commission in 2021 to consider expanding the scope of the measure to include mitigation measures for deep-set longline fisheries, based on advice from the SC and TCC and on information provided by CCMs pursuant to this measure.*

4 Deep-set Longline Interactions in WCPO Fisheries

Between 2013 and 2022, a total of 181 leatherback turtle interactions were reported (from observer data) to the WCPFC by participating countries for longline fisheries operating in the WCPO. Of the 181 observed turtle interactions, 21 were dead upon retrieval (at-vessel mortality) (WCPFC. 2023). The average annual observed number of leatherback sea turtle interactions reported to the WCPFC between 2013 and 2022 was 18 (95% CI: 14-22), including one (95% CI: 1-3) at-vessel mortality (WCPFC 2023). These data were based on an average observer coverage levels of 3.1% (95% CI: 2.6% to 3.7%).

Peatman et al. (2019) assessed how WCPO longline fisheries captures differed between deep- and shallow-sets, defining deep vs. shallow sets based on the number of hooks between floats (HBF), with 10 or fewer HBF representing shallow sets and greater than 10 HBF representing deep sets. Peatman et al. (2019) note that from 2003 to 2006, only 25 to 35% of logbook data contained information on HBF which introduced more uncertainty in the estimates for that timeframe. Since 2007, at least 50% of logbook data contained information on HBF, and over 80% from 2014 to 2017 (Figure 2). Therefore we focus on the data from 2007 to 2017 in Peatman et al. (2019). Based on the data presented by Peatman et al. (2019), between 2007 and 2017, an average of 79% of longline sets in the WCPO were deep sets (Figure 3). Since 2007 there has been a significant increase in the proportion of WCPO longline fishery effort attributed to deep-sets over time (Figure 3).

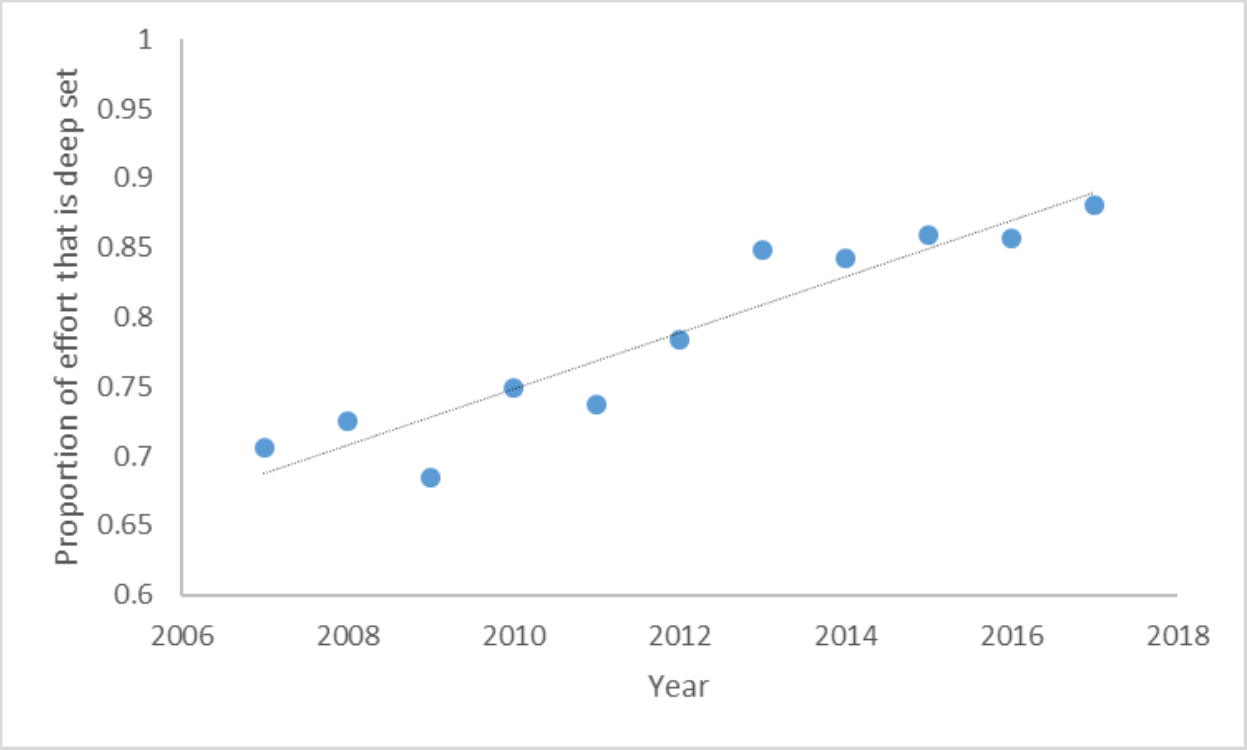

Figure 2. Trend in the proportion of WCPO longline fishing effort (number of hooks) that are attributed to deep-sets based on the number of hooks between floats (data from Table 2 of Peatman et al. 2019). Solid line indicates a least-squares linear regression fit to the 2007 to 2017 data ($R^2 = 0.89$, $F_{1,9} = 71.9$, $p < 0.001$).

Peatman et al. (2019) indicate an average of 42% of the estimated WCPO leatherback turtle captures in WCPFC Convention Area were in deep-set fisheries (Figure 3). From 2007 through 2017, there has been a similar significant increase in the percent of total estimated leatherback captures attributed to deep-sets over time (Figure 3). Peatman et al. (2019) acknowledges that data analysis was challenging because overall average observer coverage in the WCPF Convention Area between 2003 to 2017 was < 1%.

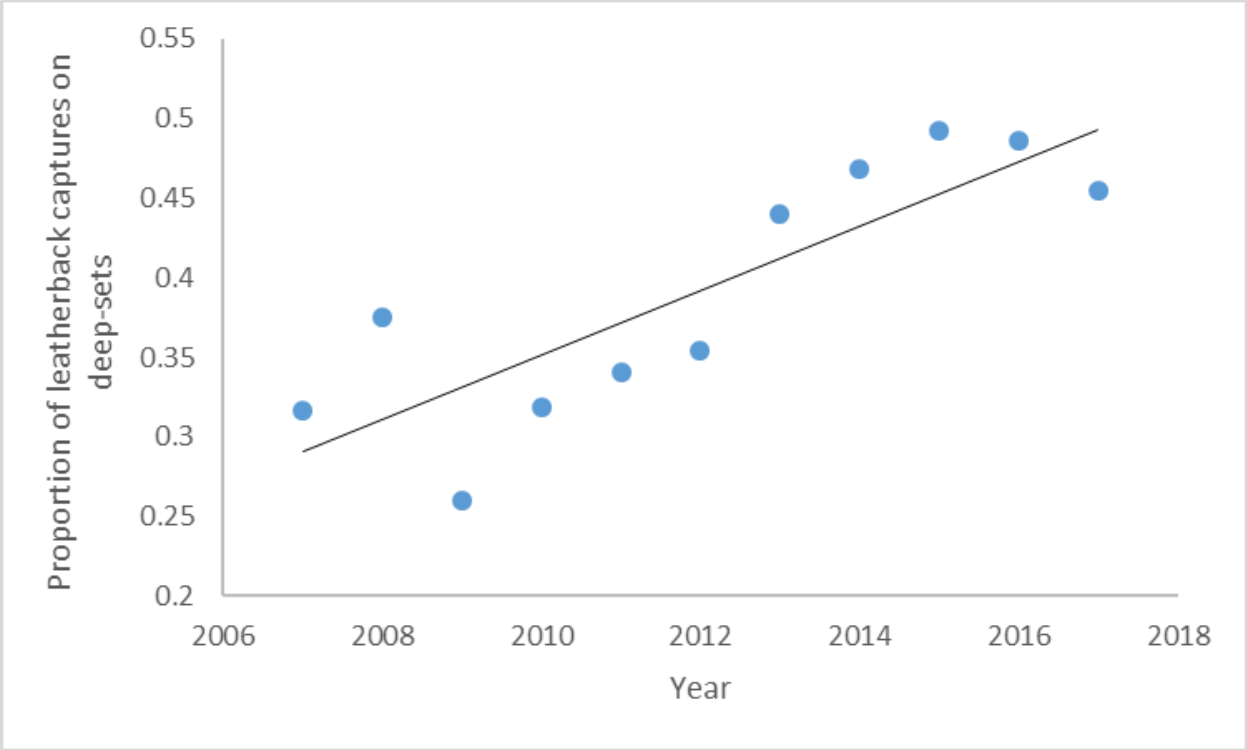

Figure 3. Trend in the proportion of estimated leatherbacks captured in WCPO longline fisheries that were captured on deep-sets based on the number of hooks between floats (data from Table 33 of Peatman et al. 2019). Solid line indicates a least-squares linear regression fit to the 2007 to 2017 data ($R^2 = 0.71$, $F_{1,9} = 21.8$, $p = 0.0012$).

5 Hawaii Longline Fisheries: Shallow-set and Deep-set

The Hawaii shallow-set longline fishery (SSLL) has a higher catch rate for leatherback sea turtles (0.0055 turtles per 1,000 hooks; WPRFMC 2023) compared to the Hawaii deep-set longline fishery (DSLL) (0.00026 turtles per 1,000 hooks; WPRFMC 2023). However, in terms of annual effort, similar to WCPFC fisheries, the DSLL represents a much higher percentage 97.5% (95% CI: 97% to 98%) of the Hawaii longline fishery effort. As an example, in 2022, the DSLL set 63.3 million hooks while the SSLL set 1.1 million hooks (WPRFMC 2023).

5.1 Hawaii shallow-set longline fishery

The SSLL fishery has 100% observer coverage, which provides robust data on the number of interactions (i.e. hooking and entanglement) of threatened and endangered species. Since enactment of gear modifications in 2004 (NMFS 2004)[1], the number of leatherback sea turtle interactions has declined by 84% (Swimmer et al. 2017).

[1] In 2004, the Hawaii longline fishery was separated into shallow and deep-set sectors and managed as two independent fisheries (NMFS 2004). Hawaii longline fisheries management is complex and driven, in large part, to reduce impacts to protected and sensitive species (e.g., sea turtles, marine mammals, and elasmobranchs). A summary of regulations and gear requirements can be found in this compliance guide: https://media.fisheries.noaa.gov/2022-07/hawaii-longline-reg-summary.pdf

In the SSLL fishery, there have been a total of 121 leatherback turtle interactions (observed hooked or entangled, but all released alive) between 2004 to 2022. Applying the delayed or post-release mortality coefficients of Ryder et al. (2006) as based on hook location, release condition and presumed degree of injury, the US NMFS (2019) conservatively estimated a mean mortality rate of 20% (95% CI: 14% to 290%). Hence, 24 leatherback turtles are estimated to have died between 2004 and 2022 despite being released alive.

5.2 Hawaii deep-set longline fishery

The Hawaii deep-set longline fishery (DSLL) has expanded from 32 million hooks set in 2004 to a high of 65.4 million hooks set in 2021 (WPRFMC 2023). Between 2004 to 2022, annual observer coverage has ranged from 19.6% to 26.0%, and fishery observers documented 46 leatherback sea turtle interactions (9 of these [~ 20%] were retrieved dead). Applying the post-interaction mortality coefficients of Ryder et al. (2006) based on hook location and release condition,[2] NMFS (2023) estimated a mean total mortality rate of 35% (95% CI: 23% to 50%) that is inclusive of at-vessel and post-interaction mortality. On average, NMFS expects a mean of 17 (95th Percentile: 43) leatherback turtles to be captured each year in the DSLL fishery (NMFS 2023).

In order to track the number of leatherbacks potentially captured in this fishery, a Bayesian Conway-Maxwell-Poisson model is used to estimate total captures based on observed captures and effort each year (NMFS 2023: McCracken 2019, McCracken and Cooper 2020, 2021, 2022, 2023). Based on these estimates, approximately 246 leatherback sea turtles were captured in the DSLL fishery during the 19-year period from 2004 to 2022 (NMFS 2023). Using the mean total mortality rate of 35%, approximately 86 leatherbacks may have died in the fishery during this time period; more than three times the estimated mortality in the Hawaii SSLL fishery. As the Hawaii DSLL fishery exhibits similar operational characteristics (deep daytime sets) and target species (bigeye tuna) as conducted worldwide by many distant-water fishing nations (Curran and Bigelow 2011), comparison to the broader WCPFC longline fisheries in terms of potential impacts is reasonable.

6 WCPFC Convention Area: Leatherback Interactions

Given the high fishing effort in the WCPO, the potential impacts of deep-set longline fisheries on populations of Pacific leatherback turtles may be quite high. Peatman et al. (2019) note that observer coverage levels are low and not ideally spatially distributed, and there are particulars with respect to the spatial overlap between leatherbacks and the fishery that are not represented in the data. These shortcomings aside, based on the available observed interactions, rough estimates of the potential impact of the WCPFC deep-set fishery can be produced. Using the 42% of interaction coming from deep-set in Peatman et al. (2019), the average of 18 annual interactions and one mortality observed in the WCPFC Convention Area, and a 3.1% observer coverage rate, suggest the potential for 257 interactions ((18+1)/0.031= 613 total interactions; 613*0.42 = 257 deep-set

[2] Coefficients are assigned based on an assumed degree of injury (such as if the hook was ingested versus external, if entangled in the line, if gear was removed from the animal, or if the animal is released with trailing gear, etc.), to indicate an assessment of likelihood of survival or mortality (Swimmer and Gilman 2012; Griffiths et al. 2024).

interactions). If the 35% total mortality (at-vessel and post-release) is applied to the interactions (based on robust data from the Hawaii DSLL), a total of 90 mortalities could be occurring each year in the WCPO deep-set longline fisheries.

An alternative estimate is to use the Hawaii DSLL fishery interaction and mortality rates with an estimated total deep-set longline effort in the WCPFC Convention Area. Over the last decade there have been approximately 538 to 703 million hooks deployed in the WCPFC Convention Area (SPC unpublished data). Using a simplified estimate of the observed Hawaii DSLL fishery interaction rate of ~0.00026 turtles per 1,000 hooks, 138 to 180 interactions could have occurred annually resulting in an estimated mean 48 to 63 mortalities each year (assuming a 35% at vessel and post-release mortality rate (Table 1)). These estimates have wide confidence intervals given the variability in the annual Hawaii DSLL interaction rate. Mortalities from the WCPO deep-set longline fishery are not inconsequential given West Pacific leatherback turtle population numbers.

Table 1. Estimated deep-set annual effort, in 1,000s hooks, in the WCPFC Convention Area and the estimated number of leatherback turtle interactions assuming a Hawaii DSLL fishery annual interaction rate (0.00026 leatherback turtles per 1,000 hooks) and associated mortalities (assuming a 35% at-vessel and post release mortality rate). Lower (L) and upper (U) 95% confidence intervals only include uncertainty in the Hawaii DSLL fishery interaction rate.

Year	1000s Hooks	L 95% CI	Mean # of interactions	Mean # of mortalities	U 95% CI
2014	593620.4	0	152	53	357
2015	627678.4	0	160	56	378
2016	614609.8	0	157	55	370
2017	631351.8	0	161	56	380
2018	661789.2	0	169	59	398
2019	703607.5	0	180	63	423
2020	665761.4	0	170	60	401
2021	608069.5	0	155	54	366
2022	587395.6	0	150	53	353
2023	538264.1	0	138	48	324

7 Conclusion

The life history and pan-Pacific migratory nature of leatherback sea turtles puts them at risk and vulnerable to numerous threats on the high seas, most notably fisheries bycatch (NMFS and USFWS 2020). While bycatch in pelagic shallow-set longline fisheries has received the most attention to date, deep-set longline fisheries cannot be ignored (Clarke 2017; FAO 2014).

The Hawaii DSLL fishery has almost double the estimated interactions, and more than three times the number of estimated mortalities than the Hawaii SSLL fishery, despite a lower rate of interactions per 1,000 hooks. The deep-set longline fisheries constitute significantly more effort than shallow-set longline fisheries in the WCPFC Convention Area (at least 97% more effort in Hawaii and four times greater effort within the WCPO) and more leatherback turtles are likely to be caught and die in deep-set longline fisheries due to greater effort and depth of operations compared to shallow-set fisheries.

Peatman et al. (2019) estimates interactions based on the interaction rate derived from the percentage of observer coverage in the WCPFC. However, these estimates may be limited due to both leatherback turtle distribution (see Figure 1; Roe et al. 2014) and uneven spatial distribution of observer coverage among fisheries and regions in the WCPFC Convention Area (Clarke 2017). In addition, historical observer coverage in some areas has been as low as <1-2% (Peatman et al. 2019). The issue is of particular concern in some areas, including in the north temperate region, where there is a particularly high level of effort with an associated historic level of observer coverage as low as < 0.3% (Peatman et al. 2019).

The WCPFC Scientific Committee acknowledges that the current required level of observer coverage in the WCPFC (5%) has not provided accurate estimates of longline bycatch, and that robust estimation of longline bycatch bycatch is currently very difficult given the low levels and spatially imbalance nature of observer coverage (SC19 Summary Report, Para. 40). However, despite low observer coverage, our assessment of available data indicates that leatherback turtle interactions in WCPO deep-set fisheries are likely increasing at a similar rate as effort in the fishery (Figures 2 & 3). Updated analysis of WCPO pelagic longline fishery interactions is warranted given that Peatman's (2019) data ended in 2017. However, estimating interactions based on the number of hooks set within the WCPO, and applying interaction and mortality rates from the Hawaii DSLL fishery, approximately 138 to 180 interactions may occur annually, resulting in an estimated 48 to 63 mortalities each year assuming a 35% at-vessel and post-release mortality rate. If extrapolations are based on data reported to the WCPFC, then interactions could be as high as 257 leatherbacks per year, with 90 mortalities.

Given concerns regarding population decline and status of the western Pacific leatherback turtle population, our data indicate a high conservation value if the WCPFC conservation and management measures aimed to protect sea turtles applied to all longline fisheries, independent of depth or target fishery. Importantly, the increasing effort of WCPO deep-set fisheries is likely resulting in higher interaction and mortality rates than previously reported by Peatman et al. (2019). We also note that current observer coverage levels in WCPFC longline fisheries are likely insufficient to adequately estimate the impact of deep-set longline fisheries on leatherback turtles. Higher observer coverage levels would reduce confidence intervals and strengthen statistical analysis, which can better inform fisheries management efforts and support more effective recovery efforts.

8 References

Beverly, S., and L. Chapman. 2007. Interactions between sea turtles and pelagic longline fisheries. Third Regular Session of the Scientific Committee of the Western and Central Pacific Fisheries Commission. p. 13-24.

Benson, S. R., Forney, K. A., Harvey, J. T., Carretta, J. V., and P. H. Dutton. 2007. Abundance, distribution, and habitat of leatherback turtles (*Dermochelys coriacea*) off California, 1990–2003. *Fishery Bulletin. 105(3):337-347.*

Benson, S. R., Eguchi, T., Foley, D. G., Forney, K. A., Bailey, H., Hitipeuw, C., Samber, B. P., Tapilatu, R. F., Rei, V., Ramohia, P. et al. 2011. Large-scale movements and high-use areas of western Pacific leatherback turtles, *Dermochelys coriacea*. *Ecosphere. 2(7):art84.*

Benson, S. R., Tapilatu, R.F., Pilcher, N., Santidrián Tomillo, P., and S. L. Martinez. 2015. Leatherback turtle populations in the Pacific. In: Spotila, J. and Santidrián Tomillo, P.(Eds.). The Leatherback Turtle: Biology and Conservation. Johns Hopkins University Press.

Benson, S.R., K.A. Forney, J.E. Moore, E.L. LaCasella, J.T. Harvey, and J.V. Caretta. 2020. A long-term decline in the abundance of endangered leatherback turtles, Dermochelys coriacea, at a foraging ground in the California Current Ecosystem. *Global Ecology and Conservation 24: e01371.*

Clarke, S. 2017. Joint analysis of sea turtle mitigation effectiveness. Western and Central Pacific Fisheries Commission. Common Oceans (ABNJ) Tuna Project Workshop. WCPFC-SC13-2017/EB-WP-10.

Curran, D. and K. Bigelow. 2011. Effects of circle hooks on pelagic catches in the Hawaii-based tuna longline fishery. *Fisheries Research 109 (2011) 265–275.*

Donoso M, Dutton PH. 2010. Sea turtle bycatch in the Chilean pelagic longline fishery in the southeastern Pacific: opportunities for conservation. *Biological Conservation: 143(11) 2672-2684. https://doi.org/10.1016/j.biocon.2010.07.011*

Dunn MR, Finucci B, Pinkerton MH, Sutton P and Duffy CAJ. 2023. Increased captures of the critically endangered leatherback turtle (*Dermochelys coriacea*) around New Zealand: the contribution of warming seas and fisher behavior. *Front. Mar. Sci. 10:1170632. doi: 10.3389/fmars.2023.1170632*

Eckert KL, Wallace BP, Frazier JG, Eckert SA, Pritchard PCH. 2012. Synopsis of the biological data on the leatherback sea turtle (*Dermochelys coriacea*). U.S. Fish and Wildlife Service, editor. Washington, D.C.: Biological Technical Publication.

FAO. 2014. Bycatch in longling fisheries for tuna and tuna-like species. A global review of status and mitigation measures. FAO Technical Paper 588. p. 200.

Griffiths et al. 2024. Vulnerability of the Critically Endangered leatherback turtle to fisheries bycatch in the eastern Pacific Ocean. II. Assessment of mitigation measures. Vol. 53: 295–326. ENDANGERED SPECIES RESEARCH. https://doi.org/10.3354/esr01305

Hays, G. C., Morrice, M., and J. J. Tromp. 2023. A review of the importance of south-east Australian waters as a global hotspot for leatherback turtle foraging and entanglement threat in fisheries. *Marine Biology (2023) 170:74; https://doi.org/10.1007/s00227-023-04222-3*

Harrison, A.-L., D. P. Costa, A. J. Winship, S. R. Benson, S. J. Bograd, M. Antolos, A. B. Carlisle, H. Dewar, P. H. Dutton, and S. J. Jorgensen. 2018. The political biogeography of migratory marine predators. *Nature Ecology & Evolution. 2(10):1571-1578.*

International Union for Conservation of Nature (IUCN). 2024. Leatherback, *Dermochelys coriacea* (West Pacific Ocean subpopulation). Available at: https://www.iucnredlist.org/species/46967817/46967821.

Lewison, R. L., and coauthors. 2014. Global patterns of marine mammal, seabird, and sea turtle bycatch reveal taxa-specific and cumulative megafauna hotspots. Proceedings of the National Academy of Sciences 111(14): 5271-5276.

Martin, S.L., Z. Siders, T. Eguchi, B. Langseth, A. Yau, J. Baker, R. Ahrens, TT. Jones. 2020. Update to assessing the population-level impacts of North Pacific loggerhead and western Pacific leatherback turtle interactions: inclusion of the Hawaii-based deep-set and American Samoa-based longline fisheries. U.S. Dept. of Commerce, NOAA Technical Memorandum NOAA-TM-NMFS-PIFSC-101, 62 p. https://repository.library.noaa.gov/view/noaa/24251

McCracken, M. L. 2019. Hawaii Permitted Deep-set Longline Fishery Estimated Anticipated Take Levels for Endangered Species Act Listed Species and Estimated Anticipated Dead or Serious Injury. PIFSC Data Report DR-19-011. p. 26.

McCracken, M. L. and B. Cooper. 2020. Data Report Hawaii Longline Fishery 2019 Seabird and Sea Turtle Bycatch for the Entire Fishing Grounds, Within the IATTC Convention Area, and Seabird Bycatch for above 23°N and 23°N–30°S. Pacific Island Fisheries Science Center. Honolulu, HI. 4 p.

McCracken, M. L. and B. Cooper. 2021. Hawaii Longline Fishery 2020 Seabird and Sea Turtle Bycatch for the Entire Fishing Grounds, Within the IATTC Convention Area, and Seabird Bycatch to the north of 23°N and 23°N–30°S. Pacific Island Fisheries Science Center. Honolulu, HI. 11 p.

McCracken, M. L. and B. Cooper. 2022. Hawaii Longline Fishery 2021 Seabird and Sea Turtle Bycatch for the Entire Fishing Grounds, Within the IATTC Convention Area, and Seabird Bycatch to the North of 23° N and 23 °N–30° S . Pacific Island Fisheries Science Center. Honolulu, HI. 4 p.

McCracken, M. L. and B. Cooper. 2023. Hawaii Longline Fishery 2022 Seabird and Sea Turtle Bycatch for the Entire Fishing Grounds, Within the IATTC Convention Area, and Seabird Bycatch to the North of 23° N and 23 °N–30° S . Pacific Island Fisheries Science Center. Honolulu, HI. 4 p.

McCracken, M. L. and B. Cooper. 2023. Hawaii Longline Fishery 2022 Seabird and Sea Turtle Bycatch for the Entire Fishing Grounds, Within the IATTC Convention Area, and Seabird Bycatch to the North of 23° N and 23 °N–30° S . Pacific Island Fisheries Science Center. Honolulu, HI. 5 p.

NMFS. 2004. Biological Opinion on Proposed Regulatory Amendments to the Fisheries Management Plan for the Pelagic Fisheries of the Western Pacific Region. p. 281.

NMFS. 2019. Biological Opinion. Continued Authorization of the Hawaii Shallow-set Longline Fishery. NMFS, Pacific Island Regional Office, Honolulu, HI. 506 p. PIR-2018-10335

NMFS. 2023. Biological Opinion. Continued Authorization of the Hawaii Deep-set Longline Fishery. NMFS, Pacific Island Regional Office, Honolulu, HI. 414 p. PIR-2018-10461

National Marine Fisheries Service and U.S. Fish and Wildlife Service. 1998. Recovery Plan for U.S. Pacific Populations of the Leatherback Turtle (*Dermochelys coriacea*).

NMFS and USFWS. 2020. Endangered Species Act status review of the leatherback turtle (*Dermochelys coriacea*). Report to the National Marine Fisheries Service, Office of Protected Resources, Silver Spring, MD, and U.S. Fish and Wildlife Service, Southeast Region, Jacksonville Ecological Services Office, Jacksonville, FL. 396 p.

NMFS and USFWS. 2021. Species in the Spotlight: Pacific Leatherback Turtle (*Dermochelys coriacea*) Action Plan 2021 - 2025. U.S. Dep. Commerce. https://media.fisheries.noaa.gov/2021-04/SIS-Action-Plan-2021-leatherback-FINAL-508.pdf

Peatman, T., L. Bell, V. Allain, P. Caillot, S. Williams, I. Tuiloma, A. Panizza, L. Tremblay-Boyer, S. Fukofuka, and N. Smith. 2019. Summary of longline fishery bycatch at a regional scale, 2003-2017 Rev 2 (15 April 2019). Busan, Republic of Korea 8-16 August 2018. p. 60.

Roe JH, et al. 2014. Predicting bycatch hotspots for endangered leatherback turtles on longlines in the Pacific Ocean. Proc. R. Soc. B 281: 20132559.http://dx.doi.org/10.1098/rspb.2013.2559

Ryder, C. E., T. A. Conant, and B. A. Schroeder. 2006. Report of the Workshop on Marine Turtle Longline Post-Interaction Mortality. U.S. Dep. Commerce, NOAA Technical Memorandum NMFS-F/OPR-29. 36 p. https://repository.library.noaa.gov/view/noaa/23893

Suarez, A., and C.H. Starbird. 1996. Subsistence hunting of leatherback turtles, *Dermochelys coriacea*, in the Kai Islands, Indonesia. Chelonian Conservation and Biology 2:190-195.

Swimmer, Y., and E. Gilman.2012. Report of the Sea Turtle Longline Fishery Post-release Mortality Workshop, November 15–16, 2011.U.S. Dep. Commer., NOAA Tech. Memo., NOAA-TM-NMFS-PIFSC-34, 31 p.

Swimmer, Y., A. Gutierrez, K. Bigelow, C. Barceló, B. Schroeder, K. Keene, K. Shattenkirk, and D. G. Foster. 2017. Sea Turtle Bycatch Mitigation in U.S. Longline Fisheries. Frontiers in Marine Science. 4.

Tapilatu, R. F., P. H. Dutton, M. Tiwari, T. Wibbels, H. V. Ferdinandus, W. G. Iwanggin, and B. H. Nugroho. 2013. Long-term decline of the western Pacific leatherback, *Dermochelys coriacea*: A globally important sea turtle population. *Ecosphere. 4(2):1-15.*

Tiwari, M., Wallace, B. P. and M. Girondot. 2013. *Dermochelys coriacea* (West Pacific Ocean subpopulation). 2013. The IUCN Red List of Threatened Species https://doi.org/10.2305/IUCN.UK.2013-2.RLTS.T46967817A46967821.en

WCPFC. 2023. Science and Scientific Data Functions. Available at: https://www.wcpfc.int/node/29966

WPRFMC. 2023. Annual Stock Assessment and Fishery Evaluation Report Pacific Island Pelagic Fishery Ecosystem Plan 2022. Remington, T., Fitchett, M., Ishizaki, A., (Eds.) Western Pacific Regional Fishery Management Council. Honolulu, Hawaii 96813 USA. 400 pp. https://www.wpcouncil.org/wp-content/uploads/2023/07/Pelagic-FEP-SAFE-Report-2022-Final_v5.pdf

Wallace BP, DiMatteo AD, Bolten AB, Chaloupka MY, Hutchinson BJ, et al. (2011) Global Conservation Priorities for Marine Turtles. *PLoS ONE 6(9):e24510. doi:10.1371/journal.pone.0024510*

Wallace, B. P., M. Tiwari, and M. Girondot. 2013a. *Dermochelys coriacea*, Leatherback. The IUCN Red List of Threatened Species 2013: e.T6494A43526147. https://www.iucnredlist.org/species/6494/43526147

Wallace, B. P., C. Y. Kot, A. D. DiMatteo, T. Lee, L. B. Crowder, and R. L. Lewison. 2013b. Impacts of fisheries bycatch on marine turtle populations worldwide: toward conservation and research priorities. *Ecosphere. 4(3).*