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Estimating annual leatherback bycatch in the Pacific Ocean by fishery and country to inform targeted conservation strategies

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Executive Summary

The Pacific Ocean supports two critically endangered leatherback sea turtle populations, both severely impacted by ongoing fisheries bycatch. Conservation planning includes population viability analyses (PVA), which depend on accurate demographic inputs to yield realistic results for informing management decisions. These projections are currently limited by a lack of fisheries bycatch data, and as population recovery is dependent on reducing leatherback bycatch, it is critical that we know where, when, and how much bycatch is occurring.

Here, we undertake a systematic review to aggregate existing estimates of leatherback bycatch within the Pacific Ocean for the purpose of creating the most contemporaneous and comprehensive estimate of Pacific leatherback bycatch. Searches through scientific databases and Google Scholar yielded 29 bycatch and mortality (hereafter: interaction) estimates from WCPFC fisheries that were deemed valid. Validity was determined by aligning article data with the SPIDER search methodology. These estimates covered 11 WCPFC fisheries and came from the years 1993 - 2024. In summation, they recorded the bycatch of 2058 leatherbacks and the mortality of 543, averaging to 66 bycaught leatherbacks and 18 mortalities per year. When linear extrapolation accounts for the countries not represented and fisheries not observed, this becomes an estimate of 381 leatherback mortalities per year attributed to WCPFC fisheries. However, linear extrapolation is not representative of the total fishing effort by each fishery.

Therefore, effort per fishery was calculated using Global Fishing Watch estimates of fishing hours in 2020. When incorporating actual fishing hours of the WCPFC fisheries, it was found that mortality could be as high as 1599 leatherbacks per annum, making the literature estimate 1% of the actual value (and the linear extrapolation 24% of the actual value). This highlights the severe data paucity for two populations that are predicted to go extinct within the century. Finally, 2020 mortality estimates were used to identify the Pacific fisheries that are currently most at-risk for causing leatherback mortality.

For the scope of this working paper, we focus on the fisheries of the WCPFC: purse seines and longlines in member countries, participating territories, and cooperative non-members. We first compare interaction rates from WCPFC observer data with other published literature sources, showing that the WCPFC observer program appears to overestimate bycatch but underestimate mortality, though this is not statistically significant. We then identify a decreasing trend in interaction rates as reported by observers, though longline mortality is much higher than purse

seine. Mortality rates for WCPFC fisheries from all data sources from 1993 - 2024 are compared by fishery size, gear type, region, and target species to identify the leatherback risk. Literature suggests that industrial fisheries, longlines, the North and West Pacific, and targeting tuna make a fishery more likely to cause higher rates of leatherback mortality. It's important to note that not all fishery sizes, gears, regions, and target species were encompassed within this search; these results are based on the literature available but literature coverage is incomplete. To account for this, mortality rates were scaled up to annual leatherback mortality estimated from annual fishing effort as available from Global Fishing Watch data.

When incorporating realistic fishing hours per annum using Global Fishing Watch estimates of annual fishing effort, we identify 21 WCPFC fisheries with the capacity to kill at least 1 leatherback per annum, with a total mortality of 1599 leatherbacks per annum for all fisheries. We identify the top five fisheries contributing to this estimate, which comprise 1388 of the 1599 mortalities: longlines in Japan, Korea, Vanuatu, Fiji, and the United States. We then created a risk matrix to identify data gaps within these fisheries to further identify risk. For example, there are no published estimates of interaction rate in Vanuatu and Fijian longlines, indicating that there may not be an awareness of the threat nor sufficient resources to address it. Conversely, the United States longline fisheries have numerous published estimates of interaction rates, including increasing observer coverage and establishing seasonal limits for leatherback interactions, which indicates an awareness and concern of their threat to leatherbacks, making this fishery less risky.

These are a narrow representation of whole-Pacific findings, for which additional research is underway. The final methods will be approved by an independent panel of experts, and the final results for all Pacific fisheries will inform PVA updates for both leatherback populations. These findings will be presented to a stakeholder group of government officials, fisheries representatives, and leatherback conservationists to inform an update of the conservation action plans for Pacific leatherbacks and promulgate additional efforts to prevent their extirpation.

Introduction

Leatherback turtles in the Pacific Ocean are critically endangered, with an ongoing risk of fisheries bycatch: being incidentally caught and killed by routine fisheries operations (Spotila et al., 2013; Tapilatu et al., 2013). They are extremely long-lived and highly migratory, with annual migrations that span the Pacific Ocean and make them vulnerable to numerous fisheries (Vekshin & Frolova, 2019). Because it takes a leatherback over a decade to reach sexual maturity, eliminating even small numbers of leatherbacks each year would be detrimental to these populations.

Despite decades of conservation effort, leatherback bycatch in the Pacific Ocean has not been comprehensively addressed, due to the broad scope of countries, gear types, and stakeholders involved (Wallace et al, 2010; Roe et al, 2014). However, Pacific leatherbacks are on an extinction trajectory , and extirpation for the East Pacific population is only considered avoidable with an immediate, 40% reduction in bycatch (LaúdOPO, 2020). However, fishing effort has not been quantified, nor attributed to particular fisheries, making the proposed 40% reduction impossible to achieve without a deeper and more comprehensive understanding of fishing activity in the Pacific or where to target conservation strategies to be most effective.

Leatherbacks risk entanglement in longlines, gillnets, seine nets, and trawls deployed by both industrial and small-scale fisheries (Wallace et al., 2010). Industrial fishing fleets have very low observer coverage and very limited information is available for small-scale fisheries (Roe et al., 2014). As a result, the cost and feasibility of reducing Pacific Ocean leatherback bycatch at any incremental level is extremely difficult to discern. With < 60 years to extirpation, it would be beneficial to understand which fisheries are most likely to encounter and inadvertently cause leatherback mortality, so that conservation strategies could be targeted appropriately. Additional research will identify the areas and times of year that leatherbacks are at most at-risk in the Pacific. This and further analysis required a quantification of fishing effort in the Pacific Ocean by each fishery, which is possible to extract from Global Fishing Watch's publicly available dataset.

Global Fishing Watch (GFW, 2024; www.globalfishingwatch.org) is an online mapping platform to track the movement of vessels at sea through their use of Automatic Identification Systems (AISs). GFW hosts a publicly available dataset which identifies probable fishing vessels, their location, their gear type, their country, and the suspected number of hours fishing on each day. Combining bycatch and mortality rates (hereafter: interaction rates) per fishing hour with this dataset would yield estimates of possible leatherback mortality per fishery. Bycatch rates could be extracted with a systematic literature review to cover as many Pacific fisheries as possible. These methods in combination would increase the understanding of which fisheries are riskiest for leatherback turtles in the Pacific Ocean, and are precisely the methods presented here.

Methods

Literature review

To ensure comprehensive scope in the literature search required an initial scoping exercise: 10 references articles chosen to cover all characteristics of interest (fishery size (industrial, small-scale), gear type (direct take, gillnet, longline, purse seine, squid jig, troll, trawl), target species (tuna, billfish), Pacific regions (North, East, South, West, Central)). The abstracts of the ten articles selected by experts were run through word cloud generation software to identify keywords and common terms (Foo et al., 2021; Harrison et al., 2021). The key terms were aligned with the SPIDER search methodology, where a sample, phenomenon of interest, design, evaluation, and research type are chosen to answer a target question, "*How many leatherbacks are caught in the Pacific Ocean as bycatch?*":

> *Sample*: wild, leatherback turtle bycatch
> *Phenomenon of interest*: conditions of bycatch
> *Design*: data source
> *Evaluation*: number of turtles
> *Research type*: quantitative

Once all words were fit to a category of SPIDER, the Boolean search string was formed and manipulated until it could retrieve all ten reference articles from a database. An additional ten independent articles were chosen by searching "Pacific leatherback bycatch" in Google Scholar, sorting by relevance, and selecting the first ten articles. This Boolean search string was validated after it retrieved all ten reference articles, and all ten independent articles: (((marine AND turtle) OR (leather$back*) OR (leatherback) OR (critically AND endangered AND migratory)) AND (pacific OR (global AND overview) OR (east* AND pacific) OR (west* AND pacific) OR (ep AND leatherback*) OR (wp AND leatherback*)) AND (bycatch OR (fisheries AND interaction) OR (turtle-fisheries) OR (risk AND management AND tool) OR (rapid AND assessments) OR (direct AND take) OR purse-seine OR longline OR gillnet OR (small-scale AND fishery AND bycatch)) OR (pelagic AND trawler AND Atlantic)).

Three bibliographic databases were searched with this string: SCOPUS, Web of Science Core Collection, and Aquatic Science and Fisheries Abstracts. All ten independent articles were retrieved, however, two reference articles were completely missing from these databases. The Boolean search string was considered valid, but additional methods to include grey literature were added.

Grey literature was searched through Google Scholar, but instead smaller, targeted Boolean search strings were used. First, characteristics of interest were identified including categories of fishery size, gear type, target species, fishing country, and region (Table S1). The smaller Boolean search strings followed this format "Pacific + leather$back + by$catch + American Samoa", or "Pacific + leather$back + by$catch + gill$net". If the primary language of a fishing country was not English, the string "Pacific + leatherback + bycatch" was translated into the primary language of the country and searched. For each case, Google Scholar searches were sorted by relevance, and the top ten results were added to the article pool for consideration in the study.

This combination of academic and grey literature search strategies yielded all ten reference articles and all ten independent articles. Therefore, this method was deemed valid, and determined able to achieve our desired scope and deemed suitable for this review. Additional data were sourced through identifying regulatory agencies relevant in this area (e.g. the Western and Central Pacific Fisheries Commission, etc.) and searching their websites directly for bycatch reports.

Validity for inclusion
Titles and abstracts were reviewed for each article, and screened against the SPIDER search strategy criteria. If the article failed to meet all mandatory fields for Sample, Phenomenon of Interest, Design, Evaluation, and Research Type within its title and abstract, it was eliminated from the article pool, i..e. unless the title and abstract indicated that the paper would provide a quantification of leatherback bycatch, it was omitted from this study. To encompass a broad variety of data sources, data quality was rated using fisheries reconstruction methods (Pauly & Zeller, 2016). In the event that published data were unclear, corresponding authors were contacted for clarification. If clarification was unable to be provided, that article was excluded from the analysis. A number of parameters were recorded for each "valid" article, including the reference, the source (academic or grey lit), the bycaught species, the region it was encountered in, the lifestage and sex of the leatherback, the gear type, the number of vessels monitored, the number of hours monitored, the number of hooks, nets, or area as available, the fishery size

(industrial, small-scale), the country fishing, the target species, the design of the study, the observer coverage, the number of turtle interactions, the fate of those interactions, and the number of mortalities.

From these data, interaction rates per fishing hour were calculated. If multiple estimates of bycatch or mortality rate were provided for the same fishery, an average was taken. If no estimate of bycatch or mortality rate was provided for a fishery, the average for that gear type among all fisheries was extrapolated to that fishery, since leatherback behavior indicates that some gear types are more risky for leatherbacks (Spotla et al., 2000; Roe et al., 2013; Barbour et al., 2023). The authors acknowledge that this increases uncertainty, which was taken into account during analysis of these data.

Fisheries bycatch data is broad, its scope includes multiple countries, regions, languages, gear types. To minimize bias, every article was subject to screening by a consistent reviewer to determine its validity for inclusion. Articles were searched for in multiple languages, but translation discrepancies or varying sentence structure or syntax in other languages may have created an unintentional bias. It is likely that some literature was unintentionally missed, though experts were contacted to share any papers relevant to this study, and no response provided a paper that was not already retrieved through these literature search methods. This may suggest that a saturation point was reached, and all accessible data was recovered. Unintentional biases have been minimized to the best of this author's ability.

Data utilization: conversion between bycatch per set and bycatch per fishing hour

Literature values for interaction rates were also converted, where needed, from turtles per unit effort (per set) to turtles per fishing hour. This required conversion from hours to fishing hours (Eqn 1), then dividing the number of turtles interacted with by the total number of fishing hours. This required assumptions: i) a set could be defined as 1000 longline hooks, 1 gill net, 1 trawl, or 1 seine, ii) if monitored hours were given for multiple vessels, fishing hours could be equal to monitored hours multiplied by the number of vessels (Eqn. 1), iii) if vessel number was not given, but instead "fleet" was specified, targeted Google searches were undertaken to quantify the size of that fleet during the monitoring period and this was used for vessel number.

$$Equation\ 1.\ \ H_F = H_M * V_M$$

H_F = fishing hours

H_M = monitored hours

V_M = vessels monitored

Data utilization: scaling up to total fishing effort

As such, interaction rates per fishing hour were quantified for each Pacific Ocean fishery, extrapolating where data were unavailable. These rates were scaled up to realistic fishing effort using Global Fishing Watch's dataset mmsi-daily-csvs-10-v2-2020. This dataset was filtered to the Pacific Ocean by using longitude and latitude (lat: -60 to 66.5, lon: 121 to 290). Daily fishing hours per fishery were aggregated to create an annual value for the most recent calendar year these data were available: 2020. Annual fishing hour values were used for calculating annual impact on leatherbacks. Fishing hours were matched to their literature bycatch rates, by fishery. These were multiplied to achieve an annual estimate of bycatch (Eqn. 2).

$$Equation\ 2.\ \ B_A = \frac{B}{FH} * \frac{FH}{A}$$

B = bycatch
A = per annum
FH = fishing hours

Data utilization: mortality rates and adding post-release mortality
To achieve mortality estimates required two calculations: one, using the mortality per fishing hour rates from literature, and two, incorporating post-release mortality using post-release mortality estimates from Griffiths et al., 2024 (Eqn. 3) to create a "total mortality" estimate that encompasses both during capture and post-release mortality.

$$Equation\ 3.\ \ M_T = M_L + (B_L * M_{PR})$$

B_L = bycatch estimate (literature)
M_X = mortality estimate
X : L = literature
T = total
PR = post-release

Data utilization: gear category reclassification
To maximize analysis of results, gear types were recategorized into broad categories for longline, gillnet, seine, and trawl. Set depth of longline fishery has been shown to impact interaction rates, so any available information from this literature search will be used to validate this. For the purpose of this working paper, only a subset of results will be presented to focus on information relevant to the WCPFC fisheries.

Data utilization: WCPFC scope of these results
First, we compared observer coverage within the WCPFC reporting scheme with a compilation of all articles with data for WCPFC countries. Thisdetermined whether the RMFO observer program has higher or lower coverage of its fisheries than targeted case studies. We also analyzed interaction rates and compared WCPFC hosted observer data to WCPFC fisheries data from other sources to assess how the observer program records interaction rates compared to targeted case studies on WCPFC fisheries. Next, we analyzed the trends in interaction rates presented in the WCPFC BDEP Table dataset over time to determine if interaction rates are increasing over time. These comparisons provided context for the next analyses.

We subset the data to include any bycatch rates for a WCPFC member fishery, then compared the mean total mortality rates between different levels of fishery size, gear types, target catch species, and Pacific regions to identify which fishery size, gear, target, and regions are interacting with the highest levels of leatherbacks. Finally, incorporating total fishing hours from GFW datasets, we reviewed the total mortality possible in 2020 by WCPFC fisheries, highlighting the riskiest fisheries for leatherbacks within the WCPFC. To contextualize those findings, we created a risk matrix for the top five riskiest fisheries to highlight other risk metrics that included i) the number of publicly available bycatch estimates for a fishery, ii) whether a fishing country is RMFO compliant and which RMFO(s) it is a member of, and iii) the level of fishing permissions allowed in the Marine Protected Areas of a country (data from Protected Seas:Navigator). Publicly available bycatch estimates are quantified by the number found from our literature search methods which had enough data to be valid for inclusion in this study. Each category (i,ii,iii) is scored in a points system (publicly available estimates (0 = 0 points, 1-5 = 1 point, 5-10 = 2 points, 10+ = 3 points); RMFO compliant (yes = 1 point, no = 0 points); percentage MPAs with fishing permissions (the three sub-categories are averaged (fishing unknown or allowed = 0 points, restricted (including indigenous take) = 1 point, prohibited = 2 points)).

This allowed an understanding of data gaps, since a "risky" fishery may be practicing good fisheries behaviors, such as reporting bycatch estimates, being compliant with an RMFO, and protecting its marine areas. Or, a risky fishery could be even more risky if it was not reporting bycatch, not compliant with an RMFO, and not protecting its marine areas.

This work to estimate leatherback bycatch in the entire Pacific Ocean is currently *in prep* for publication, pending two stakeholder workshops to validate methods and discuss the implications of results. These are preliminary results, and should be used to inform where data gaps exist. If you would like to be part of the data validation or stakeholder workshops, please contact the author at anna.ortega@research.uwa.edu.au with your workshop preference(s).

Results

For methods validation, combining differing set-depth vessels was deemed permissible. Only two valid bycatch rates were identified with either "deep-set" or "shallow-set" fisheries - gillnets with average bycatch rates of 0.0021 and 0.0060 respectively. However, deep-set gear has a higher mortality rate 0.0009 versus 0.0003 in shallow-set. Taking these together, while the bycatch of shallow-set fisheries is higher, and the mortality of deep-set fisheries is higher, the likelihood of a turtle getting caught and killed is the same (deep: 0.00019, shallow: 0.00018). Therefore, combining gear types into broad categories was permissible, and allowed further analysis of results.

The entire literature review resulted in 251 articles, with 69 valid estimates of leatherback interaction from 1982 to 2024. When narrowed to WCPFC fisheries, results encompassed 29 valid articles totalling 2058 bycatch interactions and 543 mortalities. Observer coverage averaged at 22%, and 11 WCPFC CCM countries were represented (out of 41). Linear extrapolations to account for missing data accounted for low observer coverage and partial coverage of countries fishing (11/41 = 27%). Therefore, a linear extrapolation suggested that 381 leatherbacks were killed per year by WCPFC fisheries.

$$\frac{18\ mortalities}{17.59\ \%\ observed} = \frac{100\%\ observed}{26.83\%\ countries} = \frac{100\%\ countries}{year} = \frac{381\ mortalities}{year}$$

When comparing WCPFC hosted datasets (BDEP Tables), mean observer coverage was higher than from other literature sources (26.69% BDEP data, 17.59% else), indicating that the WCPFC observer program is more representative than targeted, published case studies. Within WCPFC BDEP datasets we see a decreasing trend in bycatch, mortality, and total mortality rates from 2013 to 2022 (Figure 1). This is much more pronounced in purse seine, suggesting that longline fisheries are riskier for leatherbacks (Figure 1). Overall, we see that WCPFC BDEP data shows comparable means to data from WCPFC fisheries that comes from other literature for WCPFC fisheries (Figure 3). Though it is not significant, WCPFC observers are reporting higher bycatch and lower mortality rates than other literature. Within WCPFC fisheries, we see that some regions (North and West Pacific), fishery sizes (industrial), gear types (longline), and target catch (tuna) show higher total leatherback mortality rates than others (Figure 3).

When scaling these rates up to annual fishing hours, we identify 21 WCPFC fisheries with the capacity to kill a leatherback turtle based on 2020 fishing levels and bycatch/mortality rates from 1982-2024 (Table 1). The top five of these fisheries were further assessed in a risk matrix to identify high risk countries with no effort towards "good fishery behaviors" based on ProtectedSeas data and findings from this study (Table 2). Fiji and Vanuatu have no published interaction rate estimates, and there is no understanding of fishery permissions in Japanese MPAs. These are data gaps which could be grounds for further research and direct leatherback fisheries bycatch mitigation immediately toward these nations to reduce leatherback mortality. Conversely, the risk matrix also highlights less risky fisheries: e.g. a large amount of published research on leatherback bycatch exists in the United States (16 valid estimates), indicating awareness and addressing of the issue.

Discussion

The WCPFC fisheries contribute greatly to the mortality of leatherbacks in the Pacific Ocean, estimated at 1,599 leatherback turtles per annum. It is crucial to note that these interaction estimates come from likely outdated publications. Contemporary bycatch rate data is not easily available for any Pacific Ocean fishery, but has a huge impact on the understanding of these results. However, the most comprehensive data were used for this study, and as such, results should be interpreted as the number of leatherbacks that a fishery was capable of causing mortality to in 2020, based on published bycatch values from 1982-2024. This is not an exact quantification, but an estimate to which fisheries might need extra attention when considering how to mitigate leatherback bycatch.

Observer coverage as a percent monitored out of a whole fleet is higher in WCPFC BDEP datasets. This is a good indication that the RMFO bycatch reporting scheme is effective, and beneficial when attempting to utilize these data. However, though higher than other countries or studies, observer coverage is still low - and very low in longline fleets. Low observer coverage may be a product of limited financial resources or fishery willingness, but without it, extrapolations are necessary to understand the scale of bycatch.

WCPFC mortality rates are declining over time, with longline fisheries showing a much more stable, but higher trend of mortality rates. The setting depth of longlines was found to be irrelevant; shallow-set longlines are likely to induce less drowning but interact with more leatherbacks, and vice versa for deep-set. Thus, even though bycatch rates may differ, mortality rates are expected to be similar. There were insufficient data to assume otherwise, and all longlines were grouped in this study. It was found that longlines were the primary risk for leatherbacks when assessing WCPFC fisheries, due to large declines in mortality rates in the purse seine fisheries since 2016.

Finally, WCPFC observers were reporting higher mean bycatch rates than published case studies from WCPFC fisheries, but lower mortality rates. This could indicate that observers are recording bycatch but missing mortalities due to cut nets before leatherback condition can be assessed. This could indicate that the WCPFC observer program needs to be reassessed to be able to quantify mortalities and assess leatherback condition so that likely post-release survival of living releases can be better understood. This prompted the use of total fishing hours per annum from GFW, as incorporating annual fishing hours is crucial in assessing leatherback risk. Low mortality rates that take into account high levels of fishing effort can capture a more realistic estimate of risk, even if observer coverage in the original estimates is incomplete.

The West Pacific leatherback population is estimated to have roughly one thousand adult females capable of reproducing, and the population trend has been consistently reported as a decline (Dunn et al., 2023). Putting even one of these sexually mature females is detrimental to the longevity of the population. Within WCPFC, 21 fisheries are at risk for killing at least one leatherback per year, and could be killing 1,599 leatherback per year from multiple age classes. This is a devastating blow to a critically endangered population, and highlights the need for rapid action if extirpation is to be avoided.

Conclusions

WCPFC is doing well to report bycatch data for leatherback interactions, which appears to be higher than the bycatch rates reported for WCPFC countries outside of the observer program, but with lower mortality rates. When scaled up to total fishing hours, 21 fisheries could be killing from 1-599 leatherbacks per year in unknown age classes, but almost certainly including reproductive adults. This is actively reducing the longevity of the West Pacific leatherback population, and avoiding extirpation will require transparency and immediate action.

Based on the available interaction rate data from literature, tuna longlines are the riskiest fishery within the scope of WCPFC, and the riskiest fishing countries have been identified in Table 1. Risk has been contextualized with “good fishing behavior” in Table 2, but mitigating this threat will require effort to adjust fishing practices within these fisheries. It is certainly possible that other fisheries have higher interaction rates that were not captured in published literature, hence the scaling of interaction rates to annual fishing effort and mortality estimates.

Observer coverage should be increased, bycatch mitigation strategies need to include not only avoiding leatherbacks (migratory paths, seasonal breeding and foraging grounds), but also handling bycaught leatherbacks to minimize mortality during capture and post-release. Without significant effort, Pacific leatherbacks will face extirpation by the turn of the century.

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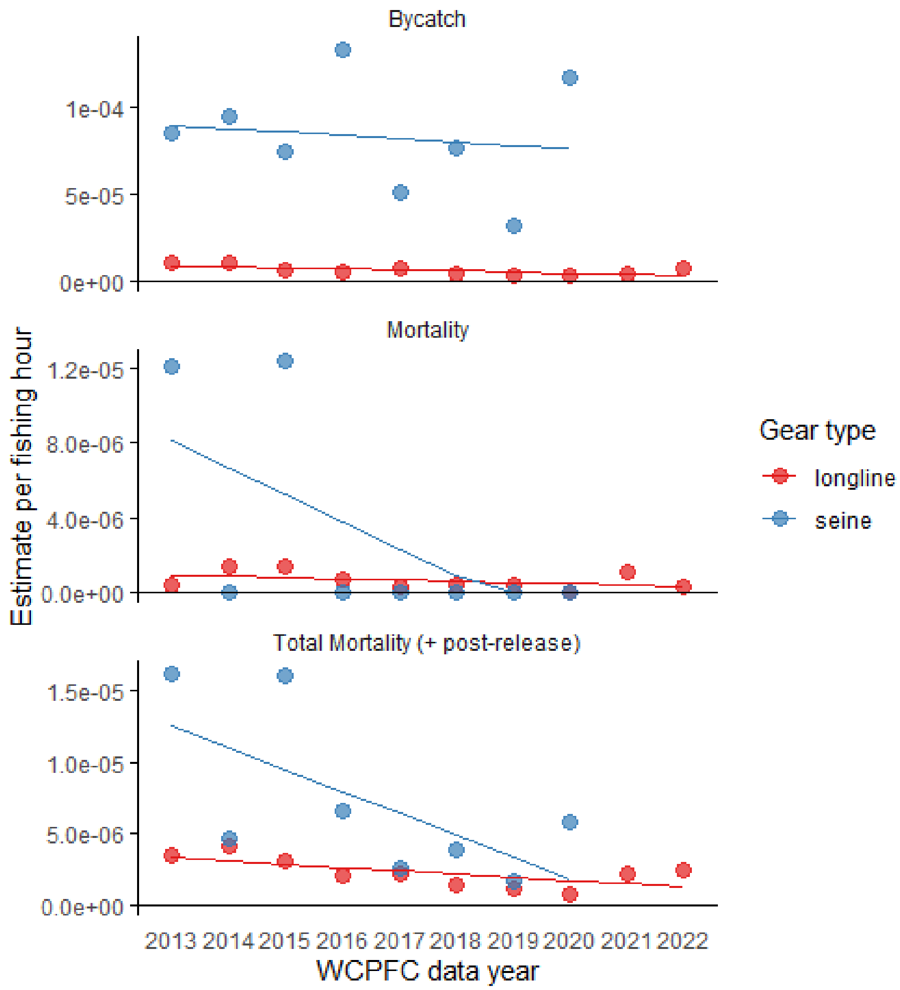

Figure 1. Bycatch data from the WCPFC BDEP Tables used to calculate bycatch, mortality, and total mortality rate per fishing hour over time for two fisheries, showing decreasing trends over time.

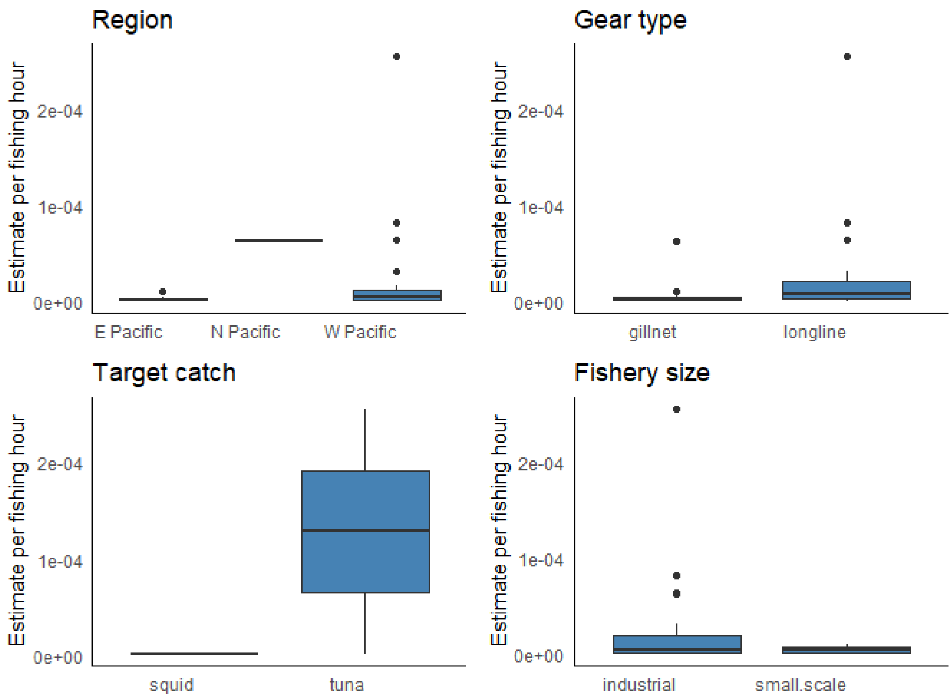

Figure 2. Bycatch data from the WCPFC members used to calculate total mortality rate per fishing hour, compared by different regions, gear types, target catch, and fishery sizes. Results show higher total mortality rates for the North Pacific region, longline gear, tuna target species, and industrial fishery size.

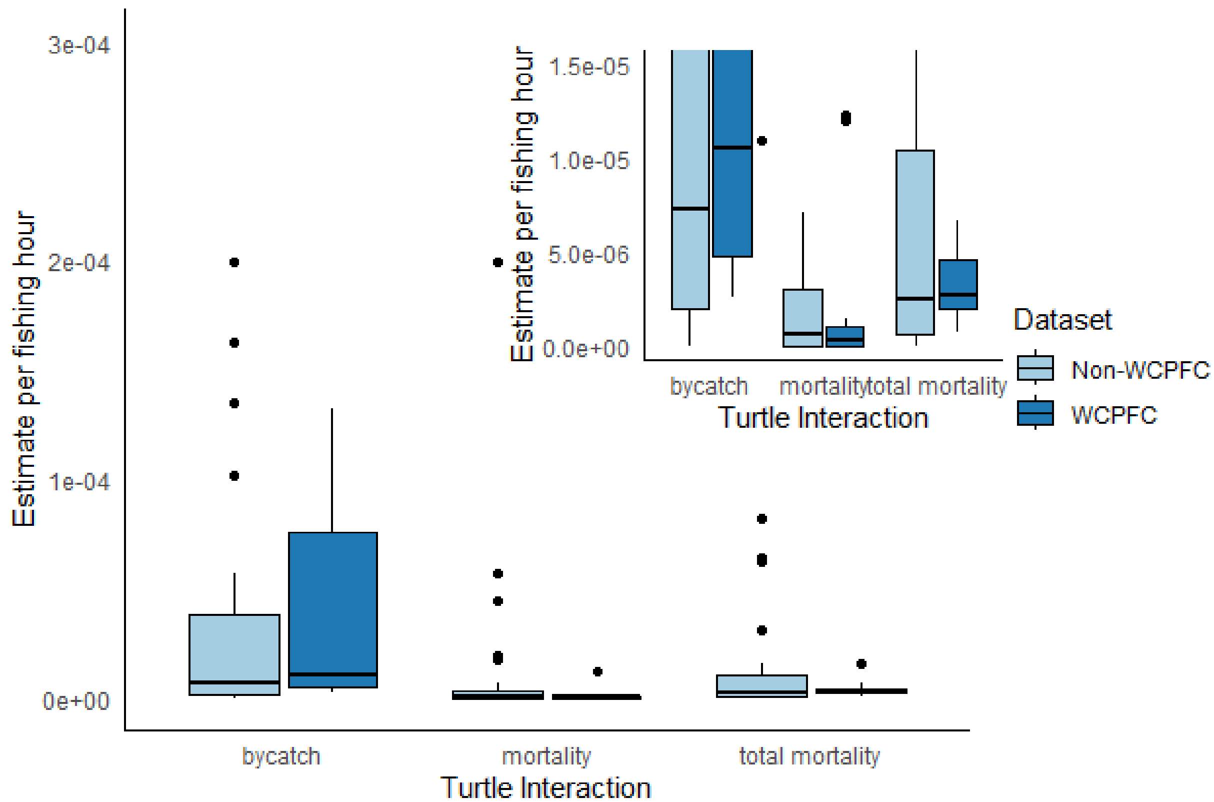

Figure 3. Bycatch, mortality, and total mortality rates compared between data from WCPFC BDEP data, and data from WCPFC fisheries from other sources retrieved from literature search. Discrepancies highlight the inconsistencies between observer data from the WCPFC and literature estimates.

Table 1. WCPFC fisheries with the potential to kill at least 1 leatherback per year, ranked as contributors to leatherback mortality per annum, based on literature bycatch estimates from 1982-2024, and 2020 fishing hours from Global Fishing Watch.

Gear type	Country	Fishing hours 2020	Possible leatherback mortalities in 2020
longline	JPN	937326	590
longline	KOR	719729	453
longline	VUT	241148	152
longline	FJI	156838	99
longline	USA	4113629	94
longline	IDN	60873	38
longline	NCL	51093	32
longline	FSM	47686	30
longline	COK	45906	29
longline	TWN	1795261	28
longline	PYF	40692	26
longline	ECU	11176	7
longline	PAN	10435	7
longline	CHN	1798121	4
longline	PNG	3490	2
longline	MHL	7040	2
longline	CAN	2407	2
seine	KOR	181993	1
longline	AUS	65724	1
seine	JPN	78155	1
seine	USA	71372	1

Table 2. Threat matrix for top five fisheries: longlines in Japan, Korea, Vanuatu, Fiji, and the United States of America. Publicly available bycatch estimates are quantified by the number found from our literature search methods which had enough data to be valid for inclusion in this study. Each column is scored in a points system (publicly available estimates (0 = 0, 1-5 = 1, 5-10 = 2, 10+ = 3); RMFO compliant (yes = 1, no = 0); percentage MPAs with fishing permissions (the three sub-columns are averaged (fishing unknown or allowed = 0, restricted (including indigenous take) = 1, prohibited = 2)).

Country	Publicly available bycatch estimates*	RMFO compliant	MPAs fishing permissions			Score (out of 6)
			Tribal	Recreation	Commercial	
Fiji (score)	0	WCPFC	0.67	restricted	restricted	2.00
	0	1	1	1	1	
Japan	2	WCPFC, IATTC	1.00	unknown	unknown	2.33
	1	1	1	0	0	
Republic of Korea	1	WCPFC, IATTC	1.00	prohibited	prohibited	2.67
	1	1	1	2	2	
United States	16	WCPFC, IATTC	0.95	restricted	restricted	5.00
	3	1	1	1	1	
Vanuatu	0	WCPFC; IATTC	1.00	restricted	restricted	2.00
	0	1	1	1	1	