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Results from the First WCPFC Workshop on Joint Analysis of Sea Turtle Mitigation Effectiveness

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Abstract

The first of two joint-analysis workshop on the effectiveness of sea turtle mitigation in longline fisheries was held in Honolulu in February 2016. This ABNJ (Common Oceans) Tuna project sponsored workshop was attended by 31 participants from 14 countries from all three oceans, as well as invited IGOs and NGOs. The first workshop characterised current sea turtle interaction and mortality rates under existing fishing operations using observer data from a variety of sources representing over 2,300 turtles caught by 31 fleets between 1989-2015. There were three types of analyses undertaken for leatherback, loggerhead, green and olive ridley turtles: 1) estimating the effects of various operational variables on interaction rates at the set level; 2) estimating how turtle interaction rates vary by hook position within baskets; and 3) estimating the effects of various operational variables on turtle at-vessel mortality rates. Post-release mortality rates were not considered due to a lack of available information. In the first analysis hook category (shape and size), bait species, hooks per basket, and soak time had the largest effect on set level interaction rates, with significant decreases in interaction rates with the use of large circle hooks and/or finfish bait. In the second analysis interaction rates of olive ridley, loggerhead and green turtles with deep set longlines were highest for those hooks closest to floats. In the third analysis, at-vessel mortality rates were influenced by turtle species, with the lowest mortality rates for leatherback and loggerhead turtles, and increased mortality rates with increased fishing depths. Participants concluded that mitigation measures based on hook shape and size, bait species, and removal of the hooks nearest each float in deep longline sets should be priorities for further analysis. The workshop also generated preliminary species-specific maps of relative abundances. A Delphi technique peer review process is being considered to confirm these maps. A second workshop, to be held in November 2016, will focus on estimating baseline interaction and mortality rates under current fishing operations and testing various mitigation scenarios to determine their effectiveness in reducing impacts.

Western and Central Pacific Fisheries Commission

SPC
Secretariat of the Pacific Community

PROJECT
Sustainable Management of Tuna Fisheries
and Biodiversity Conservation in the ABNJ

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REDUCING ECOSYSTEM IMPACTS OF TUNA FISHING

Workshop on Joint Analysis of Sea Turtle Mitigation Effectiveness

REPORT OF THE FIRST WORKSHOP

16 – 19 February 2016
HONOLULU, HAWAII, USA

COMMON OCEANS

PROCEEDINGS

COMMON OCEANS

Seeking to generate a catalytic change, the *Global sustainable fisheries management and biodiversity conservation in the Areas Beyond National Jurisdiction Program* was approved by the Global Environment Facility (GEF) under the lead of the Food and Agriculture Organization of the United Nations (FAO) in close collaboration with two other GEF agencies, the United Nations Environment Programme (UNEP) and the World Bank, as well as other partners.

Focusing on tuna and deep-sea fisheries, in parallel with the conservation of biodiversity, the ABNJ Program aims to promote efficient and sustainable management of fisheries resources and biodiversity conservation in ABNJ to achieve the global targets agreed in international fora.

The five-year ABNJ Program is an innovative, unique and comprehensive initiative working with a variety of partners. It consists of four projects that bring together governments, regional management bodies, civil society, the private sector, academia and industry to work towards ensuring the sustainable use and conservation of ABNJ biodiversity and ecosystem services.

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1 Introduction

There are seven species of sea turtles and six of these are considered to be threatened with extinction according to IUCN Red List criteria (i.e. critically endangered, endangered or vulnerable; IUCN 2015). Factors such as human consumption of meat and eggs, predation on eggs, nesting disturbance, climate change, marine pollution and boat collisions all have contributed to declines in sea turtle populations, but interaction with fishing gear is considered to be one of the most serious threats (FAO 2010; Wallace et al. 2011, 2013). Starting over ten years ago, a number of tuna Regional Fisheries Management Organizations (t-RFMOs) have adopted conservation and management measures that require mitigation to reduce the impacts of fishing operations on sea turtles. However, the effectiveness of these measures remains largely unexamined due to a lack of information on implementation, compliance and species-specific interaction and mortality rates (Clarke et al. 2014).

The Areas Beyond National Jurisdiction (ABNJ, or Common Oceans) Tuna Project is a Global Environment Facility (GEF)-funded, FAO-implemented programme of work designed to encourage and reinforce sustainable tuna fisheries. One of the three main components of the project focuses on mitigating bycatch and ameliorating adverse impacts on biodiversity. Taking its cue from a work plan developed by the Joint t-RFMO Technical Working Group-Bycatch, the ABNJ Tuna Project aims to progress prioritized research on sea turtle bycatch mitigation through encouraging data sharing and collaborative analysis (Joint Tuna RFMOs 2011). Funding has been allocated to WCPFC and The Pacific Community (SPC) under the ABNJ work programme to support two sets of workshops on bycatch mitigation issues facing t-RFMOs. The first workshops (this one and another to be held in late 2016) are designed to focus on assessing the effects of mitigation on interaction and at-vessel mortality rates of sea turtles in pelagic longline fisheries.

The WCPFC Secretariat announced the first workshop on 14 October 2015, calling for nominations of participants from WCPFC members and cooperating non-members. After confirming participation from Australia, Chinese Taipei, the Cook Islands, the European Union, Fiji, Federated States of Micronesia, Japan, Republic of the Marshall Islands, Palau, Papua New Guinea, Tonga and the United States, remaining spots in the workshop were proposed to be offered to representatives from:

- Countries with experience in sea turtle-longline interactions including Brazil, Uruguay and Mexico;
- the Secretariats of the four other t-RFMOs (i.e. Commission for the Conservation of Southern Bluefin Tuna (CCSBT), the Inter-American Tropical Tuna Commission (IATTC), International Commission for the Conservation of Atlantic Tunas (ICCAT), and the Indian Ocean Tuna Commission (IOTC));
- three inter-governmental organizations with an interest in sea turtle issues (SPREP (Secretariat of the Pacific Regional Environment Programme), the Inter-American Convention for the Protection and Conservation of Sea Turtles (IAC), and the Indian Ocean South-East Asian Sea Turtle Memorandum of Understanding (IOSEA)); and
- two non-governmental organizations which expressed interest in attending the workshop (the International Seafood Sustainability Foundation (ISSF) and the Worldwide Fund for Nature (WWF)).

Of these invited parties, representatives from Brazil, Uruguay, SPREP, the IAC, ISSF and WWF participated in the workshop. A list of meeting participants is included in *Annex A*.

Special arrangements were agreed to protect the confidentiality of shared data. Under these arrangements, SPC compiled contributed data into a common format and securely maintained these data throughout the workshop without releasing them to participants. All data analyses were conducted by the SPC statistician (Mr. Tom Peatman) and SPC database manager (Mr Sylvain Caillot) with results being projected onto a screen for discussion by the workshop. It was agreed that metadata and data products which have been confirmed to be in compliance with national data confidentiality rules (e.g. the three-vessel rule) could be shared amongst participants and included in the meeting report. It was announced in the opening session that participation in the workshop involved an implicit commitment not to copy or otherwise reveal data or discussions from the workshop directly related to data to non-participants via social media or other technology. Participants were asked to respect this commitment and refrain from jeopardizing this and future data sharing opportunities.

The data used in this workshop consisted of:

- WCPFC Regional Observer Programme data;
- National observer programme data held by SPC on behalf of its members (i.e. American Samoa, Australia, Cook Islands, Federated States of Micronesia, Fiji, France, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, Niue, Northern Mariana Islands, New Zealand, Palau, Papua New Guinea, Pitcairn Island, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, the United States, Vanuatu, and Wallis and Futuna);
- National observer programme data provided by Japan and Chinese Taipei under data confidentiality agreements specific to these two workshops; and
- Observer data for the Reunion longline fishery provided by Institut de Recherche pour le Développement (IRD) through an existing data confidentiality agreement with SPC.

More information on the dataset is provided in Section 3.

The workshop convened from 16-19 February 2016 in conference facilities graciously provided by the Western Pacific Regional Fishery Management Council (WPRFMC) in their offices at 1164 Bishop Street, Honolulu, Hawaii, United States. Ms Kitty Simonds, Executive Director of WPRFMC, welcomed participants to the workshop. Appreciation is expressed to staff of the WPRFMC who supported the workshop throughout the week. The workshop was chaired by Dr Shelley Clarke, Technical Coordinator-Sharks and Bycatch for the ABNJ Tuna Project based at the WCPFC Secretariat. Dr Eric Gilman, Hawaii Pacific University, assisted with rapporteuring.

2 Workshop Objectives

As announced in WCPFC Circular 2015/72 the workshop was designed to focus on evaluating mitigation techniques for sea turtle bycatch in pelagic longline fisheries. It was initially proposed that the workshop analyses focus on mitigation involving depth, soak time, hook width and shape, and bait type and include the species of sea turtles most likely to interact with pelagic longline tuna fisheries in the Pacific: green (*Chelonia mydas*), leatherback (*Dermochelys coriacea*), loggerhead (*Caretta caretta*) and olive ridley (*Lepidochelys olivacea*). The first workshop was intended to characterize current (or "baseline") sea turtle interaction and mortality rates under existing fishing operations. The second workshop would then work toward altering the baseline scenario defined in the first workshop to represent various mitigation options, and if possible, determine whether any of the simulated mitigation schemes are able to reduce any unacceptable impacts to sea turtle populations to acceptable levels (assuming a baseline risk assessment is available from other sources).

2.1 Status of Pacific Sea Turtles

A number of presentations were given to provide background and context for the intended analyses.

S. Clarke gave a presentation by S. Clarke and E. Gilman providing a general overview of the status of and threats to sea turtles and a quick summary of potential techniques to mitigate these based on Clarke et al. (2014). Of the six sea turtles that are currently listed in threatened categories by the IUCN Red List, only Kemp's ridley (*Lepidochelys kempii*) is not found in the Pacific. Hawksbill sea turtles (*Eretmochelys imbricata*), though found in the Pacific, generally have a coastal distribution that minimizes their interaction with tuna longline fisheries and were thus not included in the analysis conducted by the workshop. All sea turtles have been listed by the Convention on International Trade in Endangered Species (CITES) on Appendix I (i.e. a trade ban) for several decades now, and all except the flatback (*Natator depressus*) are listed by the Convention on Conservation of Migratory Species (CMS) Appendices I & II. There is one inter-governmental convention for the Americas (IAC) and there are two international memoranda of understanding on sea turtle conservation, one for Atlantic Africa, and one for the Indian Ocean/Southeast Asia. When threats from fishing are considered as a whole, the species identified as most at risk in the Pacific were the hawksbill, leatherback and loggerhead sea turtles. However, a ranking of threats specific to longline fisheries listed the South Pacific population of loggerheads of greatest concern, with olive ridley populations in the Eastern Pacific also at high risk from bycatch (but the population status at a lower threat level).

Options to mitigate threats from longline fisheries to sea turtles vary by species and life-stage but generally involve avoiding preferred habitat, altering the attraction to bait and gear, and reducing the sea turtles' propensity to ingest or entangle in gear. There have been many experiments investigating one or more of these aspects and results from different fisheries and conditions are sometimes contradictory. However, most of the evidence suggests that circle hooks, particularly those which have large minimum widths and are large relative to mouth size of susceptible sea turtles, can reduce hooking interactions or mortality or both. Use of finfish bait, rather than squid bait, is also a promising mitigation technique. Avoiding preferred habitat has potential as a mitigation option but in many cases what constitutes preferred habitat is difficult to understand or predict, especially when related to dynamic oceanographic variables. This mitigation option could also have implications for reduced catches of target species which could be a barrier to its implementation. It is important to realize that while mitigation seeks to reduce interaction rates overall, scenarios under which hooking rates do not decrease but mortality rates do (e.g. with safe release) may be considered positive outcomes. It was acknowledged that in cases where post-release mortality rates are not well understood, mortality rates estimated up to the point of safe release may under-estimate actual mortality.

The workshop was urged to consider what data are available to inform its analyses and to formulate questions that can be addressed using the data available. In addition to planning for more in-depth analysis of these data in the second workshop, participants were asked to consider what conclusions can be drawn from this week's preliminary analyses and to identify any critical data gaps to be filled in the short- and long-term.

In discussion of this presentation it was clarified that disturbance of nesting habitat, human consumption of meat and eggs, and predation on eggs can be a major threat to turtles but the situation with regard to this threat has improved in recent years with increased nesting beach protection in some areas and so attention has turned to mitigating the threats from fisheries. The severity of the threat posed by interaction with fisheries varies by species but is considered to be particularly of concern for leatherback turtles given their status.

I. Kinan-Kelly (National Oceanic and Atmospheric Administration (NOAA) Pacific Islands Regional Office (PIRO)) presented a review of sea turtle nesting and habitat information. Sea turtles are a long-lived, late maturing, highly migratory species with variable life histories. Total sea turtle population estimates are problematic due to a lack of demographic information. Nesting females are the most accessible component of sea turtle populations and can be used as population indices. Published nesting population trends and available pelagic habitat use information were summarized for the key species as follows:

- Green turtles are widely distributed, occurring in over 140 nations and nesting in at least 80 countries. In the Indo-Pacific, there may be approximately 200,000 females nesting annually at over 230 nesting locations (Seminoff et al. 2015). In the Pacific, a number of nesting populations have been monitored over a relatively long time period (20-30+ years) that provides evidence of increasing, decreasing, or stable nesting trends, although overall populations are reduced from historic levels or continue to be threatened by habitat loss, directed capture of turtles and eggs, fishery interactions, and climate change (Seminoff et al. 2015). Some published and unpublished satellite telemetry data exists for Pacific green turtles suggesting that post-nesting females tend to migrate west from Oceania nesting beaches to foraging habitats of the western Pacific (Craig et al. 2004; Kolinski et al. 2014; Parker et al. 2015; NMFS PIFSC unpublished).
- Olive ridley turtles have two primary nesting strategies: arribada (mass) nesting and solitary, with the species defined by a western Pacific population that nests primarily in India and an eastern Pacific population which nests primarily in Mexico, Costa Rica and Nicaragua. The eastern Pacific population may consist of approximately 2.5 million nesting females and the western Pacific population may be comprised of approximately 300,000 females nesting annually with additional unquantified nesting activity in northern Australia (NMFS and USFWS 2014; Limpus 2009). Overall, eastern Pacific nesting trends are increasing and recovering from directed turtle harvest that occurred prior to 1990s, although the overall population is reduced from historic levels and continue to be threatened by habitat loss, harvest, and fishery bycatch (NMFS and USFWS 2014).
- Leatherback turtles in the Pacific are comprised two demographic populations identified through genetic studies (Dutton et al. 2007) occurring in the western and an eastern Pacific. The western Pacific meta-population nests in Indonesia, Papua New Guinea and Solomon Islands where approximately 500-600 females may nest annually (Tapilatu et al. 2013; Pilcher 2011). The eastern Pacific meta-population nests primarily in Mexico and Costa Rica where approximately 150-200 females may nest annually (IUCN Marine Turtle Specialist Group. 2013a). The western Pacific population is declining at a rate of 6% per year with an overall 78% decline at Jamursba-medi the primary nesting beach in Indonesia (Tapilatu et al. 2013). The eastern Pacific population is also struggling with a nesting trend declining by 90% since monitoring began during the 1980s (IUCN Marine Turtle Specialist Group 2013a). These declining trends are a significant conservation concern. Primary threats to Pacific leatherback turtles include impacts at nesting beaches (egg harvest and beach erosion), fishery interactions in coastal and pelagic fisheries, and climate change (IUCN Marine Turtle Specialist Group 2013b; NMFS and USFWS 2013).

- Loggerhead turtles in the Pacific Ocean are comprised of two distinct population segments, a North Pacific and a South Pacific population. Approximately 500 to 1,000 loggerheads may nest annually in Japan and roughly 2-5,000 loggerheads may nest annually in eastern Australia and New Caledonia (Y.Matsuzawa, Sea Turtle Association of Japan, pers. comm. unpublished; UNEP/CMS/COP11 2014). While both populations are currently stable or increasing, both are significantly reduced from historic levels and recovering trends are at least partially dependent on continued conservation and management efforts to protect nesting turtles and their habitats, and mitigate coastal and pelagic fishery interactions (IUCN Marine Turtle Specialist Group 2015).

Over the last two decades, dedicated efforts have been made to better understand sea turtle pelagic habitats through satellite telemetry and oceanographic research. The most comprehensive migratory and foraging habitat information currently exists for North Pacific loggerhead and western Pacific leatherback turtles, with olive ridley turtle habitat use the least understood (Bailey et al. 2012; Kobayashi et al. 2008; Polovina et al. 2004, 2006). The North Pacific loggerhead turtle pelagic migratory habitat is highly correlated with Sea Surface Temperature (18°C isotherm) and the Kuroshio Extension Current, with coastal foraging hotspots located in Baja California, Mexico and the East China Sea (Howell et al 2008; Kobayashi et al. 2011; Seminoff et al. 2014). The marine habitats for the western Pacific leatherback turtle subpopulation extends north into the Sea of Japan, northeast and east into the North Pacific to the west coast of North America, west to the South China Sea and Indonesian Seas, and south into the high latitude waters of the western South Pacific Ocean and Tasman Sea (Benson et al., 2011). Identifying where pelagic longline fisheries overlap with sea turtle migratory and key foraging habitats, and implementing fishery mitigation measures to reduce interactions and mortality, is key to supporting ongoing recovery efforts.

C. Siota (Secretariat of the Pacific Regional Environmental Programme) introduced her organization's Turtle Research and monitoring Database System (TREDS). The Turtle Research and Monitoring Database System (TREDS) was developed to be the overarching database system for turtle research and monitoring conducted by member countries and territories of the Secretariat of the Pacific Regional Environment Programme (SPREP). It is a tool that can be used to compile and manage data from various governments, NGO's, community groups and researchers who undertake turtle research, monitoring and tagging. The use of TREDS ranges from simple turtle tagging and nesting surveys (recording basic information) to more complex research that collect genetics samples, uses laparoscopy to determine reproductive status, and satellite telemetry for tracking migration movements. The information derived from TREDS on important turtle nesting and foraging sites can be useful to superimpose with fishery interaction data during the workshop.

2.2 Status of Mitigation Implementation

Y. Swimmer (NOAA, Pacific Islands Fisheries Science Center (PIFSC)) described progress with an ongoing NOAA project analysing United States longline-sea turtle interaction data in order to provide useful insights for the workshop's own analysis. Her analysis focuses on using observer data from two U.S. pelagic longline observer data sets (North Atlantic / Gulf of Mexico and Hawaii-based in the North Pacific) to investigate the efficacy of sea turtle mitigation methods. Observer programs have been monitoring these fisheries since the early 1990's, and mitigation measures were put in place in 2004. A number of US longline fisheries were temporarily closed during 2000/2001 until 2004 during which time mitigation methods aimed to reduce sea turtle bycatch were identified. Fisheries were re-opened in 2004 with modified gear (e.g., relatively large circle hooks and fish bait), a higher mandatory rate of observed monitoring, requirements for training in handling of protected species, as well as (in some cases) a hard cap (limit)on sea turtle captures.

The species most vulnerable to capture and for which mitigation measures were intended were loggerhead and leatherback turtles. The closure provided both complexity in data analysis (due to confounding variables) as well as an opportunity to assess the efficacy of mitigation measures before and after the regulations were put in place. Given the operational factors associated with both target species and regions, it is critical to filter the data in order to ensure optimum comparisons among data fields. Data analysis can be performed via simple comparisons that offer limited information, and more complex analysis with modeling all interacting factors associated with sea turtle capture rates in the fisheries. The presentation aimed to provide a roadmap for this type of analysis that can inform fisheries managers on effective conservation tools.

In discussion of this presentation the workshop noted the importance of observer programmes providing reliable species identifications. It was considered that it may be possible to assign a data quality code based on factors such as whether there was photo-validation of a sighting, whether the identification was based on onboard examination, and the time of day of the sighting. It may also be necessary to improve the training of observers and increase the availability of training materials, or consult experts on whether sightings are credible.

There was also some discussion about the trade-off in modeling for this workshop between retaining incomplete data records which weaken the dataset with missing data versus discarding these records to obtain a smaller, but more consistent dataset. While both approaches have strengths and weaknesses, there was general consensus that retaining data is preferable to discarding it, particularly when analyzing data for rare events like turtle bycatch.

S. Clarke then presented a review of available information on implementation of the WCPFC's sea turtle mitigation conservation and measure (CMM 2008-03). This CMM specifies mitigation in both longline and purse seine fisheries, and is the only one of the five t-RFMO sea turtle measures to require changes in fishing behaviour in longline fisheries. These changes are limited to fleets fishing in a shallow-set manner for swordfish, and each CCM is authorized to formulate their own definition of "shallow-set". Such shallow-set swordfish fleets are required to either i) use large circle hooks with offsets of ≤10°; ii) use whole finfish for bait; iii) apply an alternative measure approved by the WCPFC's Scientific Committee (SC); or iv) be granted an exemption by the WCPFC SC on the basis of minimal interactions. A review of WCPFC's member and cooperating non-member (CCM) Annual Reports-Part 2 for CMM 2008-03 determined that nine CCMs declared that they had fleets fishing for swordfish in a shallow-set manner. One of these has left the fishery (and had no observer coverage) and one was granted an exemption by the WCPFC SC. Of the remaining seven CCMs, five provide details of what mitigation measures were implemented when. Of these five, three report implementation of mitigation from 2013 onward which provides at most one year of observer data currently available (one of these has no observer coverage). The remaining two reported mitigation as of 2005 and 2010, respectively. This situation, in combination with the facts that i) other CMMs may have switched to or from circle hooks or finfish bait in recent years for other reasons; and ii) most of the gear characterization in the observer data is available for 2008 onward, means that a before-CMM and after-CMM comparison is problematic. It was recommended instead that the workshop consider focusing on a) establishing a current baseline of interactions and mortalities (e.g. 2010-2015); b) understanding how these relate to potential mitigation practices (e.g. hook and bait types); c) identifying key parameter and process uncertainties; and d) determining priorities for future analyses.

Acknowledging the difficulties associated with a before- and after- analysis, the workshop generally agreed that the proposed objectives were appropriate, but there was considerable discussion about what kind of baseline would be constructed and which factors should be considered when standardizing interaction and mortality rates. The workshop noted that it is important to take account of effort patterns in the fishery. For example, it is not unexpected that areas with high fishing effort would have high bycatch of turtles compared to areas with low fishing effort. The models should examine how many hooks are fished per set in different fleets, and perhaps consider the proportion and distribution of hooks observed within a trip.

Participants discussed that if a limited number of gear features are used to characterize fishing operations, it is possible that two fleets might be considered to be very similar when actually they have very different fishing behaviours. For this reason, it is important to understand fishing strategies, for example using expert knowledge, rather than classifying operations solely based on observer-collected data fields.

It was noted that it might be difficult to estimate baseline (or current) values given the poor state of our knowledge and low recording rates of currently used hook sizes and offsets. Even if observers record this information, which is not always the case, measurement protocols or units vary between observer programs, and these hook features may vary from one manufacturer to another even if the hook type and hook size remain constant.

Some participants queried whether an estimated baseline should be a single value for the Western and Central Pacific Ocean (WCPO) as a whole, or whether it would be better to focus on critical habitat areas and monitor interactions and mortality over time in these areas. Given that any mortality estimate would necessarily under-estimate post-release mortality, it was suggested that estimating baseline interactions was a higher priority than estimating baseline mortalities.

3 Data Preparation and Exploratory Modelling

3.1 Characterizing Longline Fishing Fleets in the WCPO

Longline observer coverage for the WCPO tuna fleets varies between fleets and areas, and may not be representative of longline fishing operations as a whole. In an effort to improve the gear characterization information available for this workshop, SPC prepared summaries of pertinent operational information for 26 fleets (i.e. flag State-setting strategy (deep/shallow) combinations) based on observer data. These summaries included information on the mode or average for time of day of setting, soak time, number of hooks set, hooks between floats, float length, branchline length, use of wire leaders, use of shark lines, lightsticks, bait type, hook type, hook size and hook offset. The WCPFC Secretariat asked CCMs in WCPFC Circular 2016/03 to check the summaries and verify whether they accurately represent each fleet's actual gear profile.

Summaries were sent individually to Australia (AU), China (CN), Cook Islands (CI), Federated States of Micronesia (FM), Fiji (FJ), French Polynesia (PF), Japan (JP), Kiribati (KI), Korea (KR), Marshall Islands (MH), New Caledonia (NC), New Zealand (NZ), Papua New Guinea (PG), Samoa (WS), Solomon Islands (SB), Tonga (TO), Chinese Taipei (TW), United States (Hawaii (HW)/American Samoa (AS)), and Vanuatu (VU) for checking. The gear characterization summaries, including corrections received, are shown in Table 1. These data will provide input for the definition of scenarios to be tested in the simulation model (see Section 4.5).

3.2 Overview of the Workshop Data Sets

S. Caillot (SPC) gave an overview of the datasets made available for the workshop. Data from multiple sources were compiled ranging from regional and national longline observer programmes maintained by SPC to additional datasets shared by countries. Templates developed by SPC and used by observers in the region were presented along with the overall architecture of the turtle dataset. Challenges encountered during the incorporation of the datasets provided in multiple formats were explained and the different steps (harmonization, validation, optimization) to obtain a consistent and consolidated database representing more than 2,300 turtles were explained.

SPC presented a table highlighting information that was found to be missing when the data holdings for this workshop were compiled. Workshop participants were asked to check the information for the fleets they know and advise SPC of any pertinent background information (e.g. their fleets do not use shark lines and thus do not record whether or not such lines are used; or, the data are available but were simply not provided to SPC). This information on data availability was added to the gear characteristics data obtained from the CCM survey described above and presented to the workshop in a table. Participants further refined the table during the workshop to produce Table 1.

Fleet	Depth	Avg hks flt	Float length %	Hks float %	wire trace %	Light sticks %	Shark lines %	Target species %	Hook type %	Hook size %	Circle hk %	Tuna hk %	J hk %	Other hk %	Offset Y %	Bait %	Squid %	Fish %	Mack %	Other %	Position %	Date %	Soak time %	Sets_nb	Turtles cond. %	Turtle fate %	Turtle len %
AS	deep	29	100	100	100	100	0	100	100	100	98	1	0	0	97	95	0	94	1	0	100	100	100	2882	100	100	0
AU	deep	23	77	99	0	67	0	80	80	76	76	0	0	3	0	100	84	63	2	0	100	99	19	680	100	100	87
AU	shallow	8	69	99	0	48	0	71	70	58	58	0	0	11	0	99	71	61	18	0	99	99	26	852	100	100	100
CK	deep	32	100	100	89	2	12	100	95	67	60	11	0	23	9	99	3	99	4	0	100	100	99	391	100	100	88
CN	deep	23	98	98	36	79	71	99	77	73	24	51	0	0	4	96	12	81	26	0	99	98	38	4048	100	100	62
FJ	deep	34	99	99	93	44	61	92	91	84	71	14	0	4	23	98	1	88	19	0	99	99	97	3528	100	100	84
FJ	shallow	10	100	100	100	100	100	100	100	100	100	0	0	0	0	100	0	100	0	0	100	100	100	2			
FM	deep	27	100	100	100	22	22	100	100	100	100	0	0	0	0	99	0	99	0	0	100	100	100	71	100	100	100
FR	shallow	6	0	100	0	97	0	100	97	48	25	0	22	49	0	100	98	3	55	0	100	100	97	130	100	100	11
HW	deep	25	99	99	100	99	0	100	100	100	84	14	0	0	99	95	0	94	0	0	100	100	100	23219	100	100	2
HW	shallow	4	100	100	100	99	0	100	100	100	100	0	0	0	100	99	0	1	98	0	100	100	100	8668	100	100	1
JP	deep	17	99	100	62	4	0	67	15	15	0	15	0	0	0	80	3	11	76	0	100	100	97	3025	99	0	73
JP	shallow	9	98	100	0	0	0	76	0	0	0	0	0	0	0	36	36	36	15	0	100	100	98	948	98	1	43
KI	deep	38	100	100	100	0	0	100	100	100	100	0	0	0	0	100	0	100	0	0	100	100	100	17			
KR	deep	25	99	100	100	23	55	99	100	66	38	43	0	17	20	99	82	99	77	0	99	97	96	963	100	94	47
MH	deep	21	100	100	100	18	0	100	100	81	0	100	0	0	0	100	18	100	42	0	100	100	100	28			
NC	deep	30	99	100	83	41	10	99	90	88	79	9	0	1	0	99	0	98	1	0	100	98	97	1050	100	100	100
NZ	deep	13	98	100	0	0	0	82	98	91	88	0	0	10	0	34	34	14	0	0	100	100	92	651	100	100	0
NZ	shallow	9	100	100	0	0	0	84	100	93	93	0	0	6	0	14	14	7	0	0	100	100	95	184	100	100	0
PF	deep	37	96	99	91	33	21	86	90	72	37	37	2	12	7	99	0	99	1	0	99	99	98	2792	100	100	70
PG	deep	17	100	100	100	0	0	100	100	100	0	100	0	0	0	100	0	100	0	0	100	100	100	28			
PG	shallow	4	99	100	100	0	99	94	100	91	5	86	8	0	17	99	0	54	92	18	99	99	97	784	100	97	96
SB	deep	25	99	100	100	53	50	98	100	95	64	31	0	4	0	98	9	88	19	0	100	98	98	208	100	100	97
TO	deep	25	100	100	85	87	53	71	48	44	20	23	0	3	14	100	7	95	7	0	100	100	99	53	100	100	100
TO	shallow	9	100	100	100	7	0	100	100	100	100	0	0	0	100	100	100	100	0	0	100	100	100	10			
TW	deep	18	99	100	99	2	7	98	99	97	22	3	71	2	1	99	8	96	4	0	99	99	96	13229	100	99	84
TW	shallow	6	99	100	99	9	28	88	82	65	13	51	17	0	11	99	63	79	56	9	100	95	93	887	100	100	92
VU	deep	24	98	100	96	36	72	81	97	83	17	66	0	13	21	98	0	93	9	0	99	99	95	939	100	100	100
VU	shallow	7	100	100	83	78	75	50	100	57	0	57	0	42	0	98	0	97	0	1	100	100	96	105	100	100	0
WS	deep	36	98	100	100	34	20	100	100	100	100	0	0	0	34	100	0	69	30	0	100	100	99	39	100	100	50
WS	shallow	5	0	100	0	0	0	0	0	0	0	0	0	0	0	100	54	39	36	0	100	100	95	13			

Table 1. Summary of data availability and gear characteristics for the fleets represented in the workshop database based on data provided for years since 2009 (most recent year varies by fleet). Column headings shaded yellow denote those columns containing actual data. Column headings shaded orange denote those columns containing information on the availability of data (for example, 100% indicates that all records of a specific dataset have information for this data field whereas 0% indicates that none of the records of a specific dataset have information for this data field). Orange-headed columns have cells shaded green to red showing a gradient of data availability. It should be noted that red shading may result from either missing data or intentional non-collection of data (for example, that gear has been discontinued in that fleet). Column headings shaded blue denote columns which are categorical breakdowns of orange-headed columns to the left. (see Section 3.1 for fleet abbreviations)

3.3 Exploratory Analyses and Statistical Issues

T. Peatman (SPC) presented exploratory analyses undertaken with the full dataset, to provide context to participants on analytical approaches that could be used to achieve the workshop objectives. The following modelling framework was proposed based on the shark mitigation analysis conducted by SPC in 2014-2015 (Figure 1):

- modelling interaction rates at the set level as a function of explanatory variables to determine the effect of gear configurations on turtle interaction rates (Set Level Model);
- modelling interaction rates by hook position to determine where turtle bycatch is found in relation to floats, i.e. is there a higher probability of turtle catch on hooks closer to a float (Hook Level Model);
- modelling the condition at capture of turtle bycatch to determine the effects of gear configurations on the proportion of turtles caught dead/alive (Condition Model); and,
- combining information from the three models in a simulation model to estimate overall turtle interactions and at-vessel mortalities.

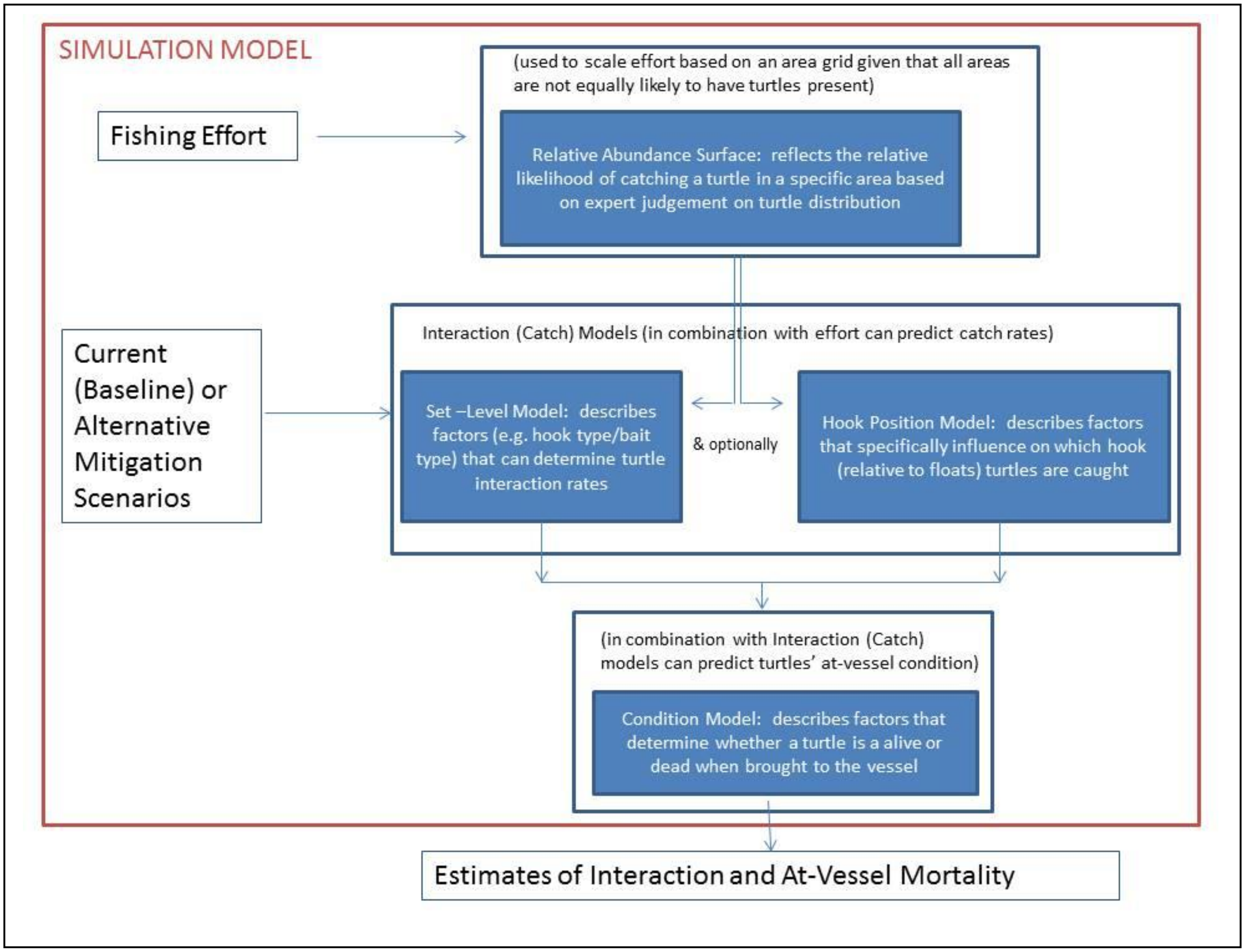

Figure 1. Schematic diagram of the simulation model used in this workshop and its components.

3.4 Discussion of Modelling Approach

There was general agreement that the Set Level Model was an important building block for further estimates and thus a good place to initially focus the work. One participant considered that a trip level model would be a better framework given that sets within a trip are not independent; however, this participant agreed that a set level model was also acceptable, particularly if there could be some accounting for potential spatial and temporal autocorrelation. SPC explained that the model data were sorted by trip and set number and tested for autocorrelation. If autocorrelation was detected in the model residuals then adjustments or alternative models were considered. Discussion of the other models was postponed until the workshop was ready to take them up (see following sections).

4 Joint Analysis

4.1 Modelling Longline Gear-Sea Turtle Interactions at the Set Level

SPC presented further details on the Set Level Model. There was agreement that modelling the presence/absence of turtle interactions separately from positive interactions was required, due to the zero-inflated nature of the dataset. The workshop agreed with the proposed use of GAMs and on the distributions to be used for the positive-catch portion of the model.

SPC presented maps of catch for loggerhead, leatherback, olive ridley and green turtles for shallow and deep longline sets separately (Figures 2-5). It was noted that the timeframe and coverage represented in each of the observer programs vary. It was also noted that it would be interesting to consider which grid squares have recorded catches of more than one species over time. The workshop was informed that of the approximately 2,300 turtles in the workshop dataset, ~330 were green turtles, ~560 were loggerheads, ~350 were leatherbacks, and ~730 were olive ridley. Participants were asked to check the maps to determine if any of the points shown were dubious (e.g. several green turtles reported north of 30°N). There was consensus that the modelling approach should take in to account species-specific differences to the extent possible given the available dataset. For example, it may be possible to include species-specific interactions for certain variables within a model fitted to turtle interactions for all species.

The workshop discussed the *a priori* division of sets into shallow and deep categories as opposed to simply using hooks between floats (hbf) as a variable in the models. Acknowledging previous work by K. Bigelow and others that suggests that hooks in practice fish considerably shallower than would be expected based on theory alone, various ways of accounting for the depth at which the hooks actually fished were discussed. SPC proposed to cluster sets by targeting strategy, as defined by the recorded species composition, and then match those strategies to the ranges of hbf fished. It was acknowledged that expert information about certain fisheries might help to refine these classifications. For example:

- it was clarified that the Papua New Guinea shallow set fishery was targeting sharks but closed in 2014.
- there is some shallow-set night-time fishing for bigeye tuna, often by Chinese Taipei vessels which operate in Palau and potentially elsewhere.

Some participants suggested that the depth at which the hooks fished could be approximated by variables that are (or could be) collected by the observer (e.g. floatline length, use of a line shooter, speed of setting, current speed, etc.). It was noted that floatline length would help determine the minimum depth of the shallowest hook in the set where a high proportion of turtle interactions occur. Other participants maintained that without TDRs (time depth recorders) estimating hook depth will be highly uncertain.

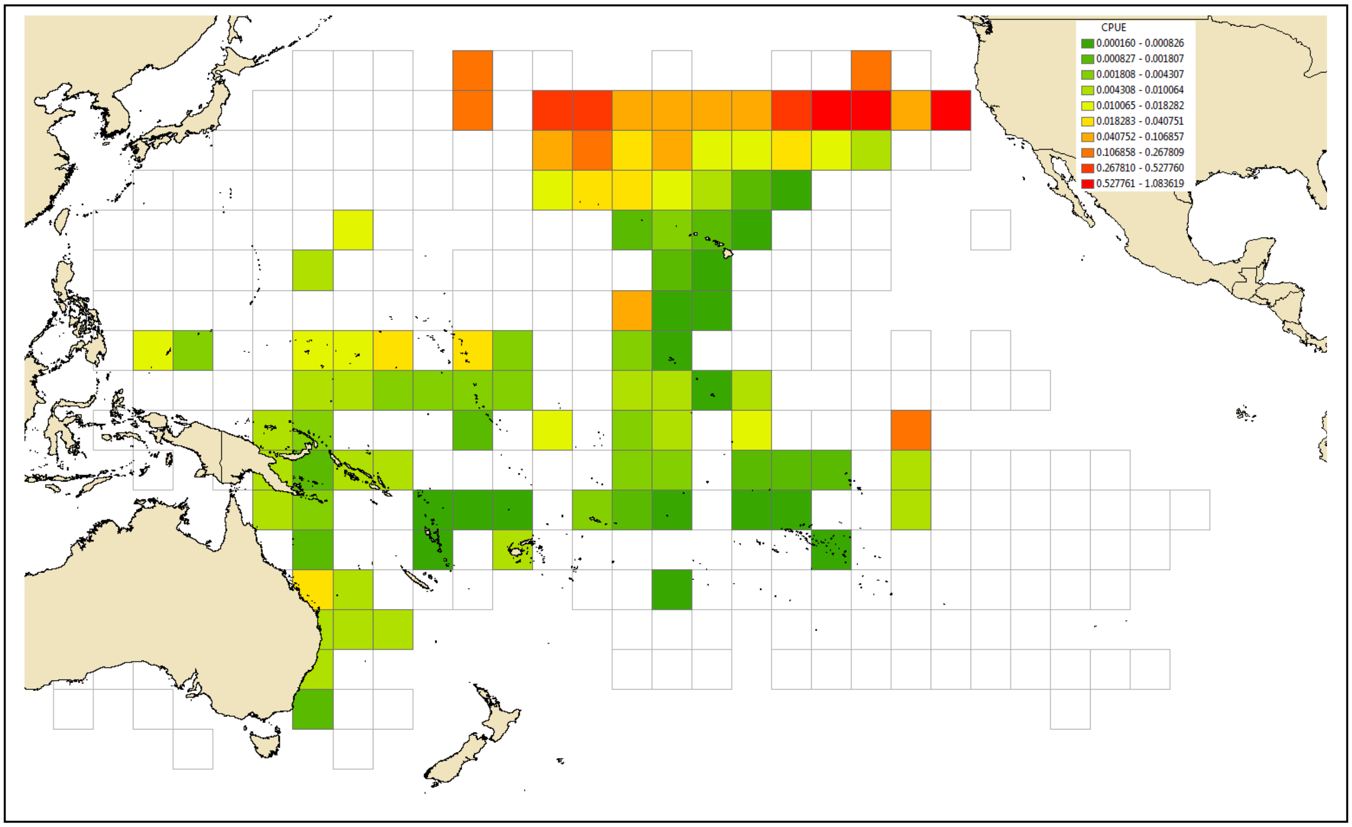

Figure 2. Catch per unit effort of leatherback sea turtle (*Dermochelys coriacea*) by 5º x 5º grid based on observer data for deep and shallow longline fisheries in the workshop dataset, 1989-2015.

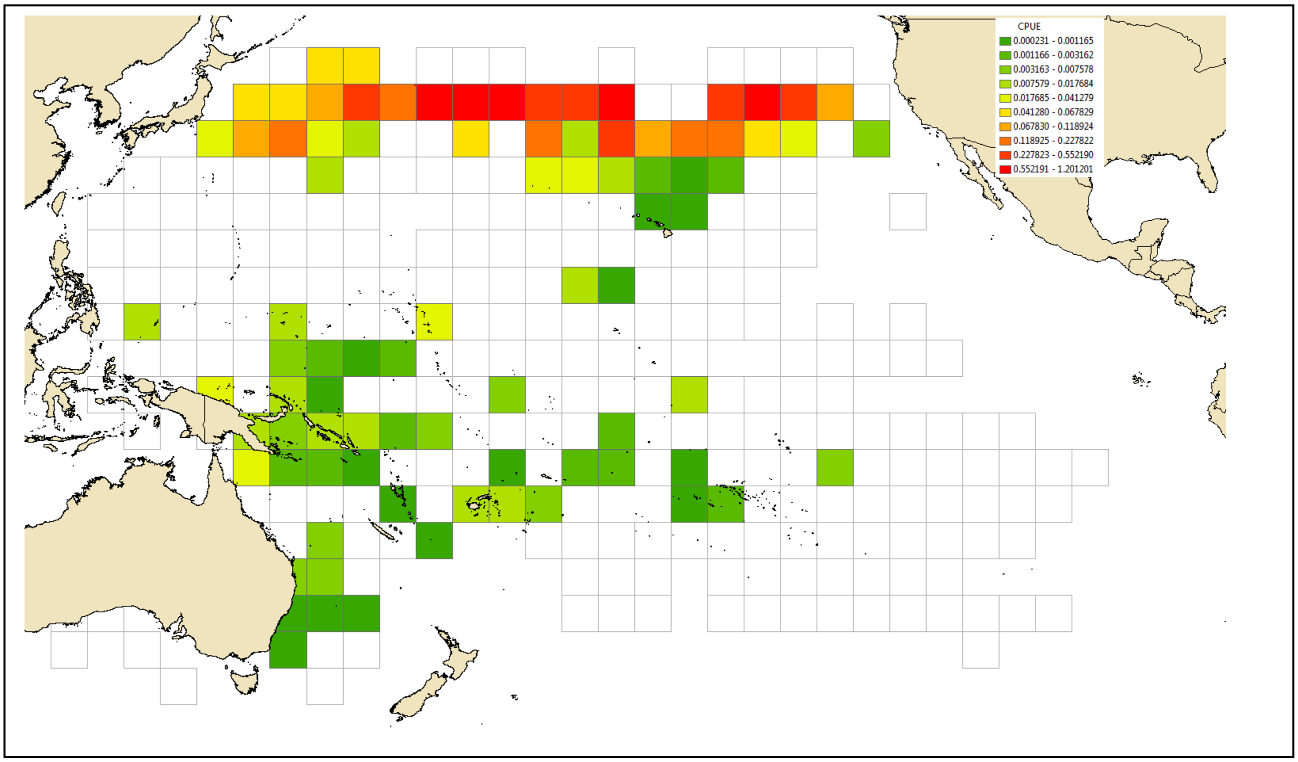

Figure 3. Catch per unit effort for loggerhead sea turtle (*Caretta caretta*) by 5° x 5° grid based on observer data for deep and shallow longline fisheries in the workshop dataset, 1989-2015.

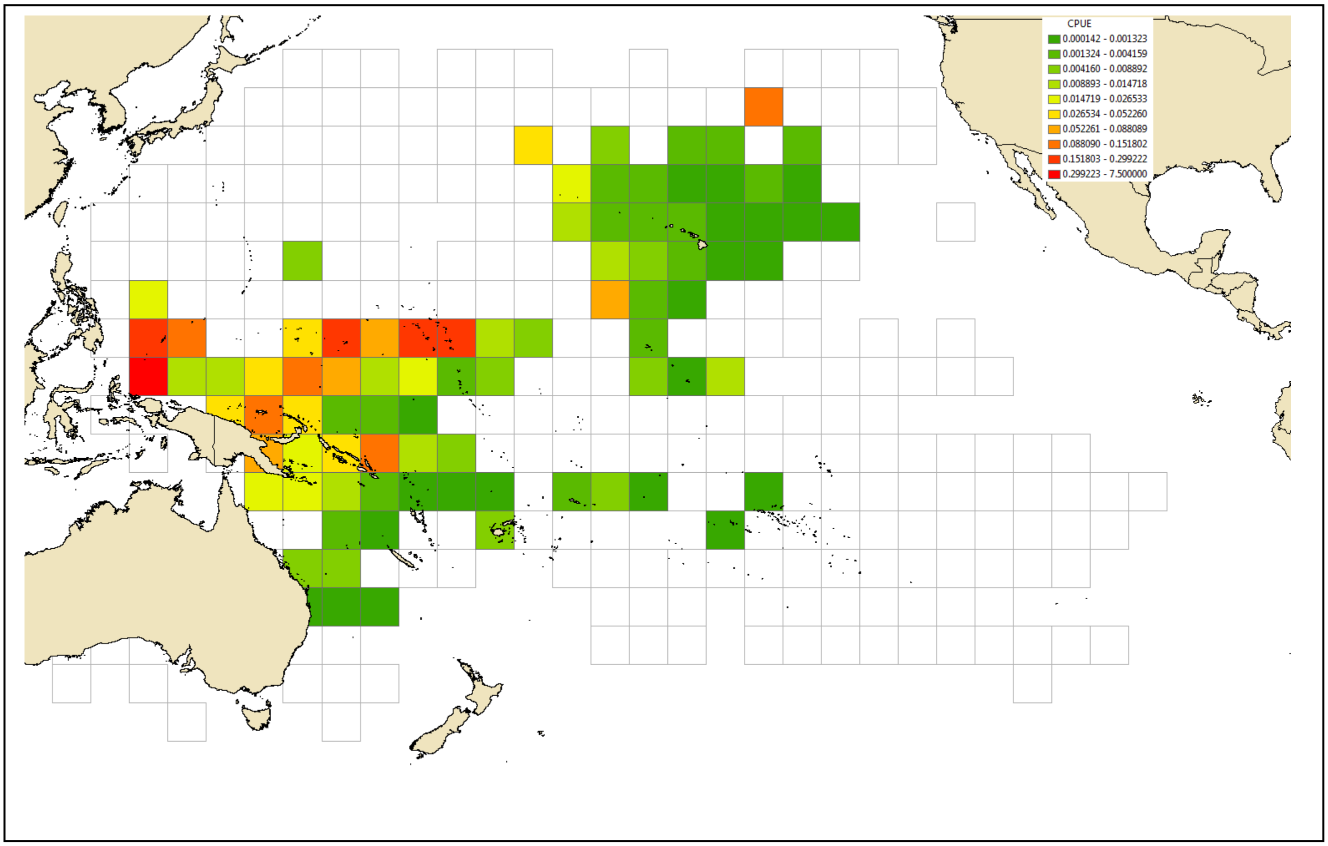

Figure 4. Catch per unit effort for olive ridley sea turtle (*Lepidochelys olivacea*) by 5º x 5º grid based on observer data for deep and shallow longline fisheries in the workshop dataset, 1989-2015.

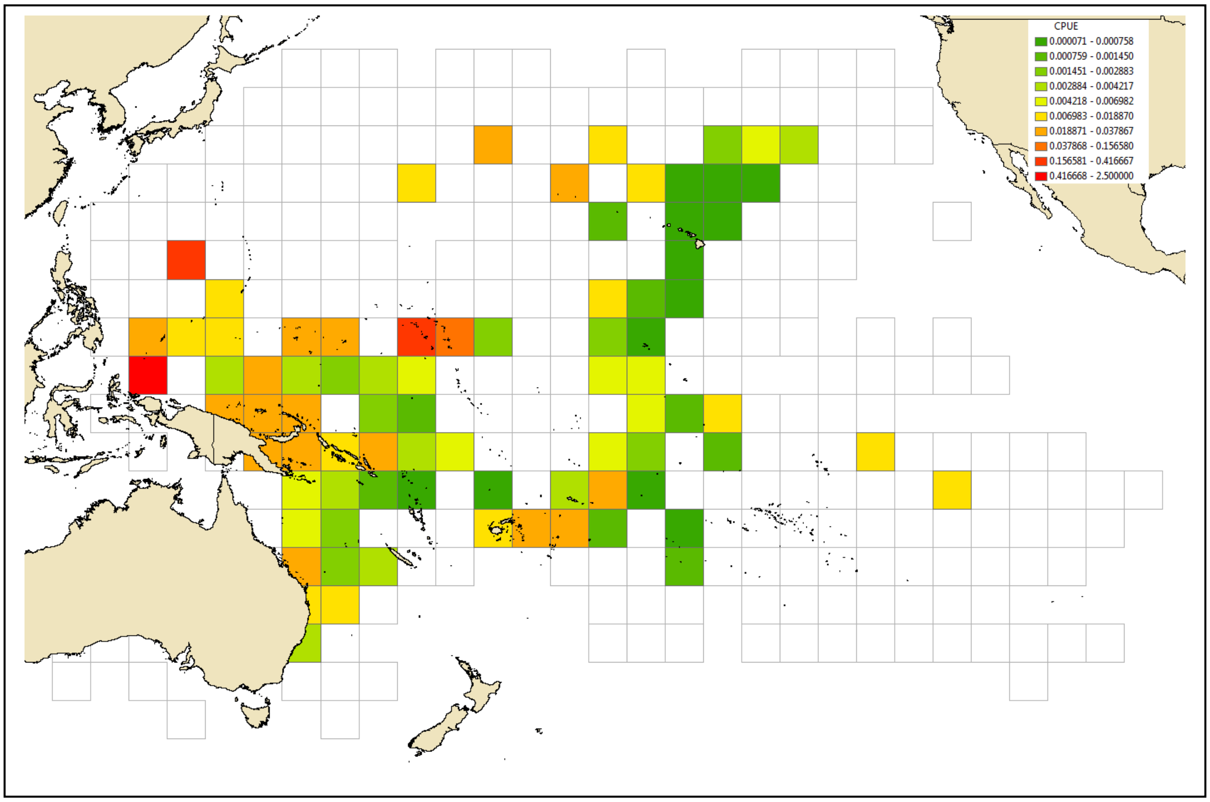

Figure 5. Catch per unit effort for green sea turtle (*Chelonia mydas*) by 5º x 5º grid based on observer data for deep and shallow longline fisheries in the workshop dataset, 1989-2015.

Some participants considered that it might be important to take account of turtle life stage in the model by using available information on turtle size. SPC explained that there is some information on turtle size for a portion of the records, and turtle specialists agreed to provide SPC with some indicative size ranges of adults and juveniles for each species. The workshop noted that the sizes of turtles recorded as interacting with longline fisheries indicated spatial separation of juveniles and this is consistent with findings in other oceans. A table of size ranges for juvenile and adult stages of various species of turtles based on input from the workshop is shown in Table 2.

Table 2. Indicative sizes (rounded for this exercise) by life stage and maximum and minimum sizes for five species of sea turtles as prepared by the workshop from various published literature sources.

Species	Code	Maximal CCL (cm)	Size not possible	Maximal weight (kg)	Minimal CCL at first maturity Pacific (cm)	Juvenile	Uncertain	Adult
Caretta caretta	TTL	110	>120	150	85	<70	[70-90]	>90
Chelonia mydas	TUG	125	>135	250	85	<70	[70-90]	>90
Dermochelys coriacea	DKK	230	>260	900	120	<100	[100-130]	>130
Eretmochelys imbricata	TTH	100	>110	120	65	<60	[60-70]	>70
Lepidochelys olivacea	LKV	90	>100	70	55	<50	[50-60]	>60

It was noted that the WCPFC Regional Observer Programme does not clearly define what measurement method should be used for measuring the size of turtles. For example, Japan and the United States use straight carapace length (SCL) as measured using calipers, whereas Chinese Taipei uses curved carapace length (CCL) using a tape measure. This topic warrants further investigation to ensure data from different programmes can be appropriately compared or combined. SPC informed the workshop that according to the data currently available in the dataset prepared for this workshop no measurements were provided for 1057 turtles, SCL was provided for 240 turtles, CCL for 7 turtles, and carapace length given but no measurement type specified for 633 turtles. More data may be available from Hawaii and American Samoa and the United States will investigate these data.

Participants then identified operational variables considered most likely to affect turtle interaction rates and for which there were sufficient data to support estimation. The following variables were identified for an initial run of the Set Level Model:

- **Soak time** – it was suggested that soak time could be calculated as ((haul start-set end) + (haul end-set start))/2 to represent the midpoint between the time all hooks were fished and any hooks were fished (based on Carruthers et al. 2009);
- **Time of day of set** – it was noted that the same time of day of set could represent variable times before or after dawn or dusk based on season and latitude. Therefore times should be adjusted if possible to account for this;
- **Hooks between floats (hbf)** – it is recognized this is an attempt to account for hook depth but will be inherently uncertain;
- **Bait type** – given that the mixed bait type (squid+fish) is more uncertain than the other categories due to the unknown proportion of the mixture, SPC would attempt to use other information to refine the mixed bait type if possible;
- **Hook type** – SPC proposed to use three types: J, C (circle hooks) and T (a combination of tuna hooks and Teracima hooks)
- **Sea Surface Temperature (SST)**[1] – although it was acknowledged that this is not strictly an operational variable (though fishermen may target certain water temperatures), it was recommended that it may be necessary to retain it in the model to account for species specific habitat preferences of turtles; and
- **Hook Size** – although there are considerable data gaps in the recording of hook size, as well as potentially some problems in determining the actual (rather than relative) size of hooks which are listed as shape+ model number (rather than actual measurements), SPC will run the model with and without hook size to explore its potential importance.

Other variables, such as the use of lightsticks, were acknowledged to be potentially important in this model but data were insufficient to include them. This model was agreed as a starting point for further examination of residuals (to determine whether other variables should be considered) and to determine the significance of the selected variables (to determine whether they should be retained or dropped).

SPC presented the result of the initial run of the Set-Level model. Soak time was recalculated according to Carruthers et al. (2009; see above) but the algorithm to adjust the time of the start of

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[1] Based on past experience, SPC recommended that SST be derived from oceanographic data (1 degree latitude-longitude square month (Reynolds)) rather than using the observers' measurement of SST, and the workshop agreed. Nevertheless it is acknowledged that deriving SST in this manner involves some uncertainty given the coarseness of the grid of the oceanographic data available.

the set relative to dusk/dawn was rather involved and could not be applied. This and other time adjustments (e.g. calculating the number of daylight hours that the hooks are fished) were deferred until there was more time available to address them properly. This situation also occurred for the partitioning of the mixed fish and squid bait type: it may be possible to glean more information about this bait category later but it was considered too time consuming to undertake during the workshop.

The preliminary model results showed, *inter alia*, that J hooks had lower catch rates than C hooks which were in turn lower than T (tuna and Teracima) hook catch rates. In addition, bait comprised of fish or a combination of fish and squid had lower catch rates than bait comprised of squid only. For the "habitat" variable SST, which was given an interaction term with species, the green and olive ridley turtles showed linear and increasing catch rates with increasing SST whereas leatherbacks showed no response to SST and loggerheads shown a non-linear relationship. The diagnostic Q-Q showed a good fit and all variables were significant with (in descending order) bait, hook type and species having the highest effect sizes. However, in some areas, there was a distinct lack of fit identified through a spatial surface fitted to the residuals of the preliminary model. When residuals were plotted spatially by species, the areas of poor predictions were shown to vary by species but were often in areas where observer data was scant.

Participants discussed a number of approaches to try to reduce the spatial residuals of the model, i.e. to improve the model fit in areas where the model substantially under- or over-predicted turtle interactions perhaps due to habitat factors that are not well informed by the observer data and are not fully captured by SST. These areas of poor prediction included areas in the Kuroshio Current off Japan for loggerheads, and the area north of Papua New Guinea for olive ridley turtles. The first approach tested was to re-run the model using a factor to identify the observer programme providing the data; this was similar to defining regions within the WCPO since each observer programme is centered in its own EEZ. (Use of a fleet factor instead of an observer programme factor, i.e. to take account of target strategies, was considered but dismissed due to the potential to conflict with the information signal from the operational variables in the model). This approach did not, however, significantly improve the spatial residuals and also introduced issues with correlated explanatory variables. Instead, it was considered that information on areas of likely higher turtle catch rates could be predicted by a relative abundance surface (or a similarly constructed coarse grid) based on existing information and/or expert judgement. Although it was acknowledged that this could over-simplify what is actually a very complex and highly uncertain situation, it can serve as a starting point for further work to be conducted before the second workshop and beyond (see Section 4.4).

The workshop then addressed the issue of informing the model about hook size. Participants considered that rather than modelling observer-recorded hook type and hook size as two variables, that categories should be formed based on a combination of the two. After examining the available observer data on hook size and shape, and comparing to existing information (Gilman et al. 2012) on minimum width and other hook dimensions, a table was produced classifying hook type-hook size combinations as small or large (Table 3). There was also a brief presentation by R.A. Sauturaga (Fiji) on the differences between hook types and sizes. Participants were referred to the SPC Longline Terminal Gear Identification Guide (http://www.spc.int/coastfish/index.php?option=com_content&Itemid=30&id=347) for more information. Participants noted that the Japan tuna hook is probably the strongest hook design; other hooks, especially those that are larger and wider, may unbend when very large fish are hooked. European fleets have fished J-hooks for a long time whereas Asian fleets have traditionally used Japanese tuna hooks. It was noted that Teracima hooks are used in the mahi mahi fishery in

Fiji (20% of hooks fished are Teracima hooks, with the remainder being circle hooks). Some evidence from Ecuador and the Mediterranean suggests rings on the hooks may increase bycatch. Hook size tends to be related to selectivity and thus targeting strategies, however it may be that hook gape may be more important than hook size in this regard. It was noted that historically (pre-2003) J-hooks and tuna hooks were classified using similar terminology. There may be a need to re-visit that classification prior to the division of effort amongst the fishing fleets using in the simulation model.

The model was then re-run with hook type and hook size combined into a hook category variable as follows: large circle hooks, small circle hooks, small J hooks and small T hooks. There were no data for large J or large T hooks (Table 3). The results showed a larger effect of hook category relative to bait type than in the previous version of the model. Large circle hooks and small J hooks had similar catch rates. Small circle hooks had similar catch rates to small T-hooks. This suggests that it may be that the overall size of the large circle hooks have more of an influence on hard-shelled turtle catch than the circle shape per se, though it was noted that for leatherback turtles (which comprise about 20% of the turtle records) the shape of the hook may be more important than its size.

Table 3. Some hook types and sizes (Gilman et al. 2012) and the category (S=small, L=large) assigned by the workshop to each.

	Hook type	Minimum Width (cm)	Category
1	Offset 3.6 sun tuna hook Tankichi	3.1	S
2	Non-offset 8/0 J hook Mustad	3.5	S
3	Non-offset 3.8 sun tuna hook Tankichi	3.6	S
4	Non-offset 3.6 sun tuna hook Tankichi	3.7	S
5	Offset 15/0 circle hook Lindgren-Pitman	3.8	S
6	Offset 3.8 sun tuna hook Tankichi	3.8	S
7	Offset 14/0 circle hook Lindgren-Pitman	3.8	S
8	Non-offset 9/0 J hook Mustad	3.9	S
9	Non-offset 15/0 circle hook Lindgren-Pitman	4.0	S
10	Offset 16/0 circle hook Lindgren-Pitman	4.4	L
11	Non-offset 18/0 circle hook Lindgren-Pitman	4.9	L
12	Offset 18/0 circle hook Lindgren-Pitman	4.9	L

Note: Only a few types and sizes of circle hooks were categorized as large. All other type and size categories of hooks not found in Table 3, such as Teracima hooks, were compared using the SPC Terminal Gear Guide (http://www.spc.int/coastfish/index.php?option=com_content&Itemid=30&id=347) and, and it was decided that these hooks probably belonged in the small category."

The workshop further considered the potential interaction between hook category and bait type. Participants theorized that it might be the case that combinations of hook categories and bait types might perform differently than estimated with additive effects. Participants also suggested that leatherback catch rates might be insensitive to bait type as they are often foul-hooked or entangled rather than hooked when taking bait. It was noted that when the United States implemented its sea turtle mitigation plan for the shallow set fishery it required large (18/0) circle hooks at the same time it prohibited J-hooks with squid bait. As a result, the combinations of large circle hooks and squid bait and J-hooks with fish bait are absent or rare in the dataset. Thus the dataset does not include data for comparing large circle hooks to J-hooks with the same kind of bait. Consequently it is likely that that is why the model fails to detect a difference between large circle hooks and J hooks. Participants also mentioned that the hook type and bait type combinations may be correlated to year given the way in which mitigation programs were phased in (see *Annex B* for more information on United States regulations).

Running the model with an interaction between hook category and bait showed that when using fish bait, small circle hooks had higher turtle interaction rates than large circle hooks. Participants noted that interpretation of the mixed fish-squid bait type was problematic as the proportions of the two bait types are unknown and the sample size is low. Nevertheless, it is useful to retain this mixed bait category in the model in order to be able to predict interactions for fleets which use mixed bait.

Participants then considered whether a species interaction with hook shape was warranted. This could account for the fact that leatherbacks are more likely to be foul-hooked on J hooks. A species interaction term with hook type resulted in a percent deviance explained of 19.3% and a species interaction term with hook category resulted in a percent deviance explained of 19.8%.

A set-level model including hook category (shape and size), bait type, hook category*species, time of set, soak time, hooks between floats, and SST*species was tentatively accepted by the workshop pending final checking. It was noted that an effort offset should be included to explicitly account for the number of hooks per set. SPC reported back to the workshop that adding an offset for effort did not appreciably change the results. Another aspect of the checking involved examining whether the interaction terms in the model substantially improved the model fit. In performing this check, SPC noted that the data available to support estimation of interaction terms for hook and bait categories are insufficient therefore it was agreed that these interaction terms would be removed from the model. It was also agreed that since set time is not meaningfully contributing to increasing the percent deviance in the set-level model it could be removed.

The final set-level model, was thus constructed as a logistic model with complementary log-log link:

(catch != 0) ~ offset(hook set) + s(soak time) + s(hbf) + s(sst, by = species) + hook category + bait + species

AIC values for the terms in the model are shown in Table 4. Plots of the final parameter estimates are shown in Figure 6. Since the workshop believed there was value in exploring the effect of hook category and bait type on interaction (catch) rates, a table of the absolute and relative increases in the probability of longline-sea turtle interactions under each combination for each species is included in *Annex C*.

Table 4. AIC values for the final set-level model adopted by the workshop.

Model	df	AIC	delta AIC
Full model	30.8	11332.4	
- soak time	29.9	11335.5	3.1
- hook time	30.5	11457.1	124.7
- bait	35.6	11535.5	203.1
- hbf	31.2	11724.1	391.7
- sst:species	18.8	12316.1	983.7

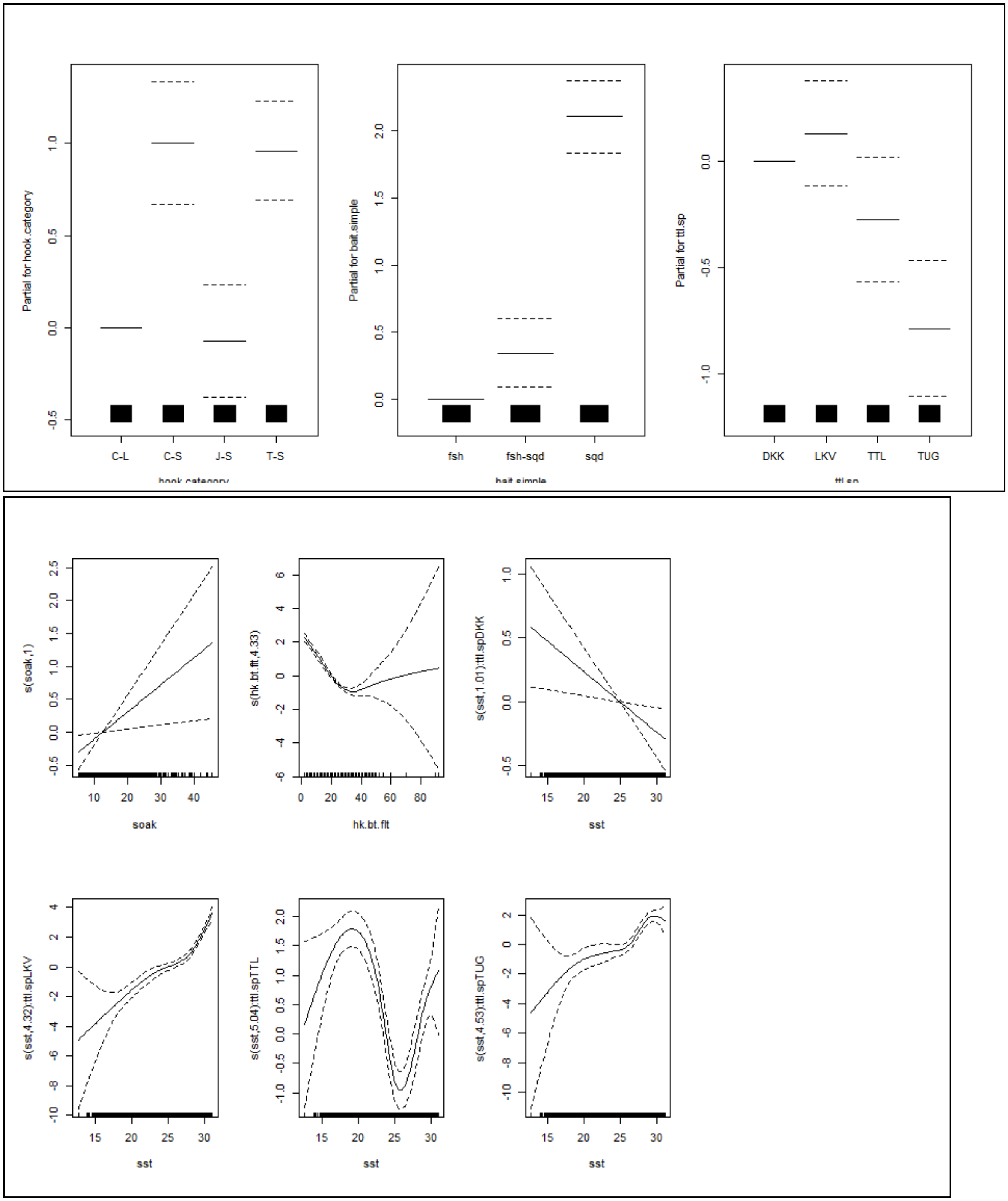


Figure 6. Plots of parameter estimates for the final set-level model for categorical explanatory variables (top panel) and continuous explanatory variables (bottom panel).

Noting that thus far the work on the set-level model had been limited to the presence/absence component, and the second step (i.e. estimating the number of turtles caught when the number of turtles caught is a positive number) is yet to be addressed. SPC noted that 90% of the turtles caught represent single catches (i.e. one turtle caught per set) and are thus represented in the presence/absence model. The maximum number of turtles for a given species per set was six. As an alternative to constructing a model for the n>1 catches, SPC suggested that the results of the presence/absence model be scaled to account for the relatively rare occurrences of multiple turtles caught in a given set. The workshop agreed that given time constraints this approach was acceptable.

4.2 Modelling Longline Gear-Sea Turtle Interactions by Hook Position

SPC explained that this model is useful to specifically address potential mitigation techniques associated with removing the shallowest hooks closest to the float. The model was constructed to estimate the probability of encountering a turtle at a given hook position and was applied only to sets in which at least one turtle was caught. Deep and shallow fisheries were modelled separately to account for the fact that the same hook position in shallow versus deep sets would actually fish at different depths.

SPC suggested and workshop participants agreed the following list of explanatory variables for an initial modelling run:

- **Hook Position** –the hook number as counted from the nearest float (with shark lines assigned a hook number of zero) and is the key variable of interest for this model
- **Hooks between floats** (hbf) **–** this was considered necessary to account for the variable depth at which a hook of a given position would fish
- **Floatline length –** like hbf this was also considered necessary to account for the variable depth at which a hook of a given position would fish
- **Species –** to account for differing interaction rates by species

An interaction between species and SST was included to account for species-specific habitat preferences where habitat is represented by SST. An additional interaction term was included for hook position and species to account for species-specific depth preferences.

Results of the initial modelling run suggested that in the deep set model there is declining catch with increasing hook position, with the exception of leatherback turtles which are found at a wide range of depths and have a higher propensity to be entangled rather than hooked. In the shallow set model there was no significant difference between turtle catches on hooks 1-4 but there was a significantly lower catch of turtles on shark lines (hook position zero).

Participants discussed whether it is important to retain the interaction between SST and species if it is not significant for leatherback turtles. SPC explained that overall the SST-species interaction term is significant even though it is not significant for leatherbacks. Participants speculated as to why this is the case but there was no ready explanation.

With regard to shark lines in particular, SPC noted that the deep set model is not well-formulated to test the extent to which shark lines affect turtle catches and thus an alternative model would be needed for this purpose. Further consideration of including shark lines in the model will require that the unbalanced nature of shark lines and branchlines be addressed.

Two additional ideas were raised for this model: i) include the presence or absence of a line shooter as an explanatory variable (most important for deep sets); and ii) run the model again for a subset of data that does not contain any mixed fish-squid bait so that if there is any confounding influence of bait on the model result this is minimized. The first idea could not be explored due to lack of data on whether a line shooter was used. For the second idea, when the model was run on the suggested subset of data the hook position effect did not change from the full model which indicates that bait is not a confounding factor. Some participants, noting that the observers' workload is heavy and their recording of hook position information is thus somewhat unreliable, cautioned against placing a heavy emphasis on hook-specific information.

The final hook position models were thus constructed as logistic models with a complementary log-log link:

Deep model
(catch != 0) ~ s(hook position, by = species) + s(float length) + s(hbf) + species+ s(sst, by = species)

Shallow model
(catch != 0) ~ as.factor(hook position) + s(float length) + s(hbf) + species + s(sst, by = species)

The hook position and species interaction term did not improve the shallow set model based on AIC, and so was not included in the final model.

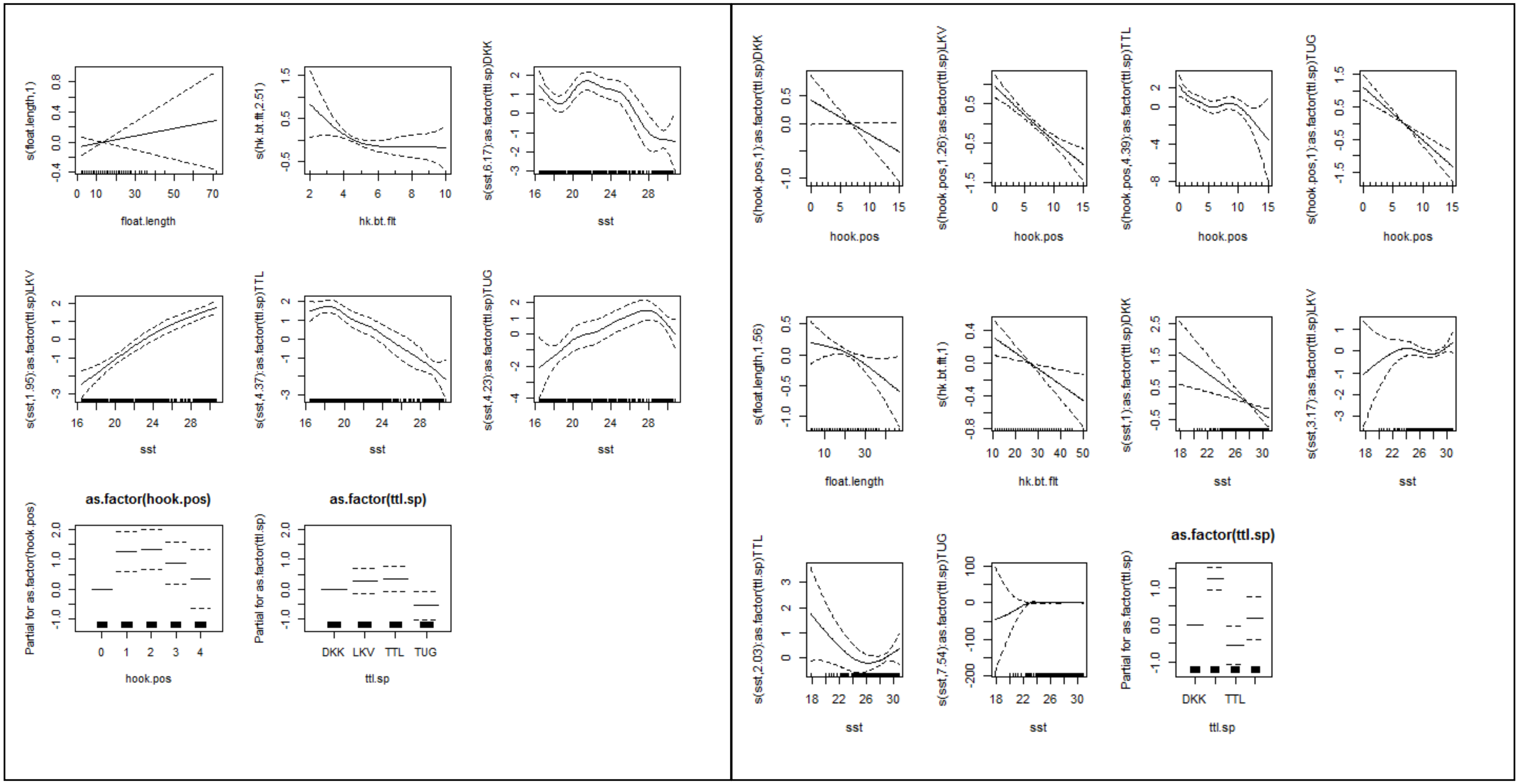
AIC values for the terms in the model are shown in Table 5. Plots of the final parameter estimates are shown in Figure 7.

Table 5. AIC values for the final hook position model for deep and shallow sets adopted by the workshop.

Deep Model	**df**	**AIC**	**delta AIC**
Full model	28.0	4501.9	
- float length	26.3	4506.3	4.4
- hbf	26.9	4507.9	6.0
- sst:species	14.1	4533.5	31.5
- hook position:species	20.4	4611.3	109.4

Shallow Model	**df**	**AIC**	**delta AIC**
Full model	28.1	3545.1	
- float length	27.1	3544.0	-1.1
- hbf	27.8	3550.1	5.0
- hook position	34.9	3572.7	27.6
- sst:species	11.0	4176.5	631.4

Figure 7. Plots of parameter estimates for the final hook position model. Results for the shallow model are shown in the left panel with deep model results in the right panel.



A table showing the percent differences in turtle interactions by hook position was constructed and is shown as Table 6.

Table 6. Percent differences in turtle interactions by hook position according to the final version of the hook position model. The interaction probability is provided for the first hook position and shown as percentage change (from the first hook position) for the other hook positions. The deep model results are shown above with the shallow model results below.

Deep	Hook Position							
Species	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**15**
DKK	0.013	-12%	-17%	-22%	-27%	-31%	-36%	-39%
LKV	0.065	-24%	-34%	-43%	-50%	-56%	-62%	-66%
TTL	0.022	-54%	-66%	-75%	-77%	-72%	-65%	-66%
TUG	0.052	-27%	-38%	-47%	-55%	-61%	-67%	-72%

Shallow	Hook Position				
Species	**0**	**1**	**2**	**3**	**4**
DKK	-70%	0.147	6%	-29%	-58%
LKV	-71%	0.078	6%	-30%	-58%
TTL	-71%	0.078	6%	-30%	-58%
TUG	-71%	0.049	7%	-31%	-59%

4.3 Modelling Longline Gear-Sea Turtle Condition at the Set Level

SPC presented some preliminary information on the structure of the set-level condition model and the data available to inform it. Condition at the point of first sighting by the observer (at-vessel) is recorded for ~ 80% of the turtles in the observer data. A binary category (alive/dead) was proposed, with all turtles seemingly alive classified as alive (even if coded as “alive, unlikely to live”). The proportion alive decreases with increasing soak time for shallow sets. Potential explanatory variables which have good coverage in the dataset were considered to be bait type, floatline length, branchline length, soak time and time of day of set. Less information is available for hook type, lightsticks and wire trace, and even less information for other variables. In deep sets 39% of turtles were recorded as alive at first observation, whereas in shallow sets 93% were recorded as alive at first observation.

Participants agreed that turtles should be considered alive if classified by the observer as alive in any way. Participants reflected on variables considered *a priori* to affect condition along with the availability of information for each data field and identified the following variables for an initial run:

- **Species** – variable conditions (alive/dead at retrieval) by species could be attributed to such factors as differing body sizes, metabolic rates, lung capacities, swimming ability or life stages likely to be encountered by longline fisheries as well as the fact that some species occur shallower and are less likely to asphyxiate on shallow hooks;
- **Hooks between floats (hbf)** – it is recognized this is an attempt to account for hook depth but will be inherently uncertain;
- **Time of day of set** – it was noted that the same time of day of set could represent variable times before or after dawn or dusk based on season and latitude therefore times should be adjusted if possible to account for this (see discussion above);

- **Soak time** – preliminary analysis suggests a relationship between soak time and survival but this may reflect some underlying conditions such as longer night soak times having more chance of daylight at the end of the soak and thus catching "fresh" turtles which are able to survive. (More work should be done to explore this factor in relation to set time.)
- **Length of the floatline** – in theory longer floatlines may be more likely to cause entanglement or be more likely to be fished at hook depths that lead to asphyxiation.

It was acknowledged that there may be interactions between some of these variables which could be explored. However, given the decision for the set-level model not to estimate interactions for which data are insufficient to support robust estimation, it was decided not to include any interaction terms other than those involving species in the condition model.

Two other explanatory variables were suggested. The first was anatomical hook location, but this was considered unlikely to be possible to explore given insufficient information in the current datasets. The second variable was the size of weights on the branchline which was suggested on the basis that the heavier the gear, the less likely a caught turtle would be able to reach the surface to breathe during the soak. This variable also suffers from insufficient data and cannot be explored.

Initial results from the preliminary model showed that according to the AIC values all of the explanatory variables should be retained in the model. However, the variables with the greatest influence on the results were hooks between floats and species, with a lesser influence from soak time and float length. Participants noted that some of these variables may be proxies for a shallow-set strategy, for example, setting later in the day is common in swordfish fisheries which catch target species at night.

The final condition model, was thus constructed as a logistic model with a logit link:

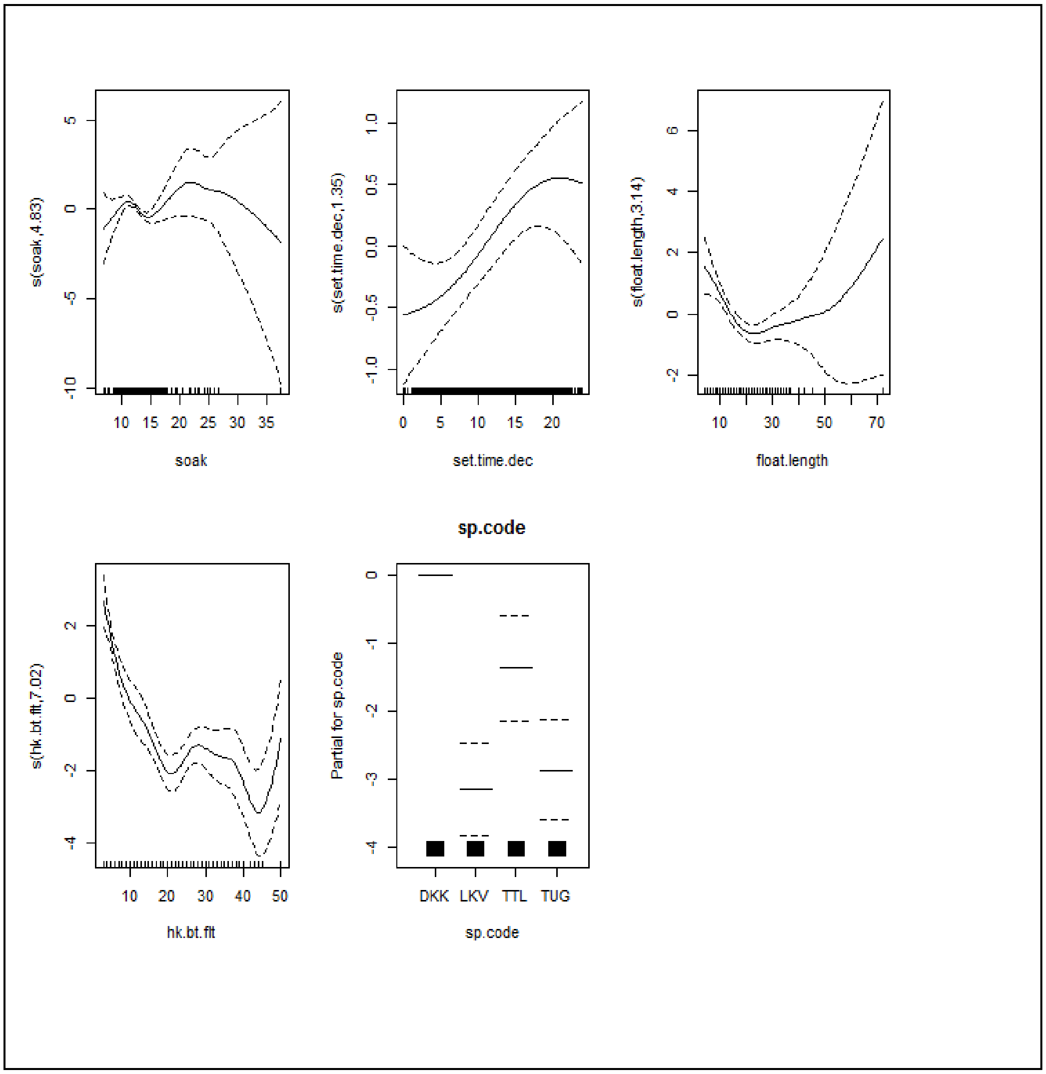
response ~ s(soak time) + s(set time) + s(float length) + s(hbf) + species

AIC values for the terms in the model are shown in Table 7. Plots of the final parameter estimates are shown in Figure 8.

Table 7. AIC values for the final condition model adopted by the workshop.

Model	**df**	**AIC**	**delta AIC**
Full model	20.34	893.1	
- set time	19.38	901.2	8.2
- soak time	15.66	903.5	10.4
- float length	18.14	909.1	16.1
- hbf	26.11	990.6	97.5
- species	19.46	1034.2	141.1

Figure 8. Plots of parameter estimates for the final condition model.



4.4 Integrating Information on Sea Turtle Relative Abundance

In recognizing that the abundance of turtles varies in time and space in ways that cannot easily be quantified in the models envisaged for this analysis, the workshop was asked to consider the basic relative abundance surfaces used in the shark analysis (SPC 2015) to see if something similar could be constructed for turtles. A relative abundance surface is important for the simulation model in order to approximate the spatial distribution of turtles and adjust fishing effort to reflect this distribution. Some participants considered that maps of regional management units (RMUs; Wallace et al. 2011) used by the State of the World's Sea Turtles (SWOT[2], OBIS-SEAMAP; Halpin et

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[2] Kot, C.Y., E. Fujioka, A.D. DiMatteo, B.P. Wallace, B.J. Hutchinson, J. Cleary, P.N. Halpin and R.B. Mast. 2015. The State of the World's Sea Turtles Online Database: Data provided by the SWOT Team and hosted on OBIS-SEAMAP.

al. 2009) project could provide a good starting point. This information included the boundaries of regional management units, distribution data, location of nesting sites and number of females at each nesting site. Other participants expressed concern about relying too heavily on these maps given that they do not correspond well with the patterns in which turtles are caught in fisheries, have little or no information on seasonal abundance or densities (by life stage and sex) within the Regional Management Units, and do not cover all areas where turtles are caught (Sales et al. 2015).

In order to produce a first spatialized estimated relative abundance by species, SPC with input from workshop participants used global distribution maps from SWOT for each species to define a “presence” area (i.e. all areas outside the “presence” area were given a weighting of zero). They then weighted each identified RMU within the “presence” area by using the abundance of nesters estimated by SWOT in each nesting site known for each RMU and that seemed to the workshop participants to be representative of the current number of nesting females. Where RMUs overlapped, the sum of the weights of each of the two overlapping RMUs were assigned to the overlap area.

In order to investigate if RMUs were representative of the abundance, SPC overlaid RMUs and turtle bycatch positions available from purse seine and longline fisheries dataset available to the workshop for each species. Results showed that a good correlation exists between these sources, but also highlighted that some key areas of abundance may not be captured by RMUs, suggesting that some RMUs boundaries may need to be revised in order to be representative of regional abundances. The absence of data from the EPO might skew the results, particularly when populations are believed to extend across the width of the Pacific. However, given that the estimation only covers the WCPO, this bias is less of a concern. The workshop agreed that it would be useful to further refine the maps by adjusting the RMUs after review of updated data including the presence/absence plots from this workshop and other available data sets not used to define RMUs. However, as this is likely to be a time-consuming task, it was agreed not to adjust any of the RMU boundaries at this workshop. Obtaining further expert input on the maps was proposed as a priority activity.

For areas outside RMUs but still within the species distribution area, a weight equivalent to half of the lowest total number of nesters for a given species per RMU was arbitrarily applied to reflect the presence of sea turtles. This exercise was repeated for the four species considered in the workshop (leatherbacks, loggerheads, olive ridley and green turtles) and a 5-degree grid with the associated weights was generated for each species to provide a relative abundance surface. In subsequent discussion it was considered that it is appropriate to adjust the weighting based on the number of nesting females as described above by the size of each colored shape on the map. The maps were prepared so that legends show this weighting scale. Participants also asked for a table showing the area of each colored shape on the map as a proportion of the WCPFC Convention Area (*Annex D*).

In discussing the map products prepared by SPC participants noted that all areas within an RMU are assigned the same weight and thus the effect of gyres and other oceanographic features which are likely to be important for turtle distributions are discounted. This may be an insurmountable issue for now as there are currently no reliable models to predict turtle presence for most species.

Participants discussed whether the fishery data should be given more weight in the maps. Some participants considered that fishery interactions are already accounted for in the set-level model

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Oceanic Society, Conservation International, IUCN Marine Turtle Specialist Group (MTSG), and Marine Geospatial Ecology Lab, Duke University. http://seamap.env.duke.edu/swot.

and should be applied in the turtle relative abundance surface only as a kind of check. It was further noted that these data do not reflect the underlying effort in each area and thus can be misleading as locations where there was effort but no interaction are not shown. In contrast, some participants considered that fishery data should be weighted more heavily and could be modelled to produce a heat map style grid similar to the shark analysis (SPC 2015).

Overall participants stressed that there are numerous substantial uncertainties associated with the maps produced but they represent the best information available to the workshop with regard to a relative abundance surface for turtles (Figures 9-16). Participants recommended that further work on the maps should be undertaken including an update of the information underlying the SWOT dataset, the use of environmental data such as SST, primary production and gyre areas, review by experts, and access to other fishery datasets to map the geographic scope of interactions.

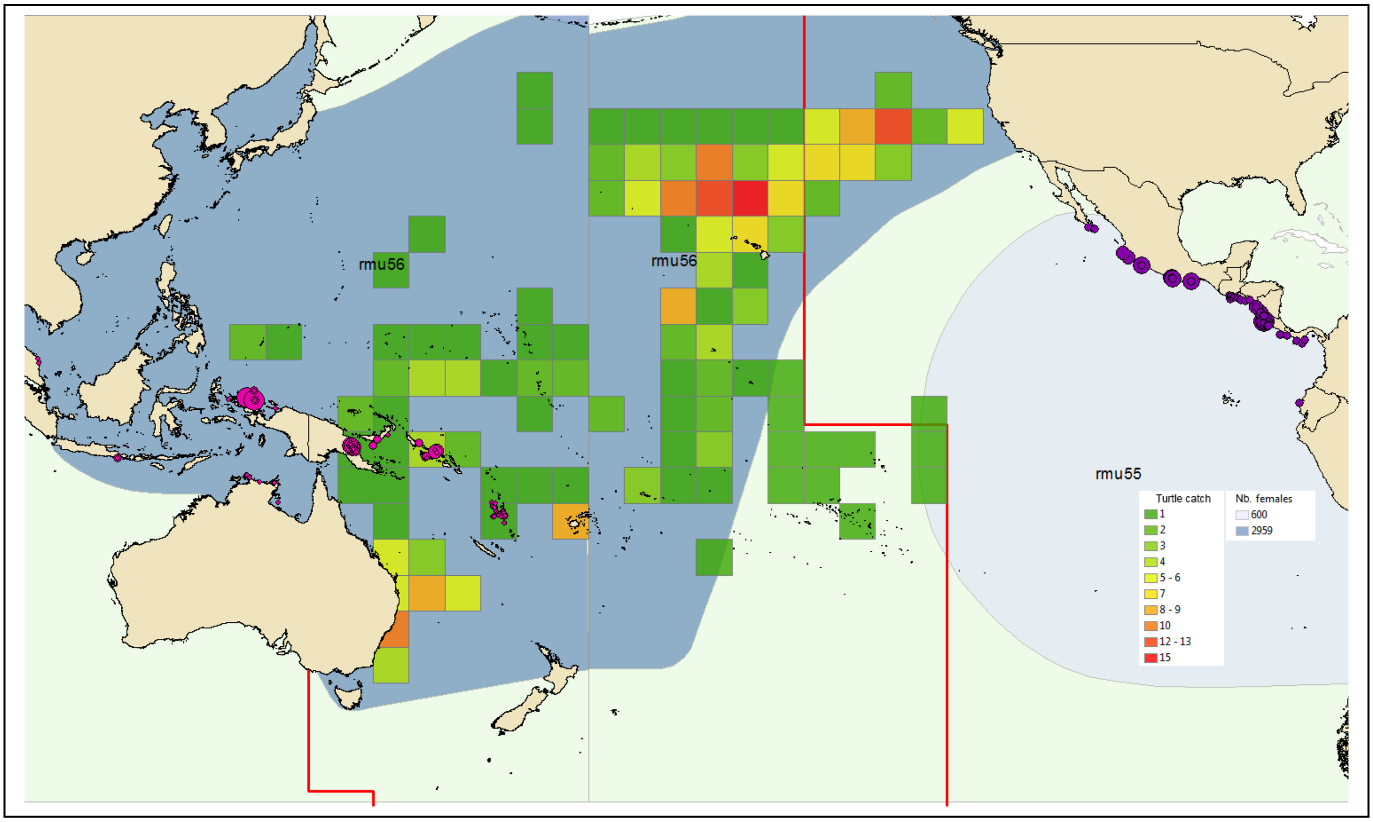

Figure 9. Input information for the relative abundance surface for leatherback sea turtle (*Dermochelys coriacea*). The shaded areas are taken from the SWOT and represent RMU boundaries for the Pacific Ocean. Blue shading indicates relative abundance of nesting females (the number of females is estimated). Circles ranging in color from pink to blue indicate nesting sites. The total number of turtle interactions recorded by observers on purse seine and longline vessels is shown in 5x5 grids. Red lines indicate the WCPF Convention Area boundary.

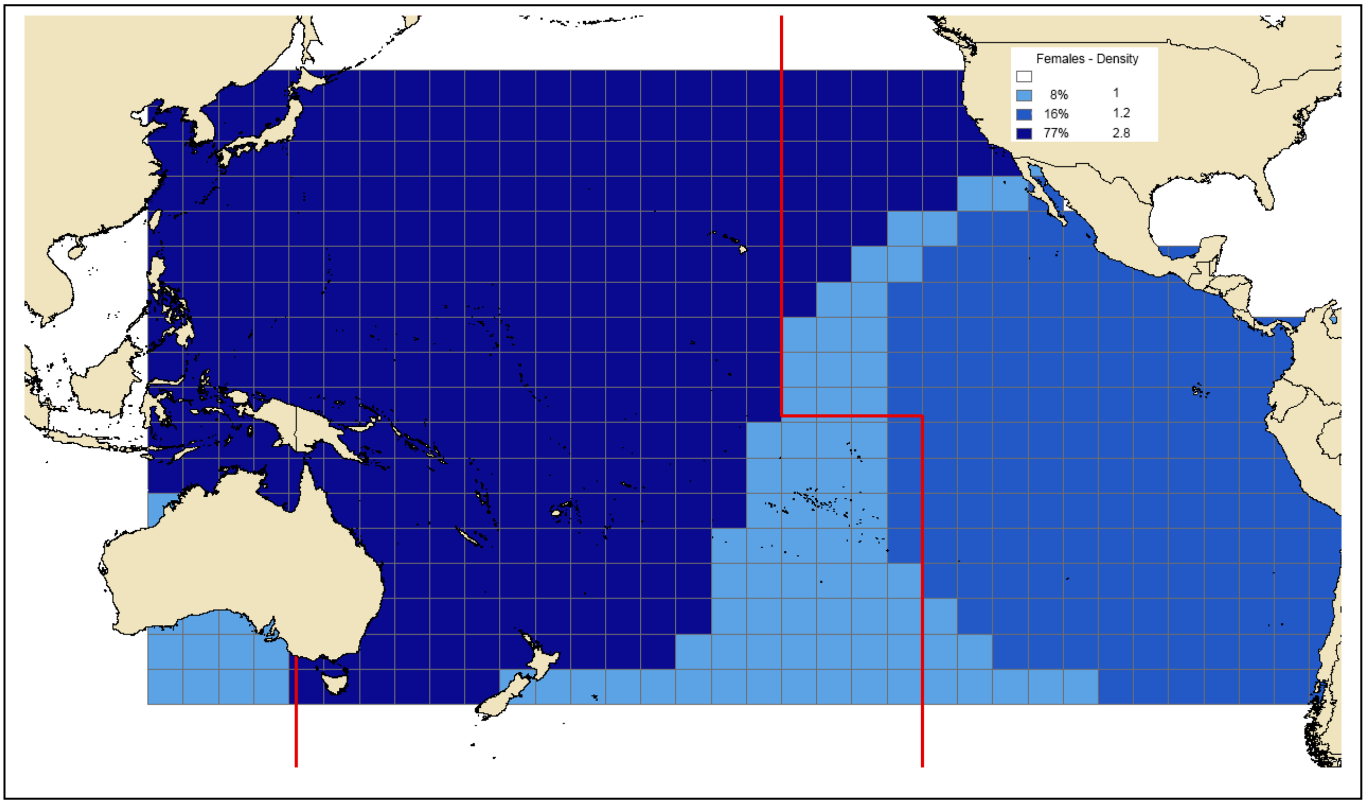

Figure 10. Relative abundance surface for leatherback sea turtle (*Dermochelys coriacea*). The shading represents the relative abundance surface (blue areas from the preceding figure) weighted by the number of nesting females in each area (from the preceding figure) with the weighting categories listed as “density” in the legend. "Females" in the legend indicates the percentage of estimated nesting females per area. Where shown, white areas represent areas outside the global distribution of the species. Red lines indicate the WCPF Convention Area boundary.

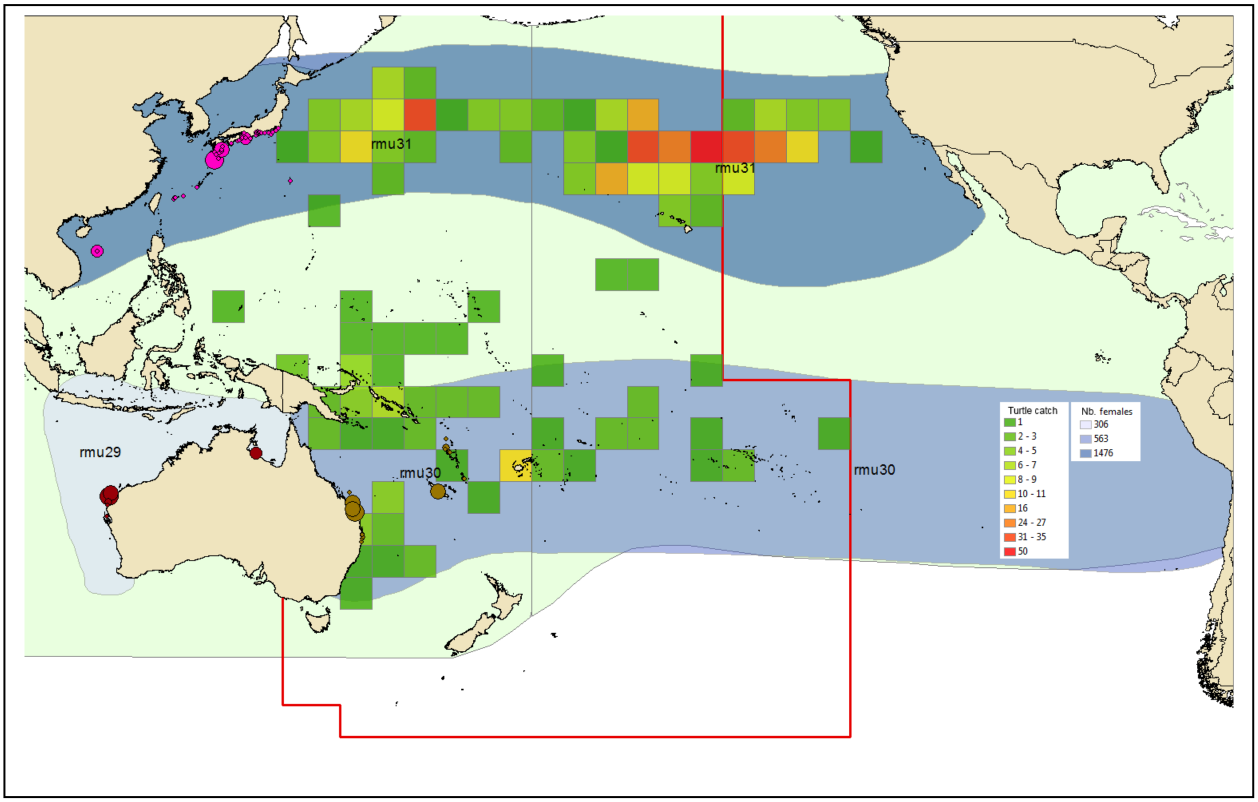

Figure 11. Input information for the relative abundance surface for loggerhead sea turtle (*Caretta caretta*). The shaded areas are taken from the SWOT and represent RMU boundaries for the Pacific Ocean. Blue shading indicates relative abundance of nesting females (the number of females is estimated). Circles ranging in color from pink to blue indicate nesting sites. The total number of turtle interactions recorded by observers on purse seine and longline vessels is shown in 5x5 grids. Red lines indicate the WCPF Convention Area boundary.

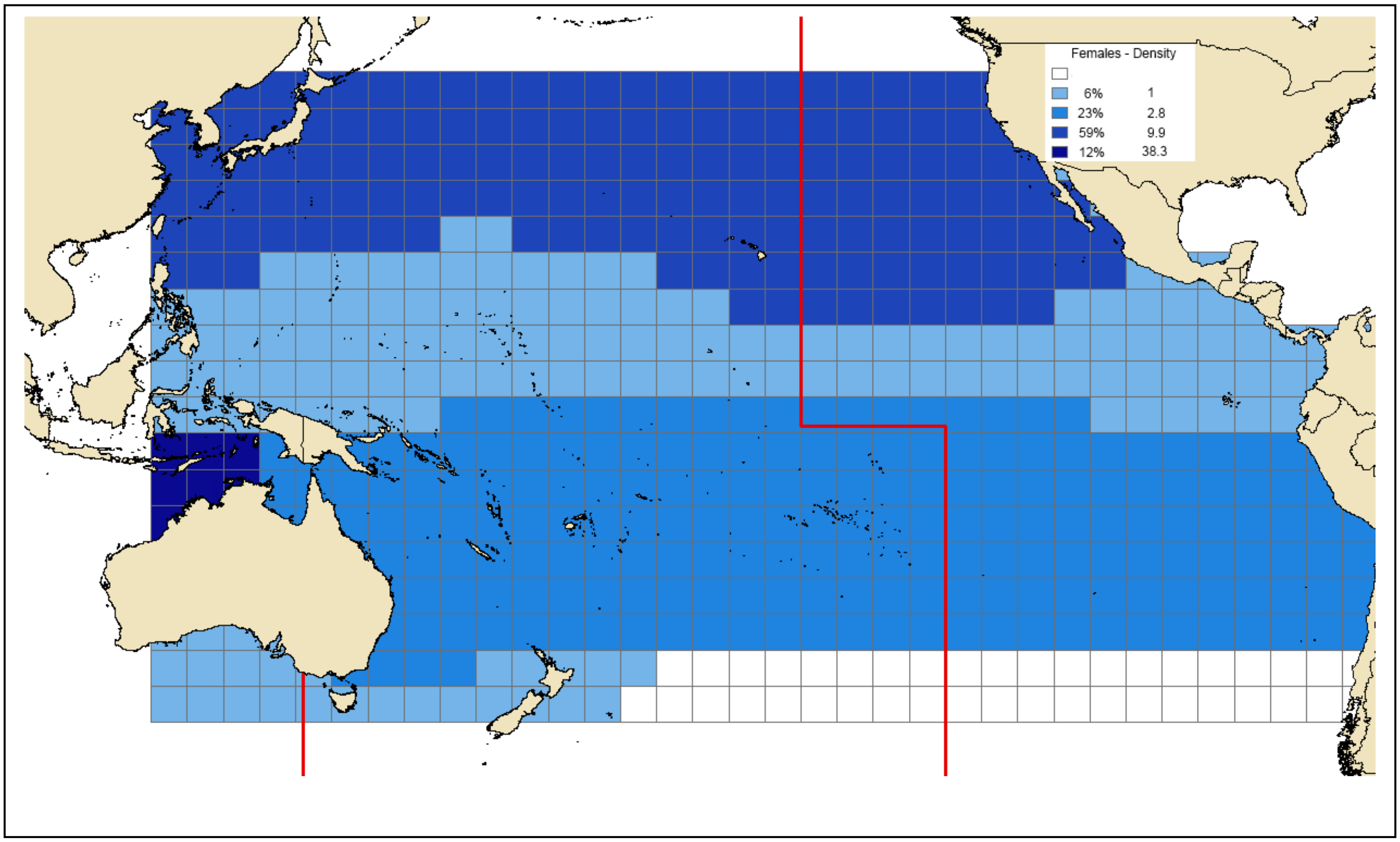

Figure 12. Relative abundance surface for loggerhead sea turtle (*Caretta caretta*). The shading represents the relative abundance surface (blue areas from the preceding figure) weighted by the number of nesting females in each area (from the preceding figure) with the weighting categories listed as “density” in the legend. "Females" in the legend indicates the percentage of estimated nesting females per area. Where shown, white areas represent areas outside the global distribution of the species. Red lines indicate the WCPF Convention Area boundary.

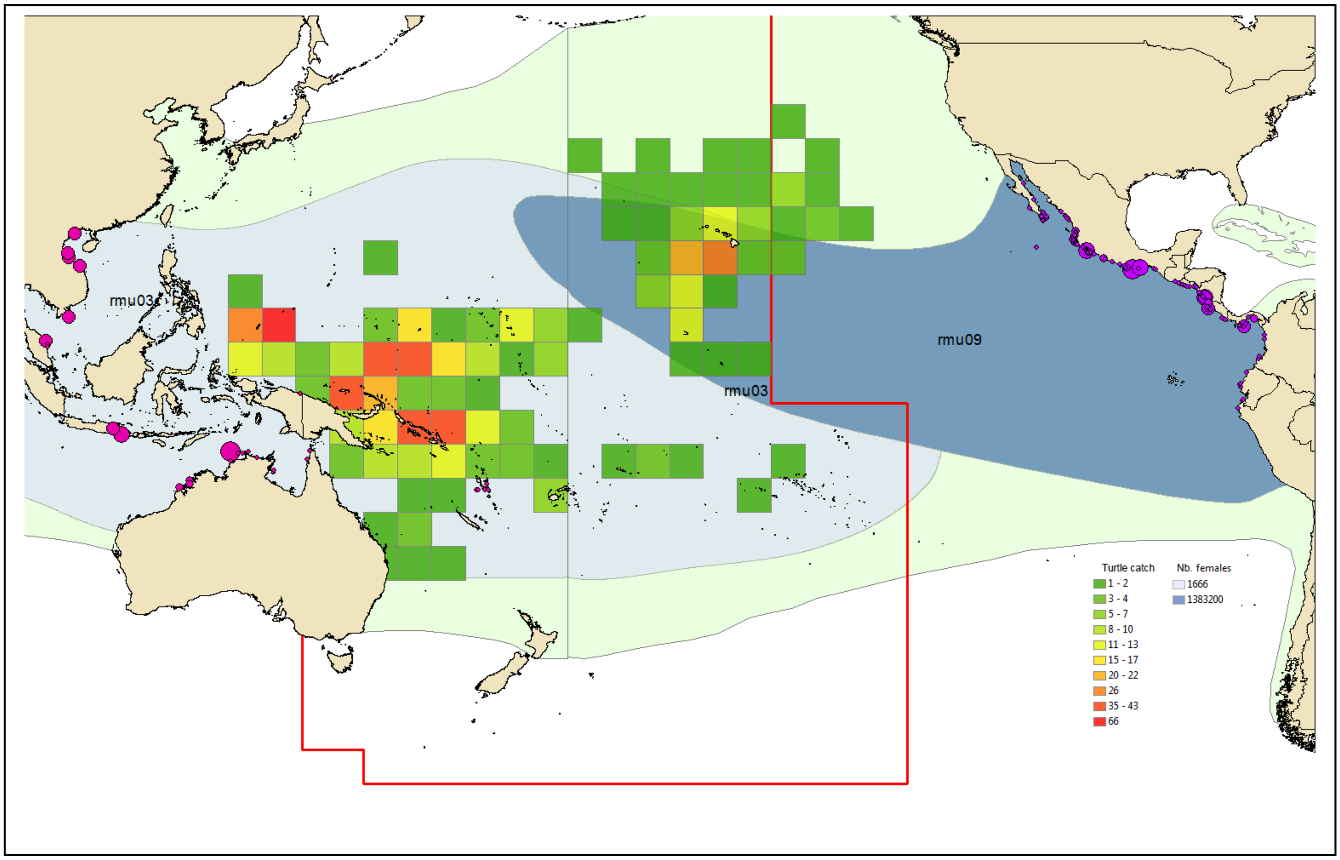

Figure 13. Input information for the relative abundance surface for olive ridley sea turtle (*Lepidochelys olivacea*). The shaded areas are taken from the SWOT and represent RMU boundaries for the Pacific Ocean. Blue shading indicates relative abundance of nesting females (the number of females is estimated). Circles ranging in color from pink to blue indicate nesting sites. The total number of turtle interactions recorded by observers on purse seine and longline vessels is shown in 5x5 grids. Red lines indicate the WCPF Convention Area boundary.

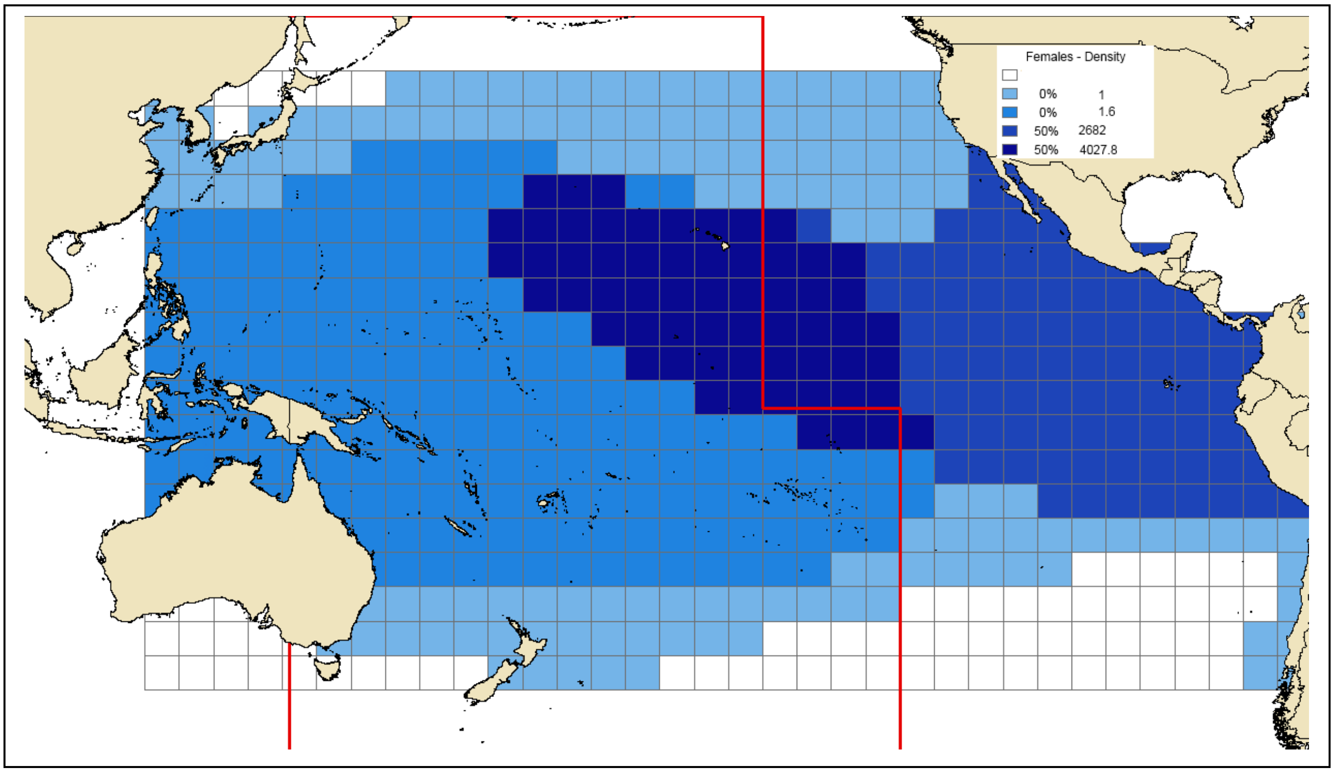

Figure 14. Relative abundance surface for olive ridley sea turtle (*Lepidochelys olivacea*). The shading represents the relative abundance surface (blue areas from the preceding figure) weighted by the number of nesting females in each area (from the preceding figure) with the weighting categories listed as “density” in the legend. "Females" in the legend indicates the percentage of estimated nesting females per area. Where shown, white areas represent areas outside the global distribution of the species. Red lines indicate the WCPF Convention Area boundary.

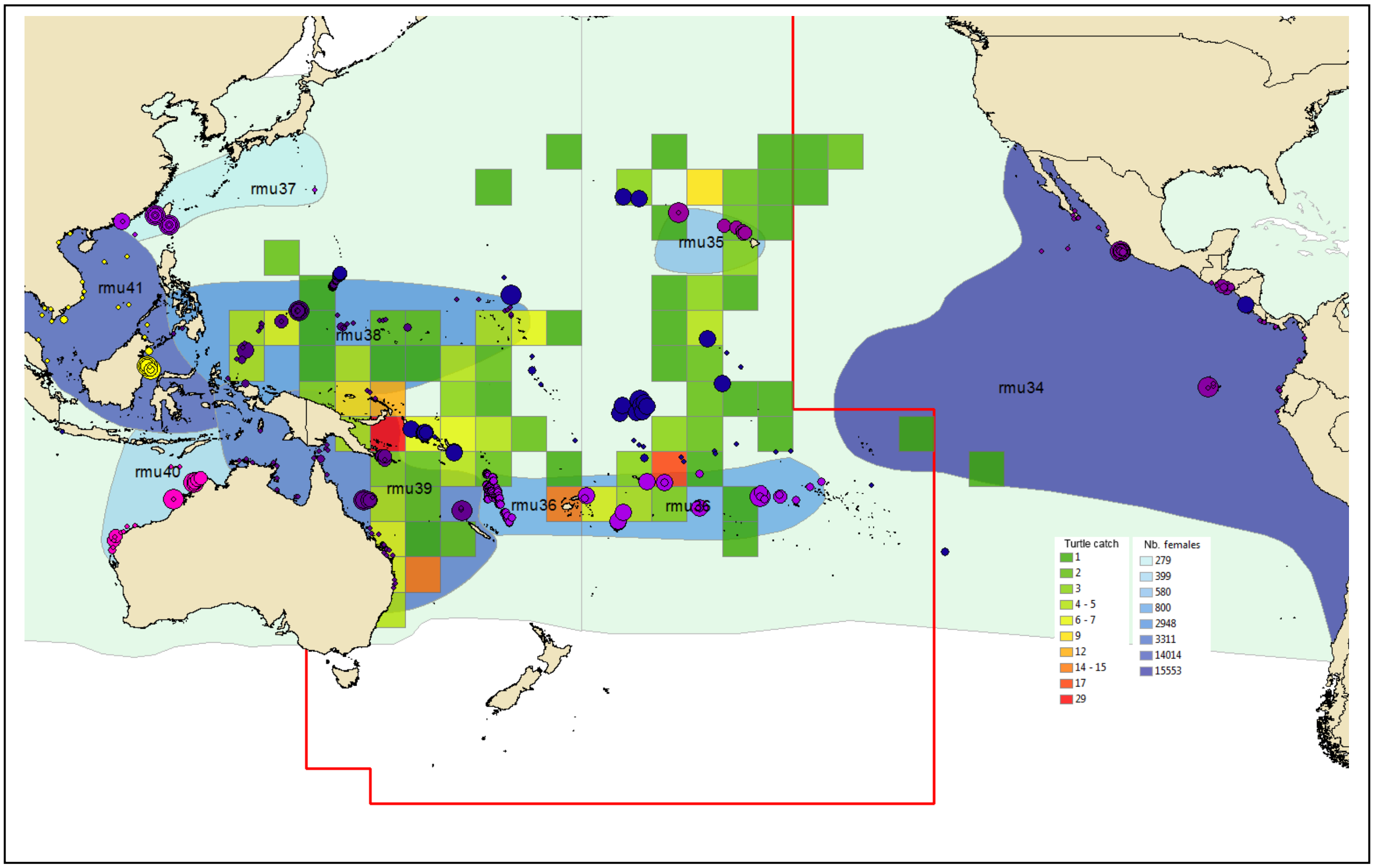

Figure 15. Input information for the relative abundance surface for green sea turtle (*Chelonia mydas*). The shaded areas are taken from the SWOT and represent RMU boundaries for the Pacific Ocean. Blue shading indicates relative abundance of nesting females (the number of females is estimated). Circles ranging in color from pink to blue indicate nesting sites. The total number of turtle interactions recorded by observers on purse seine and longline vessels is shown in 5x5 grids. Red lines indicate the WCPF Convention Area boundary.

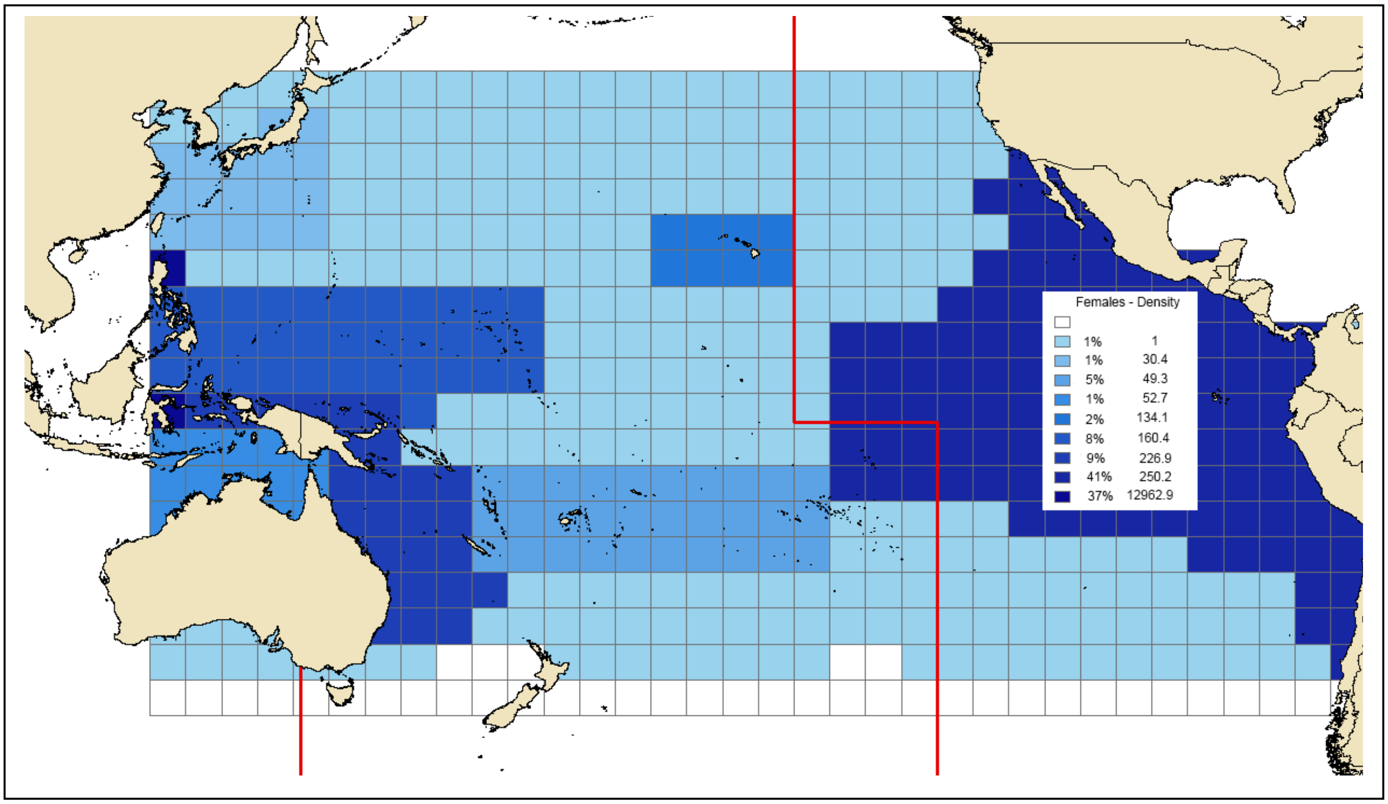

Figure 16. Relative abundance surface for green sea turtle (*Chelonia mydas*). The shading represents the relative abundance surface (blue areas from the preceding figure) weighted by the number of nesting females in each area (from the preceding figure) with the weighting categories listed as "density" in the legend. "Females" in the legend indicates the percentage of estimated nesting females per area. Where shown, white areas represent areas outside the global distribution of the species. Red lines indicate the WCPF Convention Area boundary.

4.5 Combining Model Outputs in Monte Carlo Simulations for the Entire Fishery

SPC presented an overview of the simulation model and suggested that the key variables to focus on in the scenario testing are hook category and bait type. Scenarios will thus be formulated based on combinations of fleet, fishing strategy, hook category and bait type. Each scenario will be run for each of the four turtle species.

While these variables would be the focus of the testing, the full suite of variables used in the set-level and condition models would need to be specified for the simulation model. This can be accomplished by using the average values of the required variables for the specific fleet and fishing strategy being tested.

In response to a question, SPC clarified that fleets were divided into shallow and deep fishing strategies based on species composition and time of day of setting, and then selecting the hbf range that best characterized shallow and deep strategies for that fleet. Using this method a break was established at 10 hbf for all fisheries except for the United States for which shallow sets are regulated as those <15 hbf (but in practice United States shallow set fisheries usually fish with considerably fewer than 15 hbf). Participants were reminded that the fleet-fishing strategy combinations are shown as rows in Table 1.

One participant asked SPC to look into whether catch and effort data submitted to the WCPFC in aggregated form contains the number of sets by hbf or only the number of hooks.

SPC highlighted a number of issues related to scenario definition for the consideration of the workshop:

- The possibility of predicting interaction rates for each 5x5 grid individually to take account of species-specific habitat preferences (as indicated by SST) as an alternative to using a relative abundance surface.
- The possibility of re-classifying the parameter estimate for “small J-hooks” for the simulation given that there is a relatively lower level of credibility associated with that estimate (due to it being data-poor).
- The possibility of using the small circle hook estimate for the small Japanese tuna and Teracima (T hook) category.

The workshop agreed that for the second issue it would be appropriate to conduct sensitivity runs with the existing estimate of small J hook parameters, then again with resetting this parameter equal to that for the small T hook and if there is a difference, running the model a third time with a parameter intermediate to that of the first two runs.

It was discussed that in general scenarios involving simulating combinations of variables that are not informed by the data should be avoided. An exception to this might be encountered when trying to represent fleets for which there are no observer data and thus little information on gear characteristics. In such cases, consultation with national authorities will be used to supplement the information available.

Participants suggested that defining a baseline will require careful interpretation since it will represent shifts of gear characteristics of differing magnitudes over different periods of time for different fleets. SPC clarified that the baseline (current) would be defined as starting in 2010 and running through 2014 or 2015, depending on the data source.

Two ideas for priority scenarios were identified:

- Full implementation of alternate hooks and/or fish bait for all shallow set longline fisheries with all deep set fisheries operating under the status quo; full implementation of use of alternate hooks and/or fish bait for all deep set longline fisheries with all shallow set fisheries operating under the status quo; and full implementation in both fleets.
- Testing for the deep set fishery of the effects on interaction and at-vessel mortality in the WCPO as a whole of removing one or more of the shallowest hooks closest to the floats.

5 Recommendations for Further Work

Participants outlined several ideas for further work under the following headings: modelling, gear characteristics and data, mapping, data access, preparations for the next workshop. S. Nicol informed the workshop that Australia has agreed to support this sea turtle joint analysis initiative to project completion.

5.1 Modelling

- Develop a baseline and then identify which mitigation scenarios to test (for example, 2 bait types and 4 hook categories)
- Circulate a list of mitigation scenarios to test for comment within one month of the first workshop
- Better inform the set-level model by including primary production in the model, or using water depth as a proxy for distance to nearest point of land (and/or shallow seamounts that may be important habitat for turtles (Allain et al. 2008)

5.2 Gear characteristics and data

- Undertake more work on understanding which hooks are/were fished (i.e. formulate an accurate master list) and what their key dimensions are (perhaps by means of a national survey or other types of gear research)
- Develop a variable that better represents the amount of daylight during which the hooks are being fished (use existing algorithms if possible)
- Provide a better overall/general characterization of the data for the second workshop and/or the final report

5.3 Mapping

- Develop at least one alternative turtle relative abundance surface to run as a sensitivity test
- Update the maps with the latest tracking data
- Obtain expert review of the maps
- Investigate available data on juvenile dispersal in the Pacific (take advantage of some ongoing work)
- Use existing observer data and the table of turtle sizes in this report to develop distribution maps of life stages by species

5.4 Data access

- Cooperate with IAC to develop a specific data request with which to approach Latin American countries about participating and contributing data
- Consider more effective ways of seeking the participation of Spain, Indonesia and IATTC

5.5 Preparations for the Next Workshop

- Focus the next meeting just prior to SC12 in Bali to review the results of simulation runs performed by SPC
- Include a qualitative comparison between the parameters/effects estimated in our models and parameters/effects found in other studies worldwide (requires a review of existing

studies to be compiled for use at the meeting). This review should include a consideration of effects on target species catch. E. Gilman and S. Nicol offered to help with this literature review

- Prepare workshop graphics for ease of viewing (e.g. avoid small fonts)
- Consider whether there are opportunities for collaborative work on national datasets (either SPC travels, or participants are invited to Noumea) prior to the next workshop

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Annex A. Workshop Participants List

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Annex B. Sea turtle bycatch mitigation regulatory history for the Hawaii and American Samoa pelagic longline fisheries[3].

Date Came into Effect	Action
1999-2004	A series of court-ordered closures and effort restrictions for the Hawaii-based longline fishery were implemented starting in December 1999. An emergency rule implementing a court order became effective in 2001, which prohibited shallow-set swordfish longlining north of the equator by vessels managed under the WPRFMC's Pelagics FMP and closed waters between 0° and 15°N from April through May of each year to longline fishing. The measures also instituted sea turtle handling requirements for all vessels using hooks to target pelagic species in the region's EEZ waters. The emergency rule (effective for 180 days) was extended once, and later implemented as a final rule in June 2002, remaining in place until 2004 when the swordfish fishery was reopened.
2 April 2004	Re-opened the shallow-set swordfish fishery, allowing 2,120 shallow-sets to be made annually by the Hawaii-based longline line fleet. Circle hooks and mackerel-type bait were required, along with other mitigation measures (see summary of current in effect measures, below) and a maximum annual limit on the number of interactions with sea turtles was set at 16 leatherbacks and 17 loggerheads. The rule also eliminated the closure between 0° and 15°N from April through May of each year to longline fishing.
15 December 2005	Owners and operators of vessels registered for use under longline general permits are required to attend protected species workshops annually. Owners and operators of vessels registered for use under longline general permits are required to carry and use dip nets, line clippers, and bolt cutters, and follow handling, resuscitation, and release requirements for incidentally hooked or entangled sea turtles. Extended the requirement to use circle hooks, mackerel-type bait and dehookers when shallow-setting north of the equator to include all longline vessels managed under the Pelagics FMP. These measures were adopted to obtain consistency with a 2004 Biological Opinion. As there are no general longline permit holders that fish for swordfish north of the equator, the measure had no effect other than to prevent longline permit holders from shifting to using a general permit to avoid sea turtle measures.
11 January 2010	Limit on number of shallow sets made per year was eliminated and loggerhead hard cap was increased from 17 to 46.
2011	Court order reinstates the 2004 sea turtle hard cap for the Hawaii longline shallow-set fishery.
23 September 2011	Specific gear configuration is prescribed for American Samoa longline vessels to ensure that hooks soak deeper than 100 m. This measure was intended to reduce green sea turtle interactions in the fishery.
5 November 2012	NMFS revised the limits for leatherback turtles from 16 to 26, and for loggerhead turtles from 17 to 34 for the Hawaii longline shallow-set fishery.

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[3] This summary does not describe regulatory-required measures instituted for purposes other than managing sea turtle interactions, which might affect sea turtle catch and survival rates (e.g., Hawaii longline tuna fishery requirement to use only 'weak' circle hooks under the false killer whale take reduction plan, swordfish fishery option to night set to mitigate seabird bycatch).

Annex C. Absolute and relative increases in the probability of longline-sea turtle interactions under each combination of hook category and bait type for each sea turtle species (see notes below).

Hook category	Bait	Interaction probability	% increase in absolute terms	% increase in relative terms
Leatherback				
C-L	fsh	0.00372		
C-L	fsh-sqd	0.00524	0.15%	41%
C-S	fsh	0.01010		
C-S	fsh-sqd	0.01423	0.41%	41%
J-S	fsh	0.00346		
J-S	fsh-sqd	0.00488	0.14%	41%
J-S	sqd	0.02793	2.45%	708%
T-S	fsh	0.00968		
T-S	fsh-sqd	0.01365	0.40%	41%
T-S	sqd	0.07649	6.68%	690%
Loggerhead				
C-L	fsh	0.01252		
C-L	fsh-sqd	0.01763	0.51%	41%
C-S	fsh	0.03374		
C-S	fsh-sqd	0.04732	1.36%	40%
J-S	fsh	0.01165		
J-S	fsh-sqd	0.01641	0.48%	41%
J-S	sqd	0.09140	7.97%	685%
T-S	fsh	0.03238		
T-S	fsh-sqd	0.04542	1.30%	40%
T-S	sqd	0.23601	20.36%	629%
Green				
C-L	fsh	0.000350		
C-L	fsh-sqd	0.000495	0.01%	41%
C-S	fsh	0.000954		
C-S	fsh-sqd	0.001347	0.04%	41%
J-S	fsh	0.000326		
J-S	fsh-sqd	0.000460	0.01%	41%
J-S	sqd	0.002662	0.23%	717%
T-S	fsh	0.000915		
T-S	fsh-sqd	0.001292	0.04%	41%
T-S	sqd	0.007459	0.65%	715%
Olive ridley				
C-L	fsh	0.000420		
C-L	fsh-sqd	0.000593	0.02%	41%
C-S	fsh	0.001143		
C-S	fsh-sqd	0.001614	0.05%	41%
J-S	fsh	0.000391		
J-S	fsh-sqd	0.000551	0.02%	41%
J-S	sqd	0.003190	0.28%	717%
T-S	fsh	0.001096		
T-S	fsh-sqd	0.001548	0.05%	41%
T-S	sqd	0.008932	0.78%	715%

Note: % increases are for mixed fish and squid (fsh-sqd) and squid bait (sqd) relative to fish bait (fsh). Interaction probabilities were estimated with variables set at their median value for shallow setting (effort offset – 962 hooks, set time – 19.42, soak – 12.72 hours, hbf – 4, SST – 18.9 C).

Annex D. **Percentage of the distribution area (non-white areas in Figures 10, 12, 14 and 16) and RMUs that falls within the WCPFC Convention Area for each sea turtle species considered in the workshop. Note that there is no defined western boundary of the WCPFC Convention Area but for the purposes of this table the calculations have included only areas east of 120°E.**

Species	Areas	Within WCPFC area
LEATHERBACK TURTLE	Distribution area	59.1%
	RMU 56	89.9%
	RMU 55	3.4%
OLIVE RIDLEY TURTLE	Distribution area	60.6%
	RMU 03	97.8%
	RMU 09	0.0%
	Overlap RMU 03/09	48.9%
LOGGERHEAD TURTLE	Distribution area	59.7%
	RMU 29	75.0%
	RMU 30	62.6%
	RMU 31	65.1%
GREEN TURTLE	Distribution area	66.0%
	RMU 34	7.8%
	RMU 35	100.0%
	RMU 36	100.0%
	RMU 37	100.0%
	RMU 38	100.0%
	RMU 39	100.0%
	RMU 40	85.7%
	RMU 41	100.0%