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Purse Seine Effort Creep Research Plan

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Executive Summary

With constant improvements to purse seine fishing operations in the Western and Central Pacific Ocean (WCPO), fleet efficiencies through technological advancements and experience of crew is thought to have resulted in increased catchability over time. Catchability refers to the proportion of available fish, caught with one unit of effort (Hilborn and Walters, 1992). Traditionally, catchability was assumed to be constant through time, and representative of the proportionality between catch rates and relative abundance. However, catchability of fishing fleets improves over time due to increased knowledge/skill, improved fishing vessels, and enhanced technologies, thereby enabling fishers to catch more fish per unit of effort (e.g. a fishing day); this situation is referred to as effort creep. In fisheries where management employs controls on effort to limit fishing mortality, considerations must be given to effort creep which can increase the risk of hyperstability, over-estimation to stock biomass and under estimation of fishing mortality (Erisman et al., 2011). Understanding and characterizing effort creep has become increasingly important in the WCPO tropical purse seine fishery, where an effort based management system, the Vessel Day Scheme (VDS), is used to constrain fishing pressure(Dunn et al., 2006). The VDS is used by fishery managers to regulate and control effort in the purse seine fishery by restricting fishing activity on the basis of effort allocation in units of fishing days. The VDS was fully implemented by 2008, has been associated with vast improvements in the management and flow of economic benefits to island States involved in the WCPO purse seine fishery. The VDS has been largely viewed as a success for member countries and the resource. However, the implications of effort creep for the ongoing effectiveness of the VDS in achieving stock sustainability and economic objectives, require detailed investigation.

In this paper, we document the management history of one of the most valuable tuna fisheries in the world and explore ways in which industry practices have changed and evolved over the last several decades of industrial purse seine fishing in the WCPO. Specifically, we focus on the interactions between changes in management (i.e. VDS) and fishery operations, including the introduction and technological development of fish aggregating devices (FADs) and the issue of effort creep. We explore and quantify how fishing operations have changed their patterns of fishing in time and space in response to the VDS implementation and use of FAD technologies. From this, we have proposed further research approaches for creating indicators of effort creep that can be used to inform management and stock assessment, and ultimately improve the sustainable management of this globally important fishery.

This paper includes a work plan to better address effort creep in a manner that quantifies changes in effective effort in order to provide the PNA with meaningful metrics with which to evaluate and adjust the VDS, as appropriate. The research proposal and plan includes three components:

1. Conduct a fisher survey to better understand changes in fishing technologies and strategies, by engaging directly with skippers involved in the fishery;
2. Conduct a designed data-experiment to explore the effects of specific technologies predicted to impact fishing efficency and catch rates; and

3. Evaluate the use of Vessel Monitoring Systems (VMS) data to fill in data gaps regarding changes in searching and fishing behavior patterns through time.

These research efforts are intended to improve our understanding of changes in purse seine fleet dynamics in order to better inform fishery managers as well as the assessment and monitoring efforts of the underlying stock. Including how fishery dependent data are used to develop abundance indices.

We invite WCPFC-SC16 to:

- Note the history of the VDS within the general framework of purse seine fishing development in the WCPO;
- Note the concerns with the increased efficiencies within the purse seine fleet and the potential impacts on catchability over time; and
- Consider and support the proposed research plan to better refine and understand a suite of effort creep indicators appropriate for assessing the effectiveness of effort-based management measures.

1 Background

1.1 A brief history of the WCPO purse seine fishery

Industrial fishing activity in the WCPO dates back to the start of the twentieth century, at which point the United States (US) and Japan had commissioned exploratory cruises to evaluate fishing opportunities in the region (Tamate, 2013). The first substantive industrial fisheries emerged during the 1920s and 1930s, and were largely composed of Japanese pole-and-line and longline vessels operating in the waters around Micronesia (Gillet, 2007). It was not until much later, during the early 1970s, that the development of purse seine fishing for tunas in the Pacific began in earnest. This development and expansion of the purse seine sector was motivated by the success of purse seine fleets in other parts of the world, coupled by the fishing potential from the exploratory Japanese fleets and expanding US influence with processing centers operating in the region (Gillett et al., 2002). Japan's purse seine fleet expanded rapidly in the 1980s, undergoing an increase from 70 vessels in 1981 to over 115 vessels by 1984 (Doulman, 1986). A major turning point for the WCPO tuna fishery was the emergence of demand for canned tuna, given that the reliable supply of skipjack tuna was well-suited to meet those demands. In response, Japan and the US began investing heavily in fish processing hubs in the region (Doulman, 1986), signally a new era for industrial tuna fishing in the WCPO. Purse seine catches in the region have shown rapid, continued growth from the early 1980s to the early 2010s culminating in a relatively stable catch level to the present time, with the majority of tuna harvested in the region has been landed by purse seiners, surpassing pole-and-line and longline gears (Figure 1).

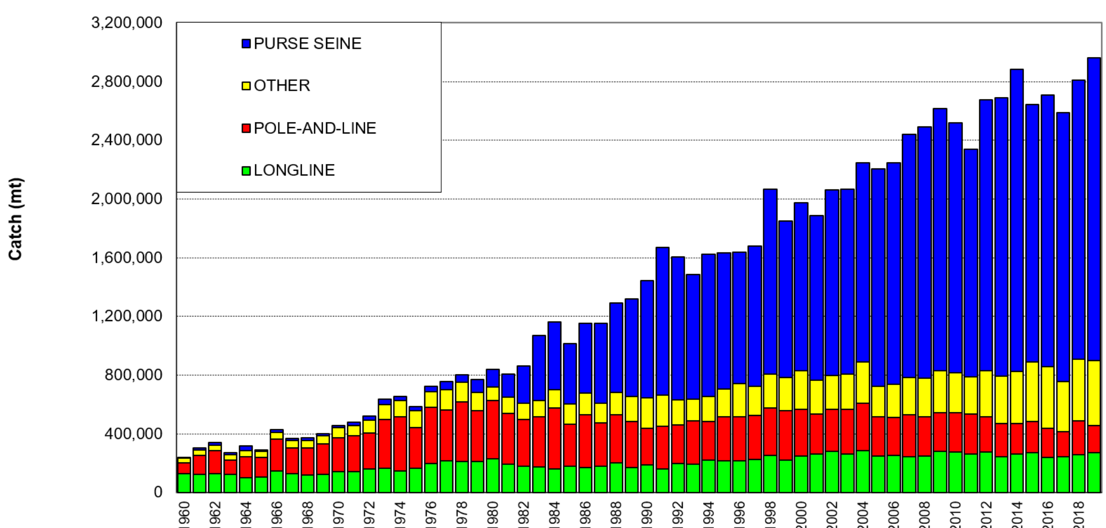

Figure 1: Catch (mt) by gear for the Western Central Pacific region, 1960-2019 (Williams et al., 2020).

Since the Japanese pioneered the purse seine fishing method in the 1980s, there has been an expansion in interest from other nations including distant water fishing nations such as the US, Korea, Chinese-Taipei, Philippines, and more recently China (Gillett et al., 2002), but also among the Pacific Island Countries and Territories (PICTs) situated at the center of the equatorial Pacific tuna fishing grounds. This saw an insurgence of investment by regional government-owned national tuna companies, with several states operating purse seine vessels as early as 1988 (Table 1). Today, the WCPO is arguably the most important fishing area in the world, accounting for over 55% of the global tuna harvests, with the 2019 harvest approximately 2.7 million mt across four key tuna species; skipjack *Katsuwonus pelamis*, yellowfin *Thunnus albacares*, bigeye *Thunnus obesus*, and albacore *Thunnus alalunga* (Williams and Reid, 2019). Purse seine harvest during this period was 1.9 million mt of which skipjack (1.5 million mt) accounted for 77% of the total purse seine catch (Williams and Reid, 2019).

	1988	**1995**	**2002**	**2003**
Japan	39	33	35	34
US	32	43	29	20
Korea, Republic of	23	30	28	27
Taiwan (Province of China)	1	42	41	38
China	0	0	3	4
Solomons	4	3	2	1
PNG	0	3	6	7
FSM	0	5	7	9
Marshalls	0	0	5	6
Kiribati	0	1	1	1
Vanuatu	0	2	11	15
NZ DW	0	0	4	4
Australia DW	3	0	0	0
Spain	0	0	1	1
Neth. Antilles	0	0	1	1
Panama	0	0	0	1
USSR	5	0	0	0
Philippines DW	9	13	23	22
Indonesia DW	3	0	0	0
TOTAL	**119**	**175**	**197**	**191**

Table 1: Number of active purse seine vessels in the Pacific Islands in 1988-2003 . Source: (Gillett et al., 2003); DW - distant water, as opposed to domestic fishing

1.2 Regional governance

Increased fishing participation by the late 1970s in the WCPO was a result of increased number of purse seine vessels, the adoption of the Exclusive Economic Zone (EEZ) concept, decolonization of territories and transition from European colonial rule to full independence (Tamate, 2013). During this transition period, there were increased efforts by PICTs to enhance their economies and increase social benefits by fully utilizing the natural resources within their EEZs and the High Seas (Tarte, 2014). Taking advantage of this momentum, the South Pacific Island Leaders Forum called for a regional fisheries agency at the 8th Pacific Islands Forum held in Port Moresby, 1977 (PIFS, 1977). The aim of this forum was to establish the Pacific Islands Forum Fisheries Agency (FFA) to assist countries in sustainable and effective management of the fishery resources within their respective 200 mile EEZs (Akehurst, 1985). Upon establishment, the FFA was also intended to serve as an advisory body providing expertise, technical assistance and other support to its members who make sovereign decisions about their tuna resources and participate in regional decision making on tuna management (FFA, 2020).

The post-independence[2] regional order which built on the foundation of Pacific Island 'ownership' of regional organizations presented its own difficulties. The FFA membership is comprised of many countries and territories with diverse and often different interests and priorities. These polarised PICTs views have presented challenges for the FFA, particularly during the post-colonial era, as the agency strove to promote regionalism and cooperation amongst its member states and achieve common goals which reflected a common regional identity; 'the Pacific Way' (Tarte, 2014). Recognising that different priorities exist between member states south of the equator, who prioritize the longline and southern albacore fishery, and the equatorial and northern group island states who prioritize purse seining and the skipjack fishery. This diversion in views presented a number of challenges and opportunities particularly with economic and ecological challenges associated with managing highly migratory stocks through discrete national level policies and legislations (Havice, 2013).

The potential to collectively govern this trans-boundary fishery ultimately led to the establishment of the Palau Agreement and Nauru Agreement Concerning Cooperation on the Management of Fisheries of Common Interest (Nauru Agreement) and the consequent formation of the Parties to the Nauru Agreement (PNA[3]) in 1982 (Tarte, 2014). The Parties to the Palau Agreement (PPA[4]) introduced the first conservation-oriented management regime in the region, in 1992, and included Federated States of Micronesia, Marshall Islands, Nauru, Palau and Tuvalu. Kiribati and Papua New Guinea signed on in 1993. The arrangement initially placed a capacity limit on the number of vessels that could be licensed to fish within the EEZs of the PNA (Aqorau, 2009). Further attempts to provide preferential access for PNA domestic fleets in PNA members waters, the FSM arrangement (FSMA) was signed which also allowed levy fees and pooling of days for PNA members, the FSMA was operationalised in 1995 (Aqorau, 2020). This input-based management approach was intended to establish control over the expansion of the purse seine fishery and address the high mortality of juvenile tuna, in particular, the concerns with yellowfin tuna stocks (Tamate, 2013). By 2000, it was perceived that the PPA was not achieving the desired efficiencies nor the domestic fisheries aspirations set by PNA members. The capacity limit restricted PNA aspirations to develop their

[2]Pacific Forum Island States which gained Independence/Self-Governance include: Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu

[3]The Parties to the Nauru Agreement are: Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Palau, Papua New Guinea, Solomon Islands and Tuvalu

[4]All PNA members with the exception of Tuvalu are parties to the Palau Arrangement (Dunn et al., 2006)

national fisheries by limiting the foreign fleets operating in their waters and foregoing potential revenues (Aqorau, 2012). These concerns motivated modifications to the management framework with the intention of providing greater control over purse seine fishing effort, addressing the issue of overcapacity, and exploring options to increase access fees as a source of revenue for PICTs (Aqorau, 2009). Following discussions to modify the PPA, the VDS initiative was implemented so that vessel days would be used as a preferred basis for management. The Nauru Agreement was administered by the FFA for 27 years; however, as the dynamics of the WCPO tuna fishery and the work of the sub-group unfolded, a decision by PNA fisheries ministers was taken to establish an independent organization, the PNA Office, for the administration of the Nauru Agreement in October 2009 (FFA, 2009).

Today, the collective makeup of the eight PNA members' EEZs accounts for one third of the global canning supplies, worth approximately US$3 billion annually (Tarte, 2014). However, the initial fisheries revenue regime for PNA members resulted in disproportionate returns to the tenure rights of the resource owners under the international law of the sea and substantial economic benefits (Aqorau, 2012). Licensing revenues alone averaged 2 – 5% rate of return, accounting for US$60 million annually. To curb this, the PNA adopted a new approach to managing the access to their EEZs, which included coordinated management measures, harmonisation of the terms and conditions of access for distant water fishing fleets and encouragement of domestication of PNA member fleets to participate in the fishery (Dunn et al., 2006). The Vessel Day Scheme (VDS) is an input-based management framework, designed to enhance the sustainability of tuna stocks by regulating the level of fishing effort by purse seine vessels within the limits consistent with sustainable levels (Dunn et al., 2006), and to increase economic benefits to the member countries. The VDS regulates the number of fishing days within the PNA EEZs and controls the minimum fee per vessel day. The distribution of fishing days to PNA members created competition among fishing companies for shares in the pool of fishing days and has contributed to the success of the VDS achieving economic and ecological objectives.

1.3 Purse seine fishing in the VDS era

The VDS was fully implemented in 2008 and remains in place as the current management framework for the tropical tuna purse seine fishery in PNA waters. Two of the key elements of the VDS are the Total Allowable Effort (TAE) and Party Allowable Effort (PAE). The TAE is defined as the maximum number of fishing days undertaken by all licensed purse seine vessels in all EEZs of the PPA, and is allocated amongst the Parties as their PAE in a manner agreed to by the Parties in any management year (Palau Arrangement, 2016). A fishing day under the VDS is defined as "any calendar day, or part of the calendar day, during which a purse seiner is in the EEZ of a Party" and any fishing activity[5] is undertaken (Palau Arrangement, 2016). Given the different sizes of

[5]Fishing activities includes the following: (a) searching for, catching, taking or harvesting fish; (b) attempting to search for, catch, take or harvest fish; (c) engaging in any other activity which can reasonably be expected to result in the locating, catching, taking or harvesting of fish for any purpose; (d) placing, searching for or recovering fish aggregating devices or associated electronic equipment such as radio beacons, or any other equipment used in the control, support or assistance of fishing operations of any description. (Palau Arrangement, 2016)

vessels operating in the region, three categories were established using vessel length to establish benchmark VDS fishing day utilisation. The categories are small (< 50 meters in length), medium (50 – 80 meters in length) and large (>80 meters in length), with the intention that the length would be reflective of the vessel's capacity to fish. Table 2 summarises the vessel length categories and the associated VDS fishing day benchmark.

Vessel Length (Overall)	VDS Fishing Day Benchmark
Less than 50 meters (Article 5, part (iv))	0.5 day
Between 50 and 80 meters (Article 5, part(v))	1 day
Excess of 80 meters (Article 5, part (vi))	1.5 day

Table 2: Vessel Categories and Fishing Days Benchmark (Palau Arrangement, 2016). This table highlights the differential vessel day accounting associated with vessel length categories. VDS Fishing Day Benchmark indicates the proportion of a VDS day a vessel is charged for a calendar day if undergoing fishing activities.

The VDS arrangement operates by placing limits on the number of days that can be fished by purse seine vessels operating in the EEZs of PNA member countries, based on historical levels of fishing effort (Dunn et al., 2006), updated information on stock status, and consideration of potential changes to catchability (Pilling et al., 2016; Vidal and Hamer, 2020). The assumption of such a framework is that fishing mortality can be effectively managed by controlling input measures (i.e. fishing days). For this assumption to hold, the effort metric must remain constant through time, or be adjusted to account for potential changes. For example, if fishers have become more efficient over time, the fishing mortality associated with one fishing day would not be the same today as it was ten years prior. Industrial fisheries are continually evolving and adapting their fishing practices and technologies to maximize profits under variable stock dynamics and management regimes. In the WCPO, the VDS has imposed input constraints on the purse seine fleet. To compensate, the fleet responded through a suite of changes including increasing the number of sets made in a day (Tidd et al., 2015), investing in vessel and gear enhancements (e.g. larger nets, more powerful skiffs) (Vidal and Hamer, 2020), and increasing technologies linked to fish aggregating devices (FADs) and their number. The PNA has requested, and has been provided with, annual reports describing the role of effort creep in the purse seine fishery (Pilling et al., 2016; Muller et al., 2018; Vidal et al., 2019; Vidal and Hamer, 2020). These reports describe changes in catch and effort proxies, as well as vessel-based characteristics; however the relationship between these effort creep proxies and fishing mortality, or effective fishing effort remains elusive. To this extent, this research plan attempts to further our understanding as we attempt to quantify effort creep. Current conventional methods are believed to be dated and no longer capture the evolving nature of the fishery, its practices and the relationship between fishery catch rates and the status of the stock.

2 Research Plan

The proposed methodology outlined here will address each of the three research components described below. The methods are preliminary as this work is in the developmental stage, and input on the proposed approaches is welcomed.

2.1 Fisher survey

Over the years, information from the fishing industry has been critical in underpinning the assessments of tuna stocks and fishery conditions that inform effective management. The purse seine fishery has evolved in many ways over the last 10-15 years. This evolution is associated with changes to fishery operations, which can have both positive and negative consequences for the industry as well as the stocks. It is important to understand and monitor how fishing operations have changed over time in order to guide data collection, analysis, and interpretation of fishery-dependent data to inform management decisions for the good of the stock and fishery.

We have worked with the Pacific Islands Regional Fisheries Observer Program, industry, and scientists to develop an exploratory questionnaire aimed at better understanding changes in the purse seine fishery, from the fishers' perspectives. The questions are intended to provide descriptive summaries of changes in the fishery, especially with respect to the VDS era, to aid in the development of more informed hypotheses for statistical modeling endeavors. Additionally, the aim is to further engage industry and foster more collaborative approaches associated with further research. The questions we have drafted to pose to industry are included in Appendix 5.2.

Quantitative survey preparation often involves a semi-structured interview stage aimed at enhancing questionnaire designs. It is intended that this survey adopts an interview type approach, where target questions are vetted by industry representatives, trained observers and other related specialists to ensure the appropriateness of questions and design of the survey for purse seine skippers and fishing masters. These interview methods provide an opportunity to gather new data as means to explore perceived technology improvements over time in a way that takes into account the respondent's representation, attitude, and practices. The survey will be recorded via the Survey Monkey[6] platform and downloaded for statistical analysis. The current approach takes into account the COVID-19 pandemic restrictions, which have presented a number of difficulties with undertaking such surveys face-to-face. As such, the current approach is to target focus groups with in-country assistance from the Pacific Community (SPC) member countries, where applicable, and external support via virtual platforms.

The information collected through this survey will potentially address limitations identified in previous work on effort creep in the WCPO, including explaining how fishing behaviours and strategies map to changes in catchability. The survey responses should enhance our understanding of short-term tactical fishing decisions, which is generally based on when and where to fish, and

[6]https://www.surveymonkey.com

longer term fishing strategies influenced by fuel prices, markets, and status of stocks (Tidd et al., 2017). In addition, enhanced skill and experience of the skipper and crew may be important drivers of catch rates, and yet, we have very little information to quantitatively address such variables with respect to effort creep and standardization of CPUE for input into stock assessments.

We hypothesize that crew experience and their skill sets are insufficiently understood when attempting to account for technological advancements. We believe accounting for this current shortcoming is essential to further understanding of CPUE hyperstability and standardising a CPUE approach to modelling effort creep.

2.2 Disentangling technology effects on catch rates

One of the main challenges associated with identifying the impacts of different technologies in catch rates, is that such changes are often confounded by changes in the underlying stock. To address this challenge, we have designed a data-driven experiment, to go back to 2010 when 100% observer coverage was mandated to attempt to isolate the influence of different technologies in space and time, in an effort to disentangle the relative effects of individual technologies on catch rates. We are proposing using a longitudinal spatial-block design model, using extant data on purse seine catch and effort from the purse seine fishery, to control for spatial and temporal variations in abundance. We plan to use observer collected data due to the detailed information observers collect on vessel, gear, and fishing technology characteristics (e.g. Table 3).

We have applied a 10° x 10° grid to the study area within the WCPO (Figure 2), assuming that abundance within each grid cell and time period (year) is constant. A mixed effects model, with interaction terms to capture changes in abundance over time and also changes in the effects of specific vessel, gear, and technology-based characteristics over time, will then be applied to tuna catch rates (mt/set). Specifically, a Tweedie generalized linear mixed model (GLMM) is proposed, as it is suitable for non-negative continuous data with a high density of observations at zero, such that set-level catch rates C_i from set type S, in year Y and location (i.e. grid cell) L are modeled as,

$$C_i \sim Tw_p(\mu_i, \phi)$$

where

$$\mu_i = exp(\eta_i)$$

$$\eta_i = \beta_0 + \beta_1(S) + \mathrm{B}_{yl}(Y * L) + \mathrm{B}_{lt}(Y : T_t) + \gamma(V) + \epsilon_i$$

and η_i is the linear predictor for tuna CPUE, at the set level, using the log-link function. Here, β_0 is the global intercept, B_{yl} is the vector of regression coefficients associated with the year-quarter and location interaction (main effects and interaction; intended to capture spatial changes in abundance over time), B_{lt} is a matrix of regression coefficients associated with the interaction term(s) between location and technology, as multiple technologies will be evaluated, γ is a vector of vessel-specific V random effects, to account for autocorrelation associated repeated measures of individual vessels over time, and ϵ_i is a residual error term. The random vessel effect and residual

Category	Variable	Description
Vessel Characteristics		
	Vessel length	Overall vessel length (m)
	Gross registered tonnage	Vessel total internal volume (mt)
	Well capacity	Vessel hold capacity (mt)
	Skiff horsepower	Skiff engine horsepower
Vessel Electronics		
	Bird radar	Yes = 1; No = 0
	Current meter	Yes = 1; No = 0
	Sea surface temperature monitor	Yes = 1; No = 0
	Satellite weather monitor	Yes = 1; No = 0
Gear Characteristics		
	Net length	Length of purse seine net (m)
	Net depth	Depth of purse seine net (m)
	Echo-sounder FAD buoy	Yes = 1; No = 0
Demographics		
	Skipper experience	Number of years of experience
	Crew number	Number of crew onboard

Table 3: Observer recorded variables of potential interest for investigating the influence specific gear, vessel, and fishing-related characteristics and technologies have had on catch rates over time.

error terms are assumed to come from Gaussian distributions with a mean of zero, and estimated variance parameters.

$$\gamma \sim N(0, \sigma_v^2)$$

$$\epsilon \sim N(0, \sigma_e^2)$$

The variance of C_i is assumed to be a function of the dispersion ϕ and power p parameters, both of which will be estimated (see Jorgensen, 1997 and Bonat and Kokonendji, 2017 for details).

$$V(C_i) = \phi \mu_i^p$$

This analysis is proposed to be set type specific; thereby analyzing drifting FAD and free-school sets separately due to the differences in fishing practices and potential importance of different technologies. We plan to fit the GLMMs using the R package *glmmTMB* (Magnusson et al., 2016).

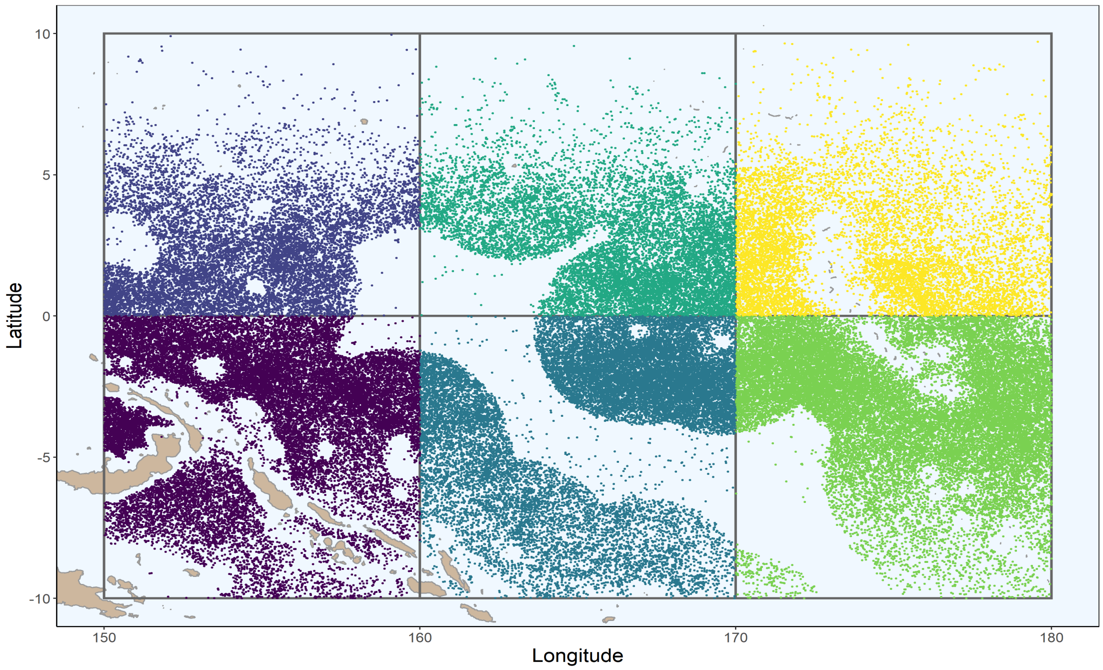

Figure 2: Map, illustrating spatial domain of interest, split into 10° blocks. Purse seine sets, reported by observers from 2010-2018, being considered for this analysis are plotted as points, color coded by the spatial block they correspond to.

The above analysis proposes to use operational (set-level) catch and effort data to evaluate the influence of specific technologies on catch rates. In addition, we plan to evaluate the aggregate effects of technology by modeling catch per day or monthly catch and effort, normalized by fishing days. These aggregate metrics may offer different insights into the role different technologies play, patterns which may be obscured by focusing solely on the set-level operations. For example, a vessel with sophisticated information technologies may be able to more reliably find productive tuna schools and minimize days with no fishing activity, while at the same time, average catch per set may remain relatively unchanged. Such change in fishing consistency may be important to understanding the purse seine dynamics, and may only be revealed at a more aggregate level.

As part of this analysis, we will focus on developing an improved database for effort related inquiries, such that finer-scale information is more readily available to analysts, in a reliable and standardized format. For example, Torres-Irineo et al. (2014) documented changes in specific models of fishing technologies, information that helped add context to change-points in the purse seine indicators they evaluated. In the WCPO, such an analysis is warranted. For example, echo-sounder FAD buoys have been in use for several years now, but it is only recently that fishers have started using double or multi-frequency echo-sounders. This advancement may help to better discriminate species composition and aid fishers in making more informed fishing decisions. This potential variability in effectiveness within technology categories is important to capture and will be explored more fully to better understand changes related to effort creep.

2.3 VMS analysis

The availability of relatively fine-scale position information from purse seine vessels enables more detailed analyses on search patterns and fishing effort through time. In the WCPO, hourly reporting of purse seine vessel positions with date-time stamps, began in 2010, and has continued to the present, with 30 minute polling during FAD closure periods. These data have rarely been used to address questions of effort creep, but offer the potential to fill in important data gaps. We have observer reported information on daily fishing activities (e.g. transiting, searching, free-school set, FAD set) that we can match up with VMS data, revealing a time series of activities in space and time throughout a fishing trip. Using the combined VMS and observer data, we plan to identify different fishing activities in the VMS in an attempt to quantify changes in searching patterns, searching time, and fishing time to re-evaluate our understanding of effort metrics in this fishery and to assess potential changes in fishing and searching time, as a proxy for effective effort, from 2010 to the present.

Using observer data, we plan to identify a small subset of vessels, those that have been active in the fishery for the entire time period of interest (2010-2019). VMS data sets can be large due to the frequency of data collection (i.e. every hour or half-hour); therefore, we have elected to explore these methods with a small subset for feasibility and to reduce model run times. We plan to expand the results, once we have developed a reliable approach. The time period (2010-2019) is proposed as it is representative of 100% observer coverage, of which we will select vessels which span the gradient of performance, based on total effort and catch rates, such that we have a mixture of high and low-performing vessels, relative to the fleet as a whole. We will then summarize fishing vessel patterns over the time series, and evaluate whether changes are detectable, and if so, how searching and fishing patterns have evolved over time.

The preliminary approach involves several steps:

1. summarize daily activities as reported by observers over the time series;
2. characterize VMS tracks related to different activities (e.g. fishing, searching, transiting);
3. quantify how fishing-related time (effort) has changed through time, and consider alternative definitions of effort; and
4. evaluate how different effort metrics, and the changes in them over time, influence our understanding of effort creep.

The subset of VMS data proposed for this analysis comprises 536,399 Global Positioning System (GPS) observations recorded from 2010-2019, the full VMS dataset corresponds to 427 purse seine vessels, operating in the WCPO, with approximately 46.7 million records between 2010 and 2019. Bez et al. (2011) undertook a VMS study by classifying different types of purse seine activities into three categories (fishing, tracking, and cruising). Using a Bayesian state-space model, the study used a small subset of spatial indicators (speed profiles, heading profiles and GPS positions) to train the model to identify these classification groups within a trip. A similar approach is suggested to compensate for data gaps between VMS data and declared positioning logbook data, particularly with short fishing trips, with an average estimate of 7% of fishing sets missing and fishing locations identified with errors within purse seine trips (Katara and Silva, 2017). VMS data typically provide full coverage of vessel activities within a fishing trip, and may offer complementary ways to visualise and understand changes in fishing patterns and behaviour characteristics, which are not obvious from observer datasets. For example, it is hypothesised that searching behaviour may change in response to advancement in technologies (straight lines versus meandering for searching) and changes in search times during FAD closures vs non FAD closure periods (e.g. directive from head office versus at-sea observations).

The proposed VMS study aims to subset the pool of purse seine vessels into two categories (i.e. high-performing and low-performing), with performance based on total tuna catch tonnage in each year. The VMS data will be matched to the observer data to identify the fishing activities associated with each VMS position, and to map a set of vessel and gear characteristics associated with each vessel over time. Observers record daily activity logs which indicate where and when a fishing activity changes (e.g. from searching to fishing or from fishing to transiting). These detailed accounts will be extremely valuable when interpreting and analyzing trends in vessel activity. A preliminary summary of observer data shows a combination of subtle and pronounced trends associated with fishing-related activities (Figure 3). For example, there is clear increasing trends with searching times compared to fishing activity times which has decreased and a dome-shaped trend with helicopter use over the assessment period, such that it seemed to peak in 2016, after which it has declined.

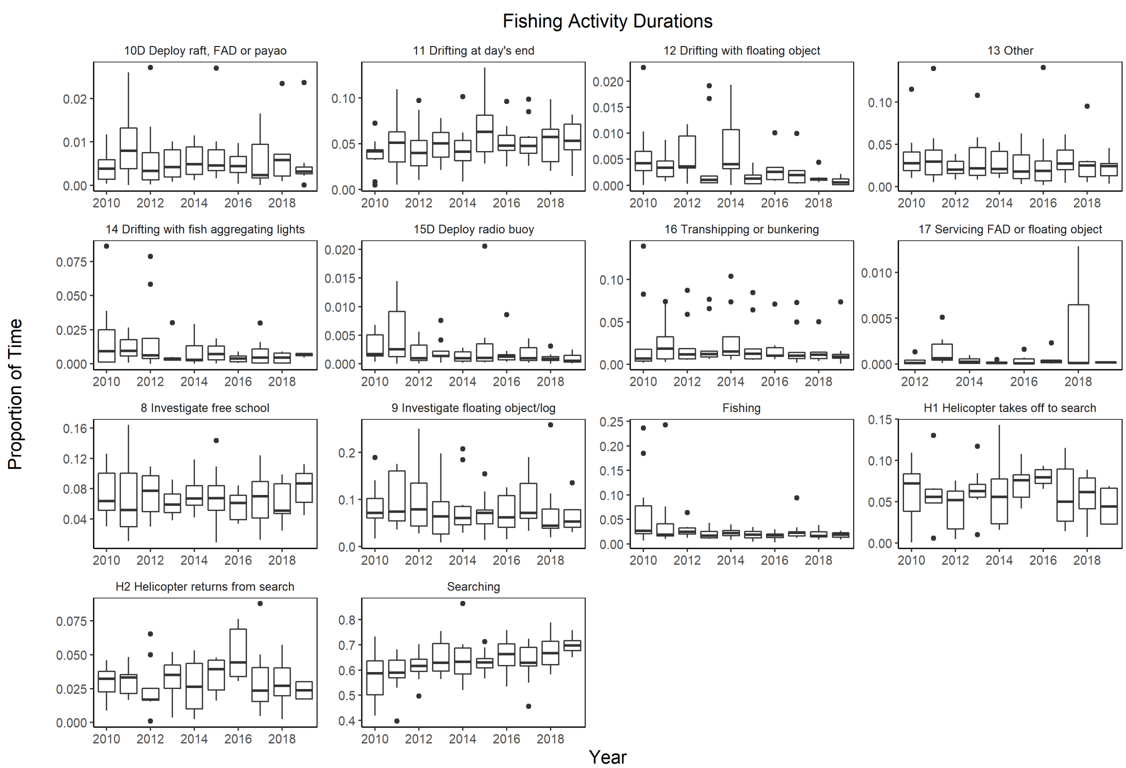

Figure 3: Distribution of the proportion of time the purse seine fleet spent on various fishing-related activities, as reported by observers, from 2010-2019.

3 Synthesis

These proposed research areas are important to better understand effort creep and its evolution over time. Since the 12th Scientific Committee(SC12), a suit of effort creep indicators were developed to assist with the development of harvest strategies across the tuna species, in particular skipjack in the WCPO (Pilling et al., 2016). There have been difficulties in quantifying effort creep due to its complex nature. The influence from a suite of variables are at play simultaneously, some of which are conspicuous in nature (e.g. vessel length) and others which present challenges in understanding and quantifying their impacts (e.g. instructions from fleet headquarters). Vidal et al. (2020) noted that the SC12 indicators focused on understanding and capturing trends thought to be influencing effort creep as opposed to quantifying the relationship between effort creep metrics and fleet catchability. This research proposal attempts to address this important knowledge gap as it is apparent that the purse seine fishery is continually changing its practices to increase efficiency, as is the case with most (if not all) industrial fisheries. There is an imminent need to quantify how such changes impact catch rates, to better inform fisheries managers. This project aims to progress research to address this need by:

1. Developing a more informed hypothesis to inform statistical modeling approaches and data collection/usage, based on information provided through the fisher surveys;
2. Quantify the influence of different technologies (potentially informed by the survey responses) using a variance-partitioning modeling framework (GLMMs), and develop data-driven estimates of purse seine effort creep; and
3. Develop descriptive and analytical tools to evaluate VMS data in an effort to identify changes in fishing behaviors over time, assess alternative definitions of purse seine effort, and quantify changes in searching and fishing behavior in order to inform managers and CPUE-based analyses informing the stock assessments.

This research approach will provide a multi-faceted approach to progress our understanding of purse seine effort creep in the WCPO, and to enhance uptake of this information with respect to monitoring and managing tuna stocks and fisheries. The proposed research areas will assist in evaluating and quantifying the influence certain technologies have had on catchability over time. We propose to also examine catch, effort and behaviour indicators based on vessel technology characteristics (e.g. skiff, well capacity, echo-sounder buoys) and draw conclusions to their respective influence on the purse seine fleet's effective fishing over time. It is premature to speculate which technologies might be used to substitute declining or less effective technologies and tools, thus this paper suggests research approaches to identify and circumscribe the effectiveness of existing and emerging technologies in the WCPO purse seine fishery. Improved understanding of technology uptake by vessels can be achieved through the fishers survey, which will refine our research parameters, particularly with operational decision making and fishing strategies influenced by technology advancements.

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5 Appendix

5.1 Fisher survey questionnaire

Included below is the questionnaire designed to survey purse seine skippers and fishing masters with respect to changes in fishing practices and influential technologies over time. This information will be used to describe changes in the fishery in a qualitative/descriptive manner, inform hypothesis about effort creep, and provide context for the development of statistical models to address effort creep and better understand the relationship between technological change and fishing mortality.

Industry interview program to understand purse seine effort creep and evolution of fishing strategies

Background

Effective management of the tuna stocks in the Western and Central Pacific Ocean (WCPO) is essential to ensure sustainable and profitable fishing opportunities.

Over the years, information from the fishing industry has been critical in underpinning the assessments of tuna stocks and fishery conditions that inform effective management. In the purse seine fishery many things have changed over the last 10—15 years, e.g. technological advances, FADs and the Vessel Days Scheme. The flow on effects of these changes to fishery operations, as they adapt, can have both positive and negative consequences for the fishing operations and the stocks. It is important to understand how fishing operations have changed overtime so that any changes are factored into decisions on how information is gathered, analysed and interpreted to inform management decisions for the good of the stock and fishery.

We thank you for your time in undertaking this fishers survey.

Industry interview program to understand purse seine effort creep and evolution of fishing strategies

1. What position do you currently hold?

- ◯ Skipper
- ◯ Fishing Master
- ◯ Fleet Manager
- ◯ Other (please specify)

2. How long have you worked on a purse seine fishing vessel in this position?

- ◯ 0 - 3 years
- ◯ 4 - 8 years
- ◯ 9 -12 years
- ◯ > 12 years
- ◯ NA

3. How long have you been fishing on a purse seiner, in any role?

- ◯ 0 - 3 years
- ◯ 4 - 8 years
- ◯ 9 -12 years
- ◯ > 12 years
- ◯ NA

4. How many vessels, operating in the WCPO, are owned by the company that owns the vessel that you fish on?

- ◯ 0 - 2 vessels
- ◯ 3 - 4 vessels
- ◯ 4 - 5 vessels
- ◯ 6 + vessels
- ◯ Unsure

5. Do you share information about the location of productive fishing areas for tuna with other vessels from your company?

- ◯ Yes
- ◯ No

6. Do you share information about the location of productive fishing areas for tuna with vessels from other companies?

- ◯ Yes
- ◯ No

7. Which tools/technologies/information have been most important for <u>improving catch rates</u> through time for <u>FAD sets?</u> Please indicate one tool for each period

	tools/technologies/information
2000 - 2005	
2006 - 2010	
2011 - 2015	
2016 - 2020	

Other (please specify)

8. Which tools/technologies/information have been most important for <u>improving catch rates</u> through time for <u>free school sets?</u> Please indicate one tool for each period

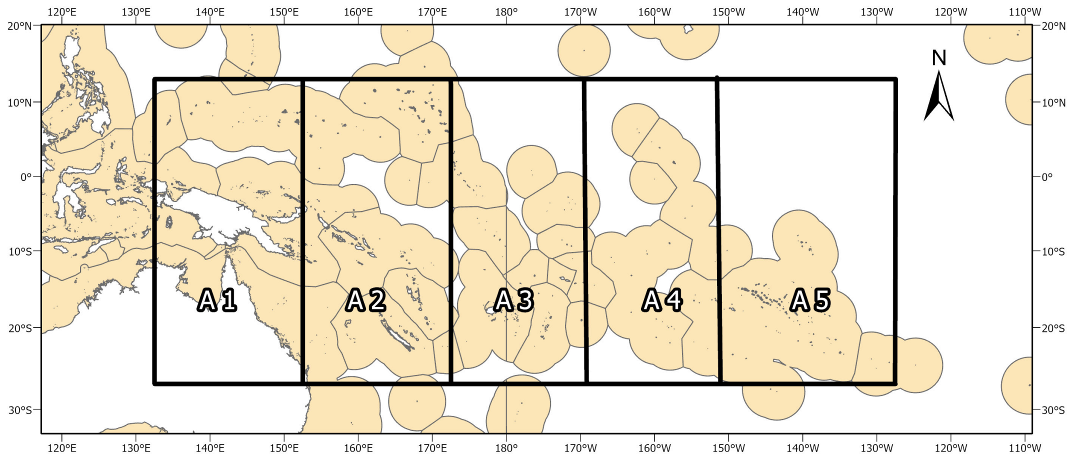
	tools/technologies/information
2000 - 2005	
2006 - 2010	
2011 - 2015	
2016 - 2020	

Other (please specify)

9. How has your helicopter use changed through time?

	Decreased	Stayed the same	Increased	Unsure
2000 - 2005	○	○	○	○
2006 - 2010	○	○	○	○
2011 - 2015	○	○	○	○
2016 - 2020	○	○	○	○

10. Which zone(s) were you fishing FADs through time? (*refer to map below, tick more than one zone where applicable*)



	A 1	A 2	A3	A4	A5
2000 - 2005	☐	☐	☐	☐	☐
2006 - 2010	☐	☐	☐	☐	☐
2011 - 2015	☐	☐	☐	☐	☐
2016 - 2020	☐	☐	☐	☐	☐

11. Which tools/technologies/information do you think will influence your fishing in the future?

1

2

3

Other

12. How many FADs were your vessel deploying per year during these periods?

	< 50 FADs	50 - 100 FADs	100 - 200 FADs	200- 350 FADs	350 + FADs	Unsure
2000 - 2005	○	○	○	○	○	○
2006 - 2010	○	○	○	○	○	○
2011 - 2015	○	○	○	○	○	○
2016 - 2020	○	○	○	○	○	○

13. How many echo-sounder buoys were your vessel deploying per year during these periods?

	< 50 Buoys	50 - 100 Buoys	100 - 200 Buoys	200- 350 Buoys	350 + Buoys	Unsure
2000 - 2005	○	○	○	○	○	○
2006 - 2010	○	○	○	○	○	○
2011 - 2015	○	○	○	○	○	○
2016 - 2020	○	○	○	○	○	○

14. In your opinion, does the number of FADs in an area influence catch rates?

○ Yes

○ No

○ Unsure

15. How likely are you to fish an area with the following FAD densities below?

	Not at all	Might fish	Likely to fish	Unsure
1 FAD encountered within 20 miles	○	○	○	○
1 FAD encountered within 15 miles	○	○	○	○
1 FAD encountered within 10 miles	○	○	○	○

16. When did your vessel start using FADs equipped with satellite buoys? (select year in the drop down box)

17. When did your vessel start using FADs equipped with satellite echo-sounder buoys? (select from the drop down box)

18. Are you using FADs equipped with satellite multi frequency echo-sounder buoys?

- ◯ Yes
- ◯ No
- ◯ Other (please specify)

19. What factors influence your decision to steam to a FAD? (Place in descending order, drag and drop with 1 being the most important factor and 9 the least important factor)

High biomass on FAD echo-sounder

☐ N/A

Increasing biomass shown on FAD echo-sounder

☐ N/A

Distance

☐ N/A

Sea conditions

☐ N/A

Other buoys showing tuna biomass

☐ N/A

Depth of biomass on FAD echo-sounder

☐ N/A

Time of the year (VDS days left over)

☐ N/A

Amount of fish on board

☐ N/A

Other

☐ N/A

20. If 'Other' was selected in Q.19 as being important, please specify below.

21. Assuming you have an empty hold and calm weather conditions, how far (nautical miles) will you be willing to travel to make a set on a FAD that has indicated the biomass estimates (in metric tonnes) below?

	< 15 nm	15- 50 nm	50 - 100 nm	100+ nm
< 10 tonne tuna				
10 - 50 tonne tuna				
50 - 100 tonne tuna				
100 + tonne tuna				

22. How confident are you to determine species and catch composition prior to setting the net, as a percentage between 0 - 100%

I dont know the species composition — I know half of the species composition — I know the species composition

23. Does the price of fuel influence your fishing decisions?

- Yes
- No

24. What is your maximum capacity (in metric tonnes) for processing fish per day?

metric tonnes per day

25. What factors are most important when choosing a port to offload your catch? (Place in descending order, drag and drop with the 1 being the most important factor and 9 the least important factor)

Port fees (unloading, provisioning)

☐ N/A

Licence conditions

☐ N/A

Port facilities (accommodation,restaurants, entertainment)

☐ N/A

Net repair facilities and expertise

☐ N/A

Proximity to fishing grounds

☐ N/A

Medical emergencies

☐ N/A

Enforcement restrictions

☐ N/A

Transhipment suitability

☐ N/A

Other

☐ N/A

26. If 'Other' was selected in Q.25 as being important, please specify below.

27. Has your search time for free school sets changed over time?

- Decreased
- No change
- Increased

28. Has the time required to find a productive FAD changed over time?

- Decreased
- No change
- Increased

29. What are the three biggest factor that contributes to a failed/skunk set?

Factor 1

Factor 2

Factor 3

30. What environmental factors do you think are most important in predicting locations of productive fishing grounds? (Place in descending order, drag and drop with the 1 being the most important factor and 7 the least important factor)

Time of day

☐ N/A

Sea surface height

☐ N/A

Sea surface conditions

☐ N/A

Winds

☐ N/A

Temperature

☐ N/A

Phytoplankton

☐ N/A

El Niño and La Niña

☐ N/A

Other

☐ N/A

31. If 'Other' was selected in Q.30 as being important, please specify below.

32. Do you have the tools to monitor these environmental variables?

Yes (please list)

No (what would you like)

Other

33. How does knowledge of El Niño conditions influence your fishing?

34. What are your concerns for future changes to the environment with respect to the tuna fishery?

35. What are your concerns for the future of the tuna stocks in the WCPO?

36. How has the Vessel Day Scheme changed how you fish? Please describe the three most important changes below.

Change 1	
Change 2	
Change 3	

37. Please provide your vessel details.

Vessel Length (meters)	
Vessel Tonnage (GRT)	
FishHold Capacity (CuM)	
Freezing Capacity (tonnes per day)	