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Towards the development of a catch per unit effort (CPUE) index for the purse seine fishery

New Zealand Fisheries Assessment Report 2025/37

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PLAIN LANGUAGE SUMMARY

Existing data sets were used to characterise the activity of the purse seine fishery for small pelagic species that is focused off the northeast of New Zealand. These included catch and effort data from the fishery, and track-line data from both the vessels and their supporting spotter planes.

Incomplete recording—particularly of search effort—currently precludes the development of standardised catch per unit effort (CPUE) series to index the abundance of fish stocks that are primarily caught by purse seining.

Additional data collection that would support a more complete characterisation of the fishery, and may allow the development of CPUE series, is described.

EXECUTIVE SUMMARY

Hill-Moana, T.[1]; Neubauer, P.[1]; Middleton, D.A.J.[2]; Vidal, T.[3]; Escalle, L.[3]; Cook, D.[4] (2025). Towards the development of a catch per unit effort (CPUE) index for the purse seine fishery.

***New Zealand Fisheries Assessment Report 2025/37*. 51 p.**

Purse seine fisheries target an assemblage of pelagic fish on the eastern coasts of the North Island, New Zealand. Key target stocks in this fishery include blue mackerel (EMA 1), jack mackerel (JMA 1), kahawai (KAH 1), trevally (TRE 1) and skipjack tuna (SKJ 1). For stocks targeted predominantly by the purse seine method (including JMA 1 and EMA 1), determining their population status is challenging.

A common metric used to provide information on population trends and abundance in fisheries is catch per unit effort (CPUE). The use of CPUE in purse seine fisheries is problematic, owing to the difficulty in defining the applicable fishing effort. Past determinations of this metric have generally been considered unsuitable for further application in stock assessments and characterisations.

To address shortfalls in the utility of CPUE for purse seine fishing activities, an initial characterisation of the fishery was conducted. Determinations of 'best available' CPUE metrics for the fishery complex were then performed using the available statutory fisheries data, with catch rates defined as both catch-per-day and catch-per-set. While some variation and trends were observable in time series of these two catch rates, they are considered to remain of limited utility for incorporation into any analysis of stock abundance.

To improve the utility of the CPUE metric, key considerations associated with its use in the purse seine fishery were addressed. It's application in a mixed species fishery was investigated, whereby the extent to which vessels switch targets during fishing trips was quantified and the prevalence of mixed species catches was determined. The visual method by which fish are targeted, which affords skippers the ability to be selective in their capture of schools, was discussed. An analysis of how frequently spotter planes are used in the fishery was conducted, whereby it was identified that spotter plane use and influence varied between species. Whether constraints associated with the holding capacity of the vessel influence the size of schools caught by skippers was also investigated, and identified to be non-significant.

Determining the search behaviours of the purse seine fleet, which represents an important form of effort undertaken in the fishery, remains the primary knowledge gap limiting the development of a meaningful CPUE index. The use of geospatial information recorded by the vessels' Geospatial Position Reporting system, and spotter plane Automatic Dependent Surveillance–Broadcast transponders, was therefore explored to identify whether they provide opportunities for determining search activity. Classification of vessel activity by speed and turning angle enabled the inference of stationary, transiting, and searching patterns of motion. Areas for further improvement of these classifications were also identified. Visualisation of select fishing trips identify that spotter planes can provide extensive searching activity in the wider area in which the vessels fish. While searching, spotter planes were also observed to identify schools that are not targeted and vessels often catch schools that were not recorded by the planes. Therefore, only a partial understanding of searching activity in the purse seine fishery can be achieved by utilising current information on either the activities of spotter planes, or vessels, independently.

Further efforts to develop a CPUE index for this fishery should focus on continued development of the geospatial data that can be collected from the vessels and spotter planes, before combining these

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datasets into a useful determination of the encounter rates of target species by both the plane and vessel. Complementary development of ‘non-fishing’ or ‘non-catch’ information collection systems that record the observations of the skippers and pilots, and the decisions made by skippers when choosing to set upon or forgo a school of fish, would further refine our understanding of the effort undertaken within the purse seine fishery to achieve their catch. A more detailed understanding of the environmental responses of these target pelagic species would also support a more complete understanding of fishery dynamics, including both the catchable component of the stocks and their overall abundance trends.

1. INTRODUCTION

The inshore purse seine fishing fleet, that primarily operates around the North Island, represents a sizeable, but incompletely understood, component of New Zealand's fisheries. For more than 25 years the fleet has largely operated out of Tauranga (Bay of Plenty), targeting small- and medium-sized pelagic fish species, including blue mackerel, jack mackerel, kahawai, trevally, and skipjack tuna (Figure 1). Jack mackerel, an assemblage of up to three species of which *Trachurus novazelandiae* typically accounts for most of the catch, and blue mackerel (*Scomber australasicus*) collectively represent the majority (>90%) of landings (Figure 2). The purse seine fishery primarily operates in the north-eastern Fisheries Management Areas (FMAs), FMA 1 and FMA 2, but also fishes off the west coast of the North Island in FMAs 8 and 9. This fishery is often described as the small pelagic fishery (SPF) to differentiate it from fisheries for larger, highly-migratory, pelagic species, such as billfish and large tuna.

Within this small pelagic fishery complex, the total allowable catch (TAC) for some stocks is caught almost exclusively by the purse seine fishing method, with negligible recreational catch, whereas other stocks are targeted by a range of fishing methods in both commercial and recreational fisheries. For stocks where purse seine is the primary method of capture, little is known about the status of the populations (e.g., JMA 1, EMA 1, and EMA 2). This is a result of difficulties estimating the abundance of these migratory species, and operational characteristics of the purse seine fishery. Species targeted by other or multiple fishing methods are generally afforded better determinations of their population status due to the assessment methods these fisheries support (e.g., KAH 1 and TRE 1).

In conventional stock assessments, a common metric used to provide information on population trends and abundance is catch per unit effort (CPUE). This metric considers that the number of fish caught per unit of effort exerted is proportional to stock size. However, for purse seine fisheries the relationship between CPUE and fish abundance is not straightforward because multiple factors are associated with the notion of effort.

In trawl fisheries, effort is normally expressed primarily as the time spent with the net at fishing depths, whereas for longline and set net the key component of fishing effort is usually considered to be the amount of gear set (i.e., the number of hooks or net length). In purse seine fishing, existing effort data allow the time spent in the actual fishing operation to be quantified. However, purse seine nets are only deployed once a fish school has been first located and then selected, after gathering information on the species and size composition. New Zealand fisheries data do not currently provide information on searching or school selection activity, although some information on the use of spotter planes—that assist in searching activities—is available.

Commonly, effort in purse seine fisheries is defined as the time spent searching for fish, which is then compared to the volume of the catch. Under this definition it becomes apparent that any changes in searching techniques or strategies will strongly influence the apparent abundance of the fish population. This is important for two reasons: (i) fish behaviour can be temporally and spatially dynamic where their availability to the fishery is highly variable even when population levels are stable, and (ii) fishers and operators are continually seeking to improve the skill and efficiency of their operations to increase catches, and reduce searching effort, to maximise economic returns (a process often referred to as "effort creep"). In the effort creep scenario, the potential for hyperstability (i.e., the maintenance of high catches when population sizes decrease) becomes apparent, whereas in the low availability scenario hyperdepletion (low catches when population sizes are high) may also occur.

Selectivity biases further complicate the use of CPUE in the purse seine fishery. The characteristics of schools such as the size distribution of fish, the mix of species present, and the school volume all influence whether a skipper decides to set upon a potential target. These factors should be considered operational in nature as they can be driven by market forces, vessel constraints (e.g., hold volumes), or by land-based processing capacities. These operational factors (discussed in more detail below) may therefore influence catches of fish, independent of their abundance. When developing a CPUE metric, information on the searching techniques, technologies, and strategies should be considered a prerequisite.

In the context of New Zealand's purse seine fishery, extensive investigations have identified the challenges of determining a CPUE metric reflective of abundance. During investigations of the developing skipjack tuna fishery, a CPUE metric (with effort defined as a season-day) was used to inform the catch patterns of the burgeoning purse seine fleet (Habib et al. 1980). Yet by the mid 2000's it was deemed that "purse seine was not a suitable method for measuring CPUE as it is targeted on schools in New Zealand waters..." (Kendrick 2006).

In EMA 1, Morrison et al. (2001) explored the use of CPUE for the purse seine catch. It was noted that their CPUE analysis violated many of the assumptions required for this metric to index abundance, largely due to the visual methods used to detect fish, market driven shifts in effort, and the opportunities for the fleet to switch their target species independent of blue mackerel abundance. Similarly, again with reference to EMA fisheries, CPUE has been considered unlikely to be reliable due to the spatial and vertical mobility of the species, their size-structured school formations, size based targeting practices (by the purse seine fleet), hyperstability, the poorly understood environmental factors influencing their abundance, and the existence of mixed species fisheries (Taylor 2002, Fu & Taylor 2011).

In a general sense, it is presently considered that there is no meaningful measure of effort in the purse seine fishery that can be used to standardise catch rates (Hartill & Bian 2016), and no further efforts to quantify CPUE from the New Zealand purse seine fleet are known to the authors.

However, while CPUE based analyses of the purse seine fisheries are not currently incorporated into New Zealand's fishery management portfolio, they are commonly utilised as a component of the stock assessment methodologies that support management efforts by international Regional Fisheries Management Organisations (RFMO's) for the tropical tuna purse seine fisheries, and in other regions where sizeable small pelagic purse seine fisheries exist (e.g., Japan).

While there is clearly a considerable amount of effort required before a CPUE based metric is incorporated into the fisheries management toolbox for New Zealand's small pelagics fishery it is considered that an understanding of the operational characteristics of the fishery, and how these characteristics interact with target fish abundance and behaviour, will provide important and complementary information that supports alternative approaches to understanding SPF stocks (e.g., including investigations into size-based management procedures). Moreover, the development of CPUE-based metrics will have additional scientific value during investigations of the environmental and habitat associated factors that influence the behaviour and catches of these lower-information species.

This investigation therefore seeks to:

- provide a characterisation of the SPF purse seine fleet since 1990;
- consider the catchability components of the CPUE metric, to develop a better understanding of the interactions between resource abundance, fishing effort, and catching efficiency;
- assess whether recently available geospatial tracking data collected from vessels and spotter planes could help inform future investigations of CPUE in the fishery; and
- identify key focus areas, and additional data capture requirements, for the ongoing development of a CPUE metric for the management and understanding of the New Zealand SPF.

While the intention of any future CPUE analysis would likely be to derive species specific indices, current investigations are focused on the complete SPF assemblage (or complex) caught by the purse seine method. This investigation forms part of a larger and broadly focused investigation into different approaches and technologies appropriate for the management of small pelagic species (SFFF project S3F-21147).

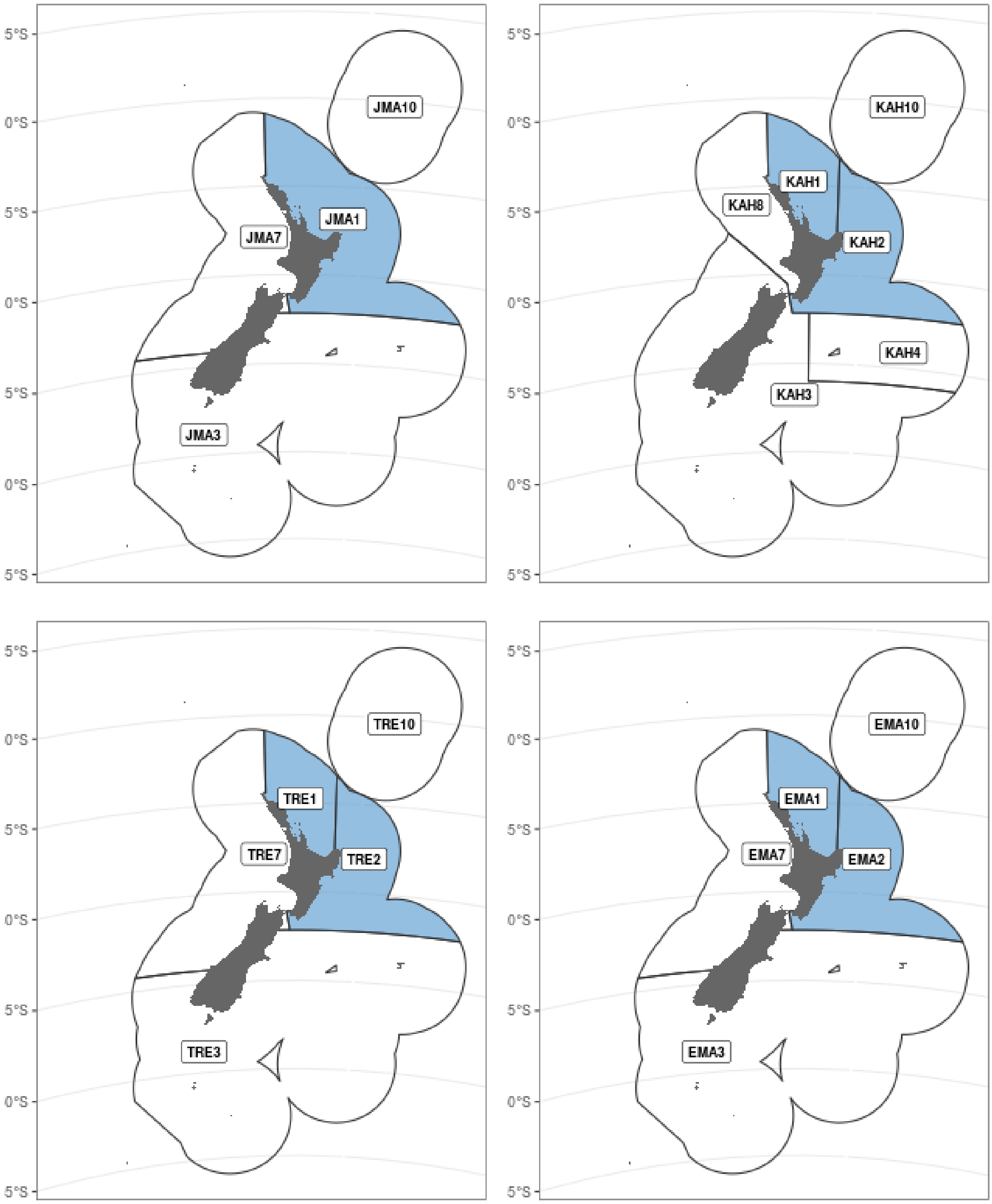

Figure 1: Quota Management Areas for jack mackerel (JMA 1), kahawai (KAH 1 and KAH 2), trevally (TRE 1 and TRE 2), blue mackerel (EMA 1 and EMA 2) and skipjack tuna (SKJ 1) respectively highlighted.

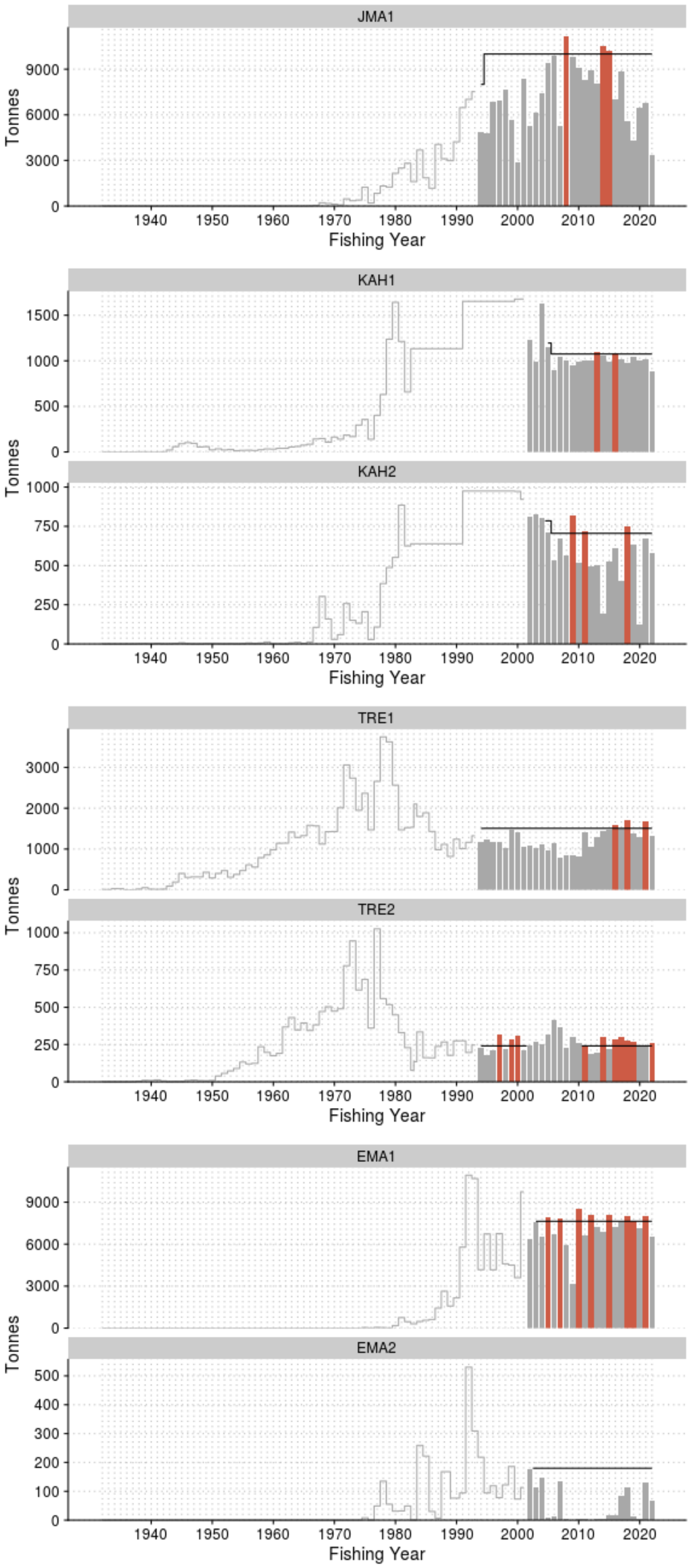

Figure 2: Total Allowable Commercial Catch (TACC; black line) and Monthly Harvest Return/Quota Management Return totals (bars) for JMA 1, EMA 1, EMA 2, TRE 1, TRE 2, KAH 1, KAH 2 from 1994 to 2022. Years where the TACC was exceeded are highlighted in red. Catches prior to 1994 are shown by the grey line using the information compiled in the stock assessment plenary (Fisheries New Zealand 2023).

1.1 An operational description of the small pelagics purse seine fishery

Small pelagic fisheries are highly dynamic. The availability of these fish varies both in time and space, as fish move between pelagic and inshore waters, and along the coastline. Even when inhabiting inshore waters, their collective behaviours readily change, with fish shifting between surface and sub-surface schooling behaviours frequently, and the composition of schools shifting between single and mixed species, and composed of individuals that can be uniform or varied in size. The total size of aggregations can also vary, and change abruptly when different schools merge or separate.

To account for these dynamic behaviours, purse seine fishing techniques are highly adaptive. To locate preferred schools for targeting over large expanses of inshore waters, spotter planes are often utilised to locate the fishing grounds that possess aggregations of desirable species and sizes. This information is then relayed to vessels and operations managers who formulate catch plans for the fleet. Fishing grounds that contain desirable schools are approached by the vessel(s) which utilise additional detection technologies (e.g., sonars, underwater cameras, and visual inspection) to characterise the schools before any attempts to capture are undertaken.

Vessels, and commonly spotter pilots, make combined decisions to target a given school based upon the size of the schools, its species composition, group behaviours, the size of individual fish in the school, water depths, bathymetric features, and the presence of protected species in the wider area, amongst other factors. When the decision to set is made, the vessel then engages the school, resulting in either capture or a skunk (failed attempt). If caught, the fish are transferred onboard the vessel into storage holds that can hold various storage media (i.e., refrigerated seawater (RSW), or brine). Different media types influence the keeping qualities and storage life of the fish, and therefore the duration of the voyage.

Species targeting can be variable within a fisheries complex. While fishing trips may plan to target a specific species, changes in the availability of the intended species, opportunism, market opportunities, or the presence of non-target species in the school (either desirable, or undesirable) may influence the species landed in any given set or voyage. The opportunity to report these targeting dynamics may not always be present, ultimately leading to scientific uncertainty on how the realised catch reflects abundance levels.

Operational decision-making and complexity also interact with the environmental and seasonal dynamics of each of the species. While some species (e.g., kahawai) are available relatively consistently throughout the year, other species (e.g., skipjack) display limited seasonal availability. The presence of species with variability in their seasonal abundance (particularly skipjack tuna) can also have a marked effect on operations, with targeting of these fish by some, or all, purse seine vessels typically occurring in the summer and autumn months, during which the targeting of other species may be limited even when they are present in high abundance.

Understanding the intricacies of each factor, decision, and action that influence encounter rates, catch, and effort in the fishery is clearly an important component of understanding how fishing vessels interact with the relative abundance of fish over both short and longer time frames.

2. METHODS

The data extracts (report logs 13159, 16844) of commercial catch and effort data were provided by the Ministry for Primary Industries (MPI) and processed using standardised grooming routines, that followed the approach of Starr (2007), with a set of rules defined for different types of data (Bentley 2012).

All years in this report refer to the standard New Zealand fishing year which runs from 1 October to 30 September. Fishing years are labelled using the later calendar year; thus, for example, 1990 refers to the fishing year 1 October 1989 to 30 September 1990.

2.1 Characterisation methods

The fishery characterisation data set included all catch and effort data from any fishing trips from the Pelco NZ Limited fleet, and purse seine vessels fishing for Sanford Limited prior to 2019, that recorded catch using the purse seine method during 1990–2022. Sanford and Pelco were considered the two primary operators of purse seine vessels over the period investigated; their permission, and that of their skippers, was obtained to report data at a finer scale than normally permitted by the Fisheries New Zealand guidelines. Throughout the investigation, all species of jack mackerel were reported as a single species group (JMA). Detailed descriptions of the fishing fleet were based upon information collected from interviews with past and present skippers that operated within the purse seine fishery through the period 1990–2022.

2.2 Catchability exploration

To explore the catchability of small pelagics, and how this is related to the operation of the purse seine fleet, catch and effort data was explored with regard to key operational characteristics of the purse seine fishery. This exploration was broken down into the following three key objectives, further described in the sections below:

1. investigate the extent to which spotter planes are used in the fishery and whether they have a detectable influence on catch levels;
2. identify whether target switching is a common phenomenon in this mixed species fishery; and
3. determine whether the hold capacity of vessels influences the volumes of fish caught.

This part of the investigation largely focused on identifying patterns within the available data, and discerning trends or indicators of potential influence on catch rates, that will help guide future investigation towards a CPUE metric for the small pelagic purse seine fishery.

2.2.1 Spotter plane effort field

If a spotter plane was used to assist a purse seine fishing set, the plane's call sign (referred to as spotter ID) was entered on the reporting form and, according to the CELR seining template, a 'N' should be entered if a plane was not used. However, the `spotter_plane_callsign` field required extensive investigation and grooming to understand what was recorded in this field.

The standard format for a spotter ID usually consists of two characters (generally ZK) followed by a three-letter code, for example ZK-ABC. However, the field largely consisted of the three letter spotter IDs, while some contained seemingly erroneous numbers, mixed letter cases and other characters (i.e., punctuation characters) or single character/letter errors, which could be due to how they were recorded, transcribed, or digitised. Interestingly, there are also cases were multiple spotter IDs are recorded for a single set, which could suggest multiple planes may been used on a fishing trip or even for a single event.

The spotter IDs were classified into four spotter plane use categories: Yes, No, Number and NA. The latter two categories were retained in the variable `spp_use` for further evaluation. In the case of spotter IDs categorised as Number, the exploratory analysis identified that these IDs largely occurred before 2000 and were mostly recorded by a single vessel. At the vessel level, the pattern appears to follow the use of spotter planes by other vessels prior to 2000. As these numeric spotter ID's remained highly cryptic, their use or meaning was not explored further. For the category NA, we have not determined how to proceed in using these data; further investigation is required to confirm if this category could refer to sets where spotter planes are not used. Spotter plane callsigns, and vessel identifiers, were anonymised throughout this report.

2.2.2 Effort-related data field, `effort_num`

Initial inspection of data recorded on CELR forms identified that effort recording appeared atypical when compared to other New Zealand fisheries. For seining, a single row was normally used per set, with geographical coordinates for the set being recorded. CELR reporting in most other fisheries typically occurred on a daily basis, with the `effort_num` field referring to the number of fishing events on the day. In this context, it was not clear *a priori* whether `effort_num` values greater than one represented multiple sets. Initial investigation of the `effort_num` field found that the distribution of reported values was very wide, suggesting potentially inconsistent use of the field. The main use appears to have been to record the set number on a particular day on a trip. If the trip extended over multiple days, the `effort_num` typically reset at the first set of the day. Given inconsistencies in the reported field, a new variable was created to denote successive sets in a trip, subsequently labelled `set_num`.

2.2.3 Hold capacity influence on catch-per-set

The size and volume of schools targeted by the PS fishery are intrinsically limited by the size of their holds (i.e., fish schools larger than the vessel's hold volume will not be caught), and by the remaining hold capacity when successive catches are made during a voyage. Capacity constraints may therefore lead to non-independence of catch-per-set metrics along a trip: large catches early in the trip may preclude larger catches on sets later in the trip. To investigate whether such non-independence was discernible in the purse seine data, we hypothesized that non-independence would lead to a saturating pattern in cumulative catch relative to hold capacity, with initial sets accounting for most catch, and successive sets being smaller.

2.2.4 Evidence of target switching

Targeting in the small pelagic purse seine fishery is a complex process that balances relative species availability, market demand, catch entitlements, as well as operational factors. Within this complexity, it is important to disentangle whether targeting is indicative of relative abundance. For example, it is conceivable that targeting may occur only when abundance is sufficient to warrant setting on the species, leading to CPUE being hyperstable. Similarly, if the abundance of a species is marginal during a voyage, switches in the target species may occur to ensure operational efficiencies. Both these possibilities indicate that targeting practices could vary with the availability of a target species. In order to obtain a better understanding of the consistency of target reporting along trips, we therefore investigated catch in relation to the declared target species, as well as the incidence of target switching during small pelagic purse seine trips.

2.3 Geospatial observations and fishing activities

Whether the activities of vessels and spotter planes could be inferred from their track data was explored utilising available geospatial datasets. This included position reports recorded by the Geospatial Position Reporting system (GPR) installed aboard vessels, and from the Automatic Dependent Surveillance–Broadcast (ABS-B) system implemented on New Zealand aircraft. GPR data were initially investigated for the vessels and spotter planes independently, before a combined investigation was performed. As ADS-B is not continuously broadcast by all aircraft, and data are not fully and freely available, only selected spotter plane trips from a discrete time period were available for this exploration. Investigations were performed by visualising spatial activity patterns, with minimal statistical or analytical techniques employed for this exploratory work.

3. RESULTS

3.1 Fishery characterisation

Catches in the purse seine fishery comprise five key target species or species groups: blue mackerel (EMA), jack mackerels (*Trachurus* spp.; JMA), kahawai (*Arripis trutta*; KAH), trevally (*Pseudocaranx georgianus*; TRE), and skipjack tuna (*Katsuwonus pelamis*; SKJ) (Figure 3). For this project we were interested in the JMA 1 Quota Management Area (QMA), illustrated in Figure 1; the QMAs for KAH 1 and KAH 2, TRE 1 and TRE 2, and EMA 1 and EMA 2 coincide with JMA 1. The SKJ 1 Fisheries Management Area (FMA) covers the entire exclusive economic zone of New Zealand and skipjack in New Zealand are considered to be a part of the Western and Central Pacific Ocean (WCPO) stock. Catches in our characterisation dataset represent only a part of the New Zealand skipjack fishery.

Purse seining is used to take the majority of the catch of the small pelagic fish stocks considered here, with the exceptions of KAH 1, KAH 2, TRE 1, and TRE 2. Kahawai is an important recreational species in the FMA1 area (KAH 1 and KAH 2) and is taken commercially by a mixture of methods, although purse seine is the dominant method (Fisheries New Zealand 2023). TRE 1 and TRE 2 are also taken by a mixture of methods, mainly by trawling in TRE 2, whereas in TRE 1 bottom trawl and purse seine dominate the catches (Fisheries New Zealand 2023). The characterisation data used in this document only contains data from the purse seine method. Reporting by purse seine vessels utilised the Catch Effort Landing Return (CELR) forms between 1990 and 2018, after which the Electronic Reporting System (ERS) was introduced (Figure 4).

The estimated catches of the key purse seine target species were largely taken in the Bay of Plenty (Statistical Areas 008, 009, 010) and off the east Northland coast (Statistical Areas 001, 002, 003, 004; Figure 5), where most catches from these areas consist of blue mackerel and jack mackerel species (Figure 6). In most years, jack mackerel is caught predominantly in the Bay of Plenty. An increase in blue mackerel catches in the Bay of Plenty was also observed in recent years (Figure 6). On the east Northland coast, blue mackerel, and a small amount of skipjack tuna, is typically caught but there have been lower catches of all species in this area in recent years. FMA 2 on the east coast, and FMA's 7, 8 and 9 on the west coast, contribute relatively small catches each year; kahawai has dominated catches on the east, and skipjack and trevally on the west.

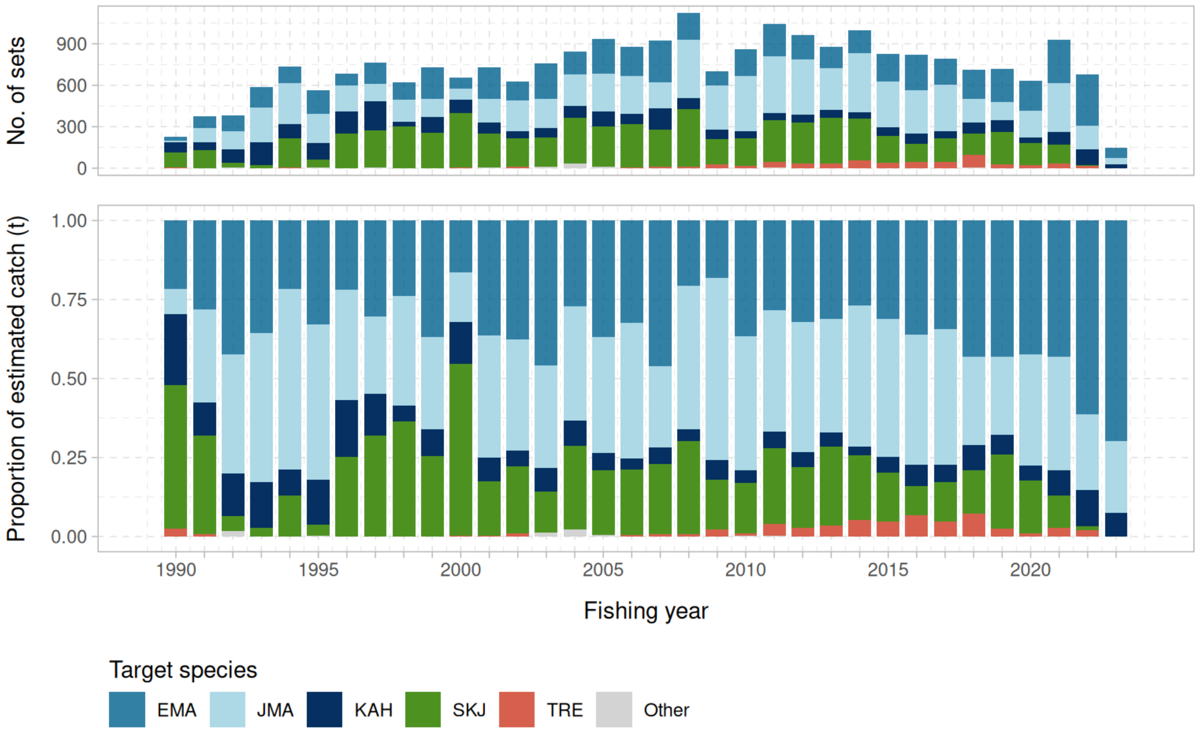

Figure 3: The number of sets (top) and proportion of estimated catch (bottom) by fishing year and species.

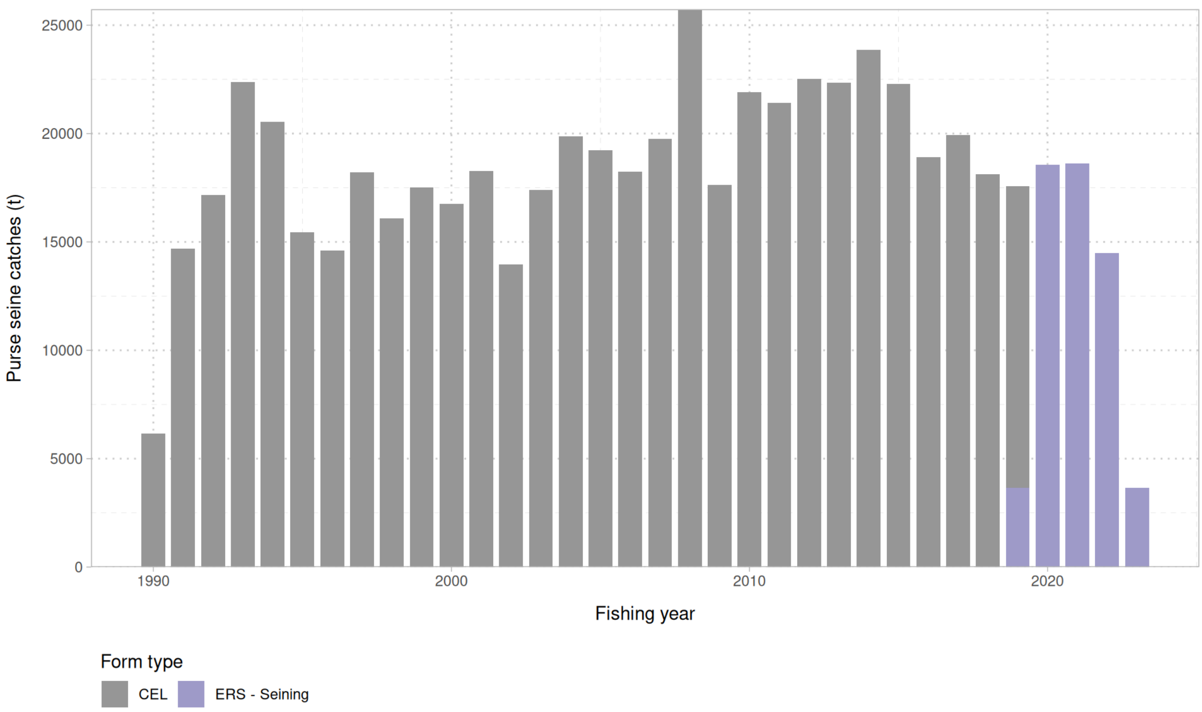

Figure 4: Annual catches (t, all species) by the purse seine fleet, with the reporting form used indicated by the bar colours.

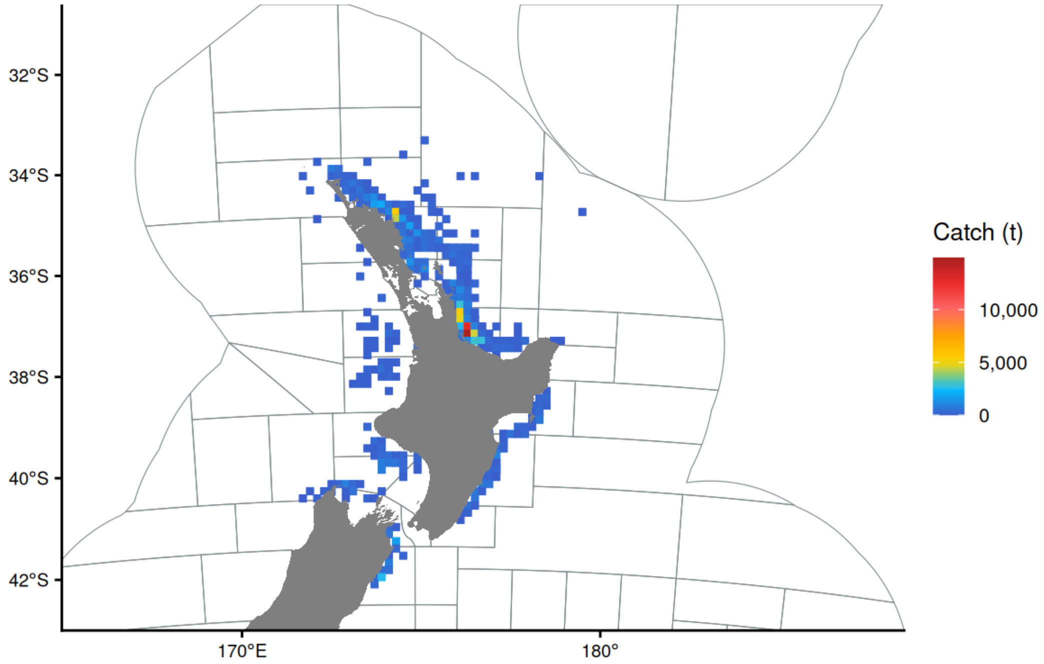

Figure 5: Catches (t, all species) for purse seine fishery events, 1990–2022. Data are plotted using a 16km grid, with the permission of the data providers; cells with a single event are omitted.

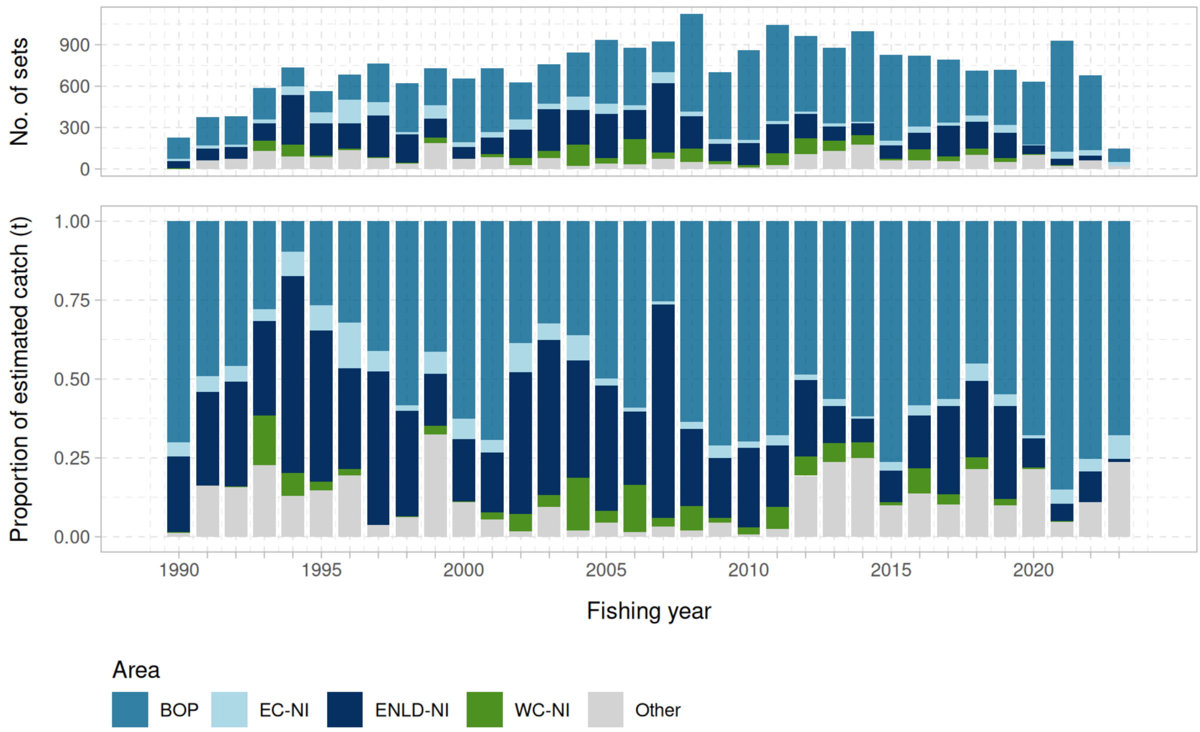

Figure 6: The number of sets (top) and proportion of estimated catch (bottom) by fishing year and area; areas are the Bay of Plenty (BoP), East Coast (EC-NI), East Northland (ENLD-NI), West Coast (WC-NI) of the North Island, while Other represents the remaining areas.

3.2 Purse seine fleet characterisation

In recent years the size of the purse seine fleet has varied between three and six vessels, peaking in the mid 2000s (Figure 7). The specifications of the vessels in the fishery are remarkably consistent, with vessels being of a similar size and power. Notable changes in the fleet include the continually increasing mean age of the vessels, and the upgrades in the vessels' sonar and storage technologies (Table A-1).

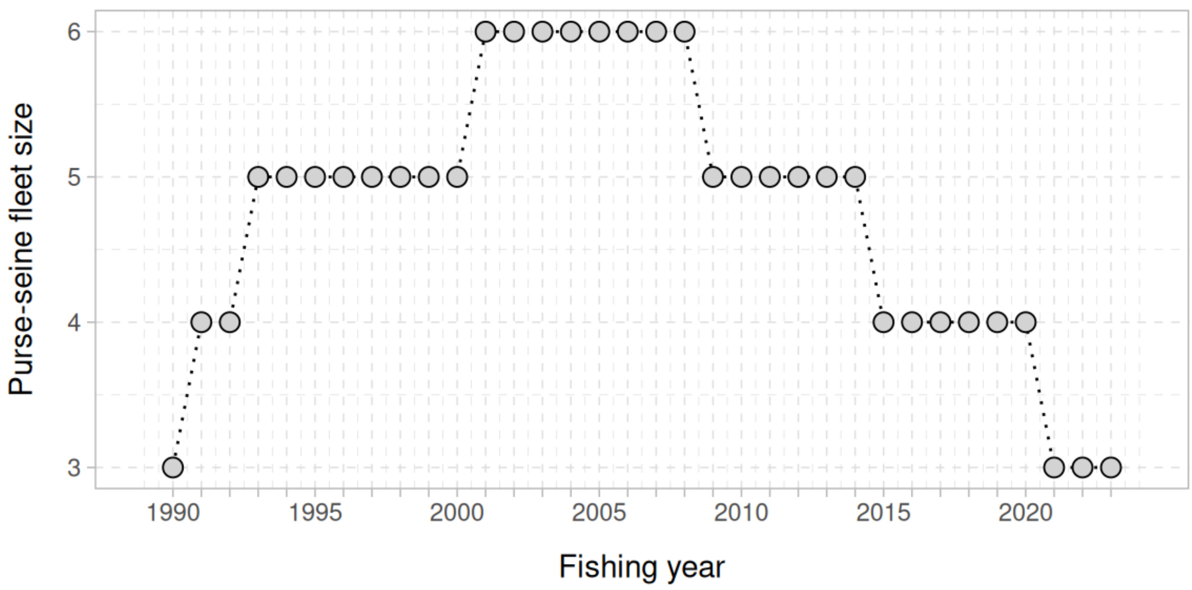

Figure 7: The size of the purse seine fleet size over time.

3.3 Catch rate indices

One of the most common fisheries metrics is catch per unit effort (CPUE). In many instances this catch rate is utilised as an index of relative abundance because it is assumed to be proportional to the density of fish in an area, which is then generalised to the entire fish population.

Catch rate in the small pelagics fishery was explored using two CPUE metrics, catch per set and catch per (vessel) day. Aggregate (all species) catches per set in the fishery showed a notable spike in the early 1990s and fluctuated with a slight increasing trend since the mid 1990s (Figure 8).

Catches per day also showed an initial peak in the early 1990s, followed by a general decline towards the mid 2000s, then returning to comparable levels in the 2020s (Figure 9). As these determinations of catch rate consider catches of a species complex, inter-annual differences in the proportions of species caught (Figure 3), and the implicit differences in catchability between these species, are likely to have influenced these patterns observed.

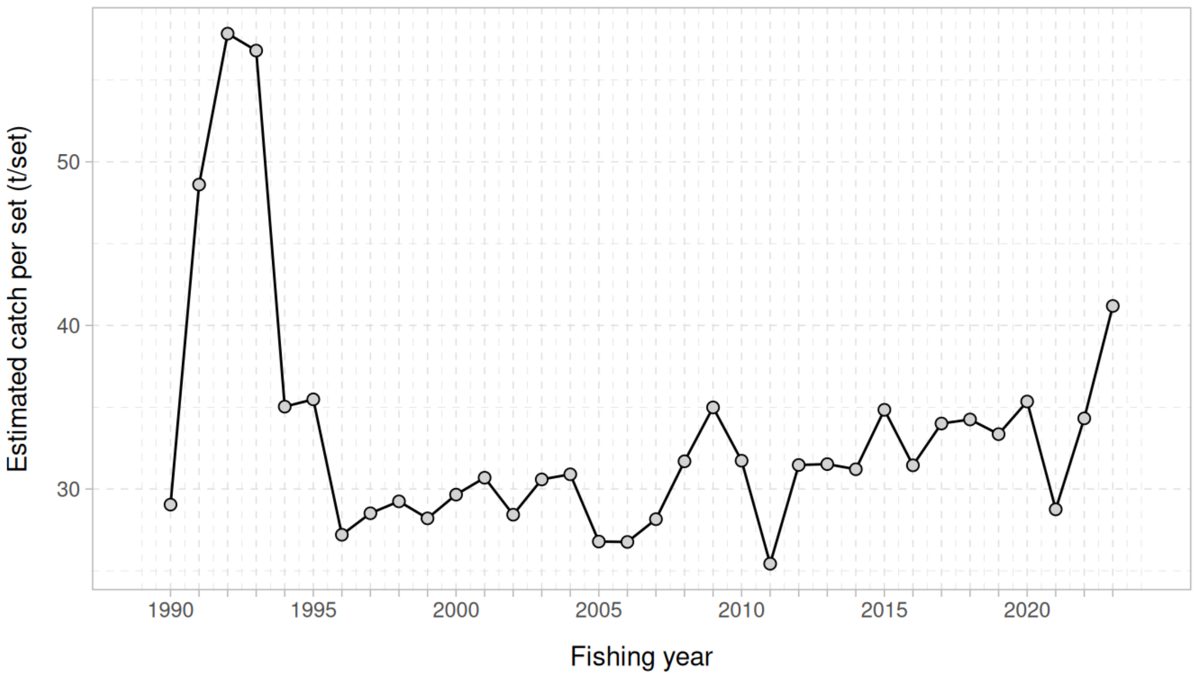

Figure 8: Catch per unit effort (CPUE) expressed as the estimated catch per set for key species targeted by the purse seine fishing method.

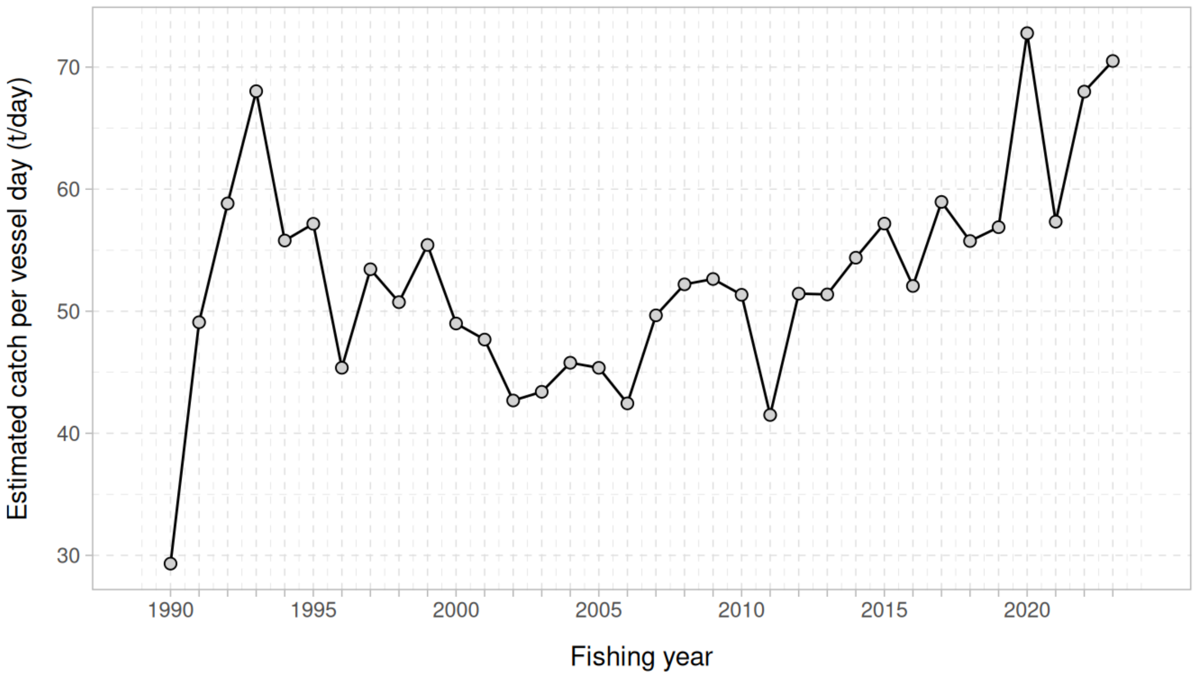

Figure 9: Catch per unit effort (CPUE) expressed as the estimated catch per vessel day for key species targeted by the purse seine fishing method.

Throughout the time period investigated herein, the success rates of fishing sets were found to vary by a factor of more than two (Figure 10). The overall trend showed low-moderate levels of between year fluctuation, with notable improvements in success rates observable at the beginning and end of the timeseries.

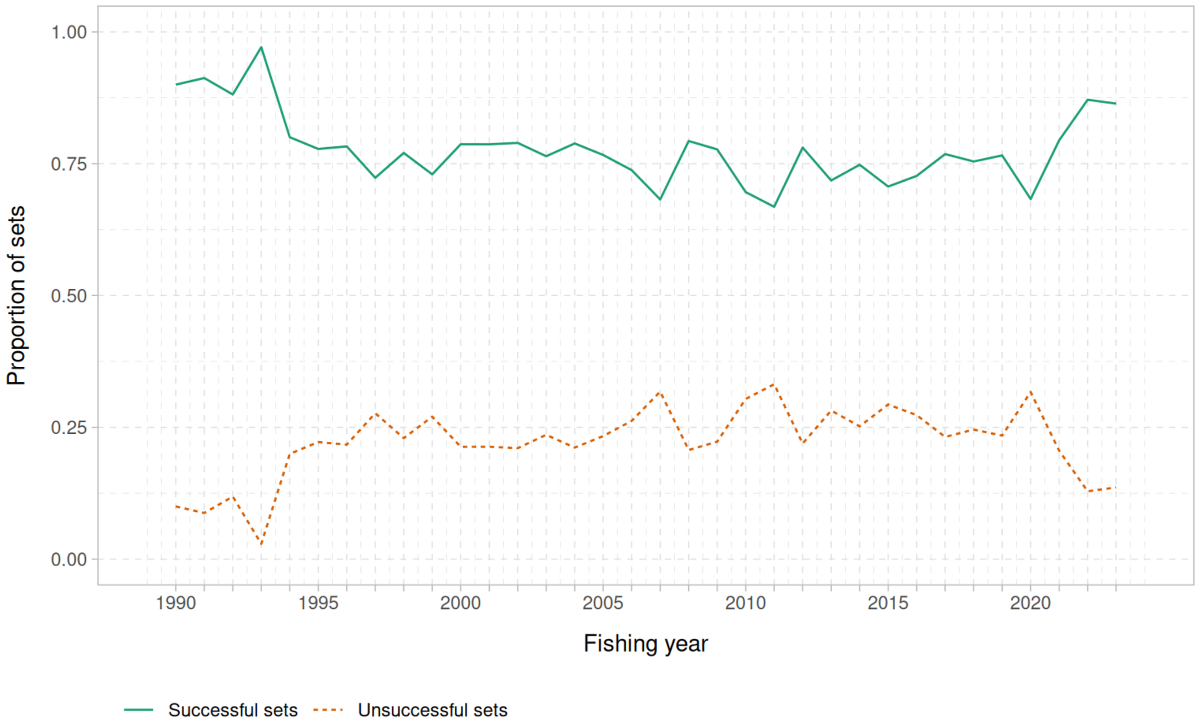

Figure 10: Success rates of purse seine fishing events, with unsuccessful catches identified as sets that landed 0 kg of fish, while successful catches refer to all other sets and landings.

3.4 Exploratory analysis

3.4.1 The use and influence of spotter planes in the fishery

Spotter plane call signs IDs have been recorded since at least the early 1990s (Figure 11). Up until 2016 there were at least 10 spotter IDs recorded within a fishing year, with a high of over 20 spotter IDs seen in 2007. There has been a general decrease in the number of spotter IDs recorded since, with around 5 or less used in recent years (Figure 11).

The significant drop in the number of spotter IDs compared to earlier years coincides with the reduction in the number of large 'super seine' vessels in the skipjack fishery over the same time period (Langley 2019) and, in more recent years, the consolidation of quota for small pelagic species under one fishing company.

Since the 2000s, a large proportion of the estimated catches have been associated with 4–5 spotter IDs, with more than 50% of sets recording these callsigns (Figure 12). There is a clear shift in the presence of particular spotter IDs, with the three most common callsigns occurring before 2005 differing from the three most commonly recorded in recent years. Whether changes in the size, or characteristics, of spotter planes have measurably changed over time was not specifically investigated. However, this could be achieved with the aid of publicly available registries of civil aircraft (e.g., flydw.org.uk).

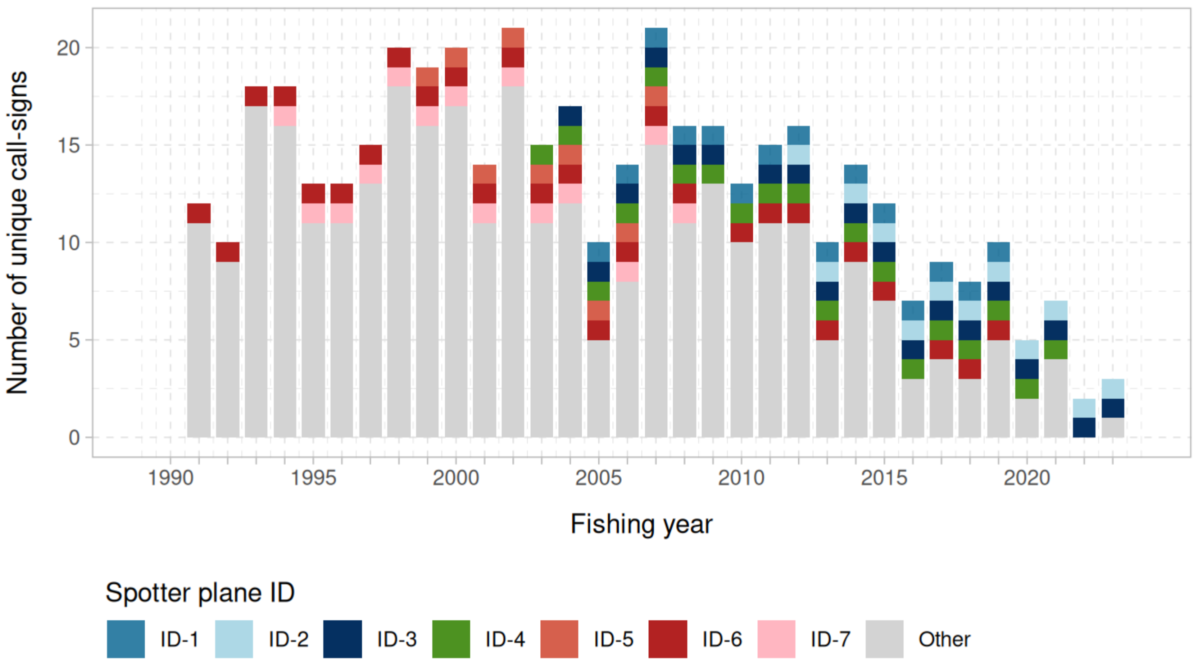

Figure 11: Spotter plane call sign IDs by fishing year and the top spotter IDs (colours). The top spotter IDs refers to the IDs ranked by the most associated estimated catches in the data and all remaining spotter IDs are grouped as Other. Includes only spotter IDs where a spotter plane was used, therefore excludes any sets where the spotter use category is considered as NAs or Numbers.

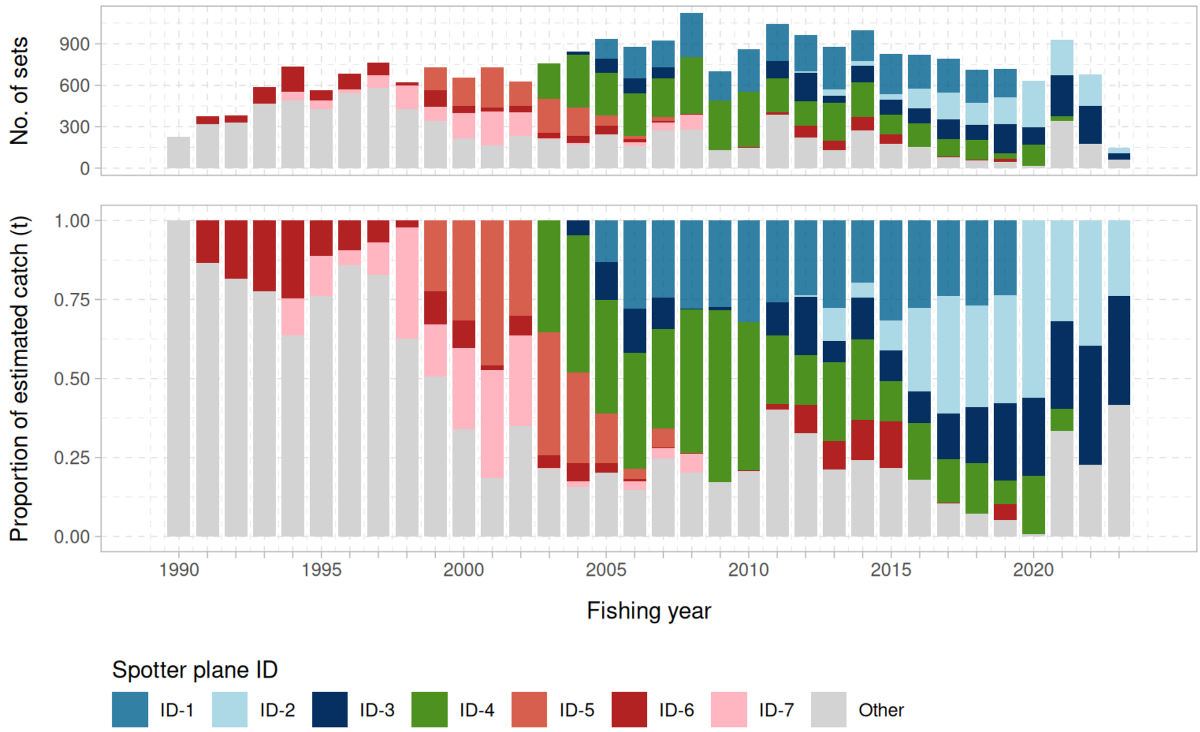

Figure 12: The number of sets (top) and proportion of estimated catch (bottom) by fishing year and top spotter IDs (colours). The top spotter IDs refers to the IDs ranked by the most associated estimated catches in the data and all remaining spotter IDs are grouped as Other.

In most years purse seine sets were accompanied by the use of spotter planes but, in recent years, a notable increase in sets without use of a spotter plane is evident (Figure 13). As a potential result of the electronic reporting system for seining, there are fewer (or no) cases where the spotter ID was NA or consisted of Numbers, suggesting an improvement in how spotter IDs are recorded.

The purse seine catch primarily occurs in the Bay of Plenty and off East Northland, with most of the sets without spotter plane use occurring in the Bay of Plenty (Figure A-4). A marked change in non-spotter plane use is apparent since 2021, with non-spotter plane use comprising up to 25% of the estimated catches (Figure 12). Fishing in the East Northland area is more frequently associated with spotter plane use, also noting the recent reduction in purse seine sets in the region since around 2020 (Figure 6). In relation to the key target species across all areas, blue mackerel and jack mackerel dominated catches and relate mostly to spotter plane use. Close to 50% of catches of jack mackerel are taken without spotter plane use and around 25% of blue mackerel catches (Figure A-5).

Catch rates, defined as tonnes per day, were relatively consistent, with a general increase over the years when using a spotter plane (Figure 14). In comparison to the non-spotter plane use data, there is high variability across time driven by the sparsity of data. The Bay of Plenty, as the region with the most fishing activity, demonstrated similar trends with a more noticeable increase in catch rates using spotter planes (Figure 14).

At the target species level, with particular focus on blue mackerel and jack mackerels in recent years, it is apparent that catch rates of blue mackerel appear to be more influenced by spotter plane use. This contrasts with jack mackerels where catch rates appear not to be influenced by spotter use (Figure 14). Despite the historical lack of non-spotter plane use data, the shift towards reduced use of spotter planes and on-going reporting will provide a better understanding of how spotter planes influence purse seine catch rates.

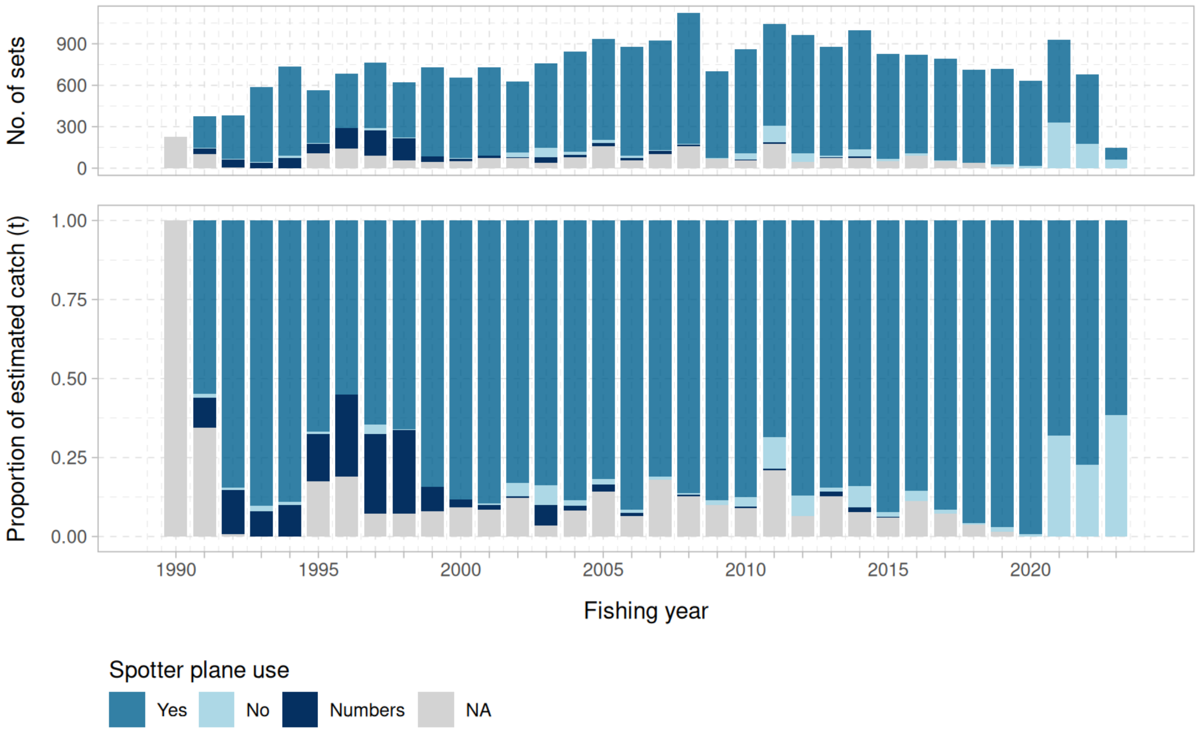

Figure 13: The number of sets (top) and proportion of estimated catch (bottom) by fishing year and spotter plane use (colours). Includes spotter plane use categories, NAs and Numbers.

Figure 14: Raw CPUE (t/day) by species and year, with and without spotter plane use (coloured lines) for key species, across all areas (left) and limited to the Bay of Plenty (BOP, right). The plotted circle areas are proportional to the number of sets.

3.4.2 Exploration of target switching

Most trips in the fishery report targeting a single species, with a number of trips reporting two target species (Figure 15). Rarely were more than two target species reported. While this pattern was consistent across vessels, there was some variability among years in the number of target species reported, with more trips reporting two or more target species in recent years.

The declared target was almost exclusively caught on relevant sets (Figure 16), with highly consistent patterns across all vessels. Sets targeting kahawai were associated with a higher proportion of mixed catches than other target species, with jack and blue mackerels typically representing the additional catch. Further analysis of kahawai catches identify that additional ‘mix’ species are a near uniform feature of sets that target the species throughout the year, and across all vessels. A similar pattern is identifiable for jack mackerels, whereby additional species, including blue mackerel and kahawai, present a minor but consistent component of catch mixes.

Figure 15: The absolute (left) and relative (right) number of target species recorded in all fishing trips for each fishing vessel over time. The number of target species in a trip is differentiated by colour according to the legend.

Figure 16: The prevalence of other species caught in sets for each target species for all fishing vessels.

3.4.3 The influence of hold capacity on catch-per-set

Typical purse seine trips performed fewer than 10 sets, with a majority (75%) of trips associated with six or fewer sets (Figures 17).

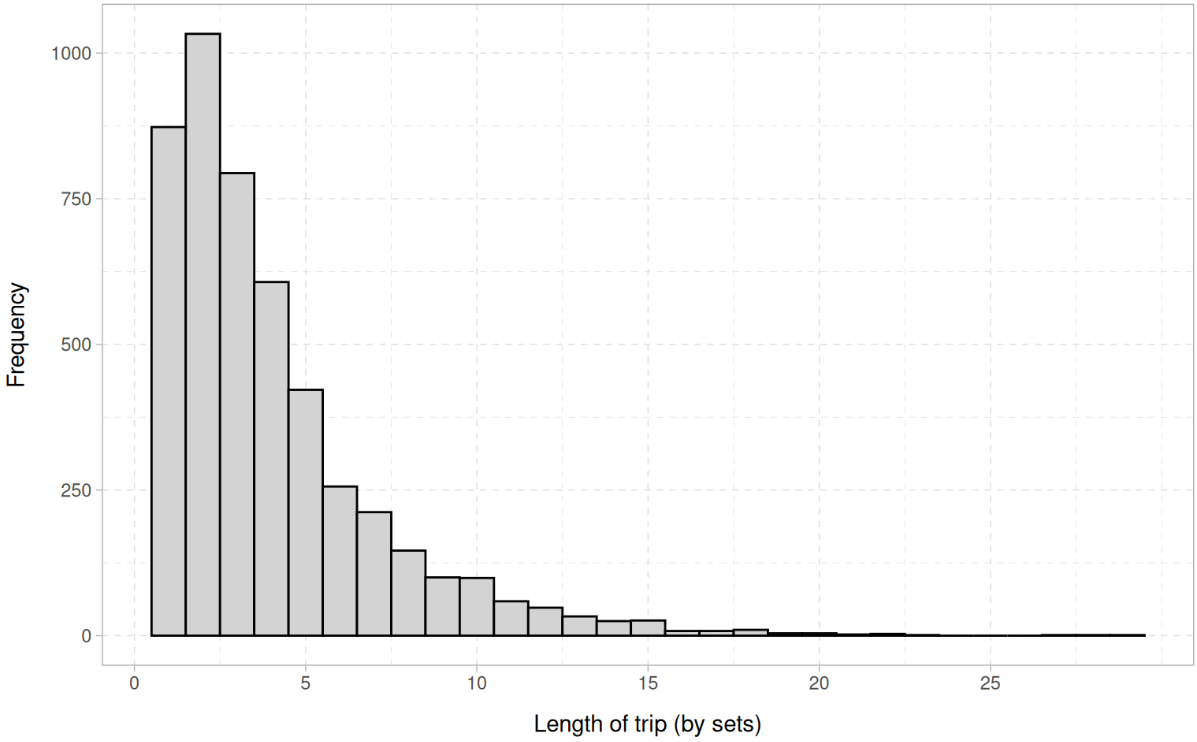

Figure 17: Distribution of the number of sets made on small pelagic fishery trips.

Initial indications suggest that catches decline with each successive set for purse seine vessels (Figure 18). However, the distribution of catch per set interacts with the number of sets on a trip such that, for a trip of given length, there appears to be no discernible influence of hold-capacity on catch-per-set (Figure A-8). All cumulative catch plots show a near linear trend towards hold capacity along a trip, rather than a saturating trend that would indicate targeting of smaller schools later in a trip to accommodate limited hold-capacity. Typically, the volumes of schools caught are much smaller than the volume available in the vessels hold. However, the presence of outliers and broad confidence intervals, also indicate that catches of single large schools that are capable of filling all (or a large proportion) of the vessel’s holds do occur, on occasion (Figures A-8, 19).

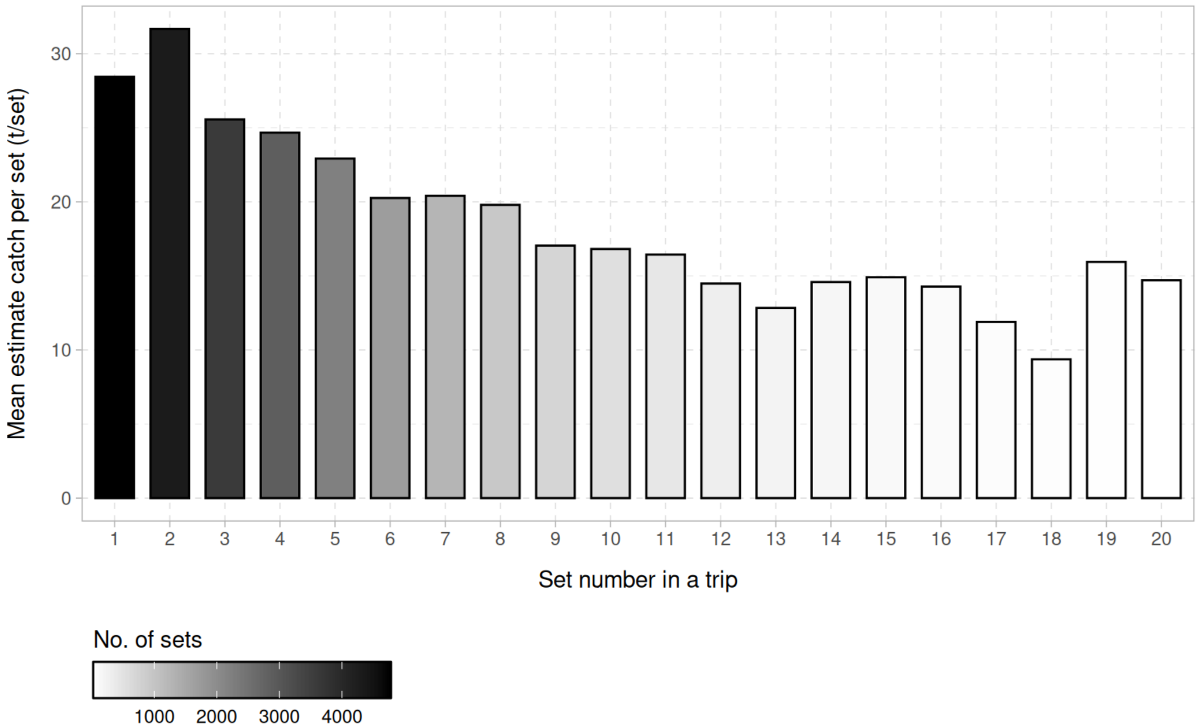

Figure 18: Mean estimated catch and number of sets (grey-scale) by set number for small pelagic purse seine trips

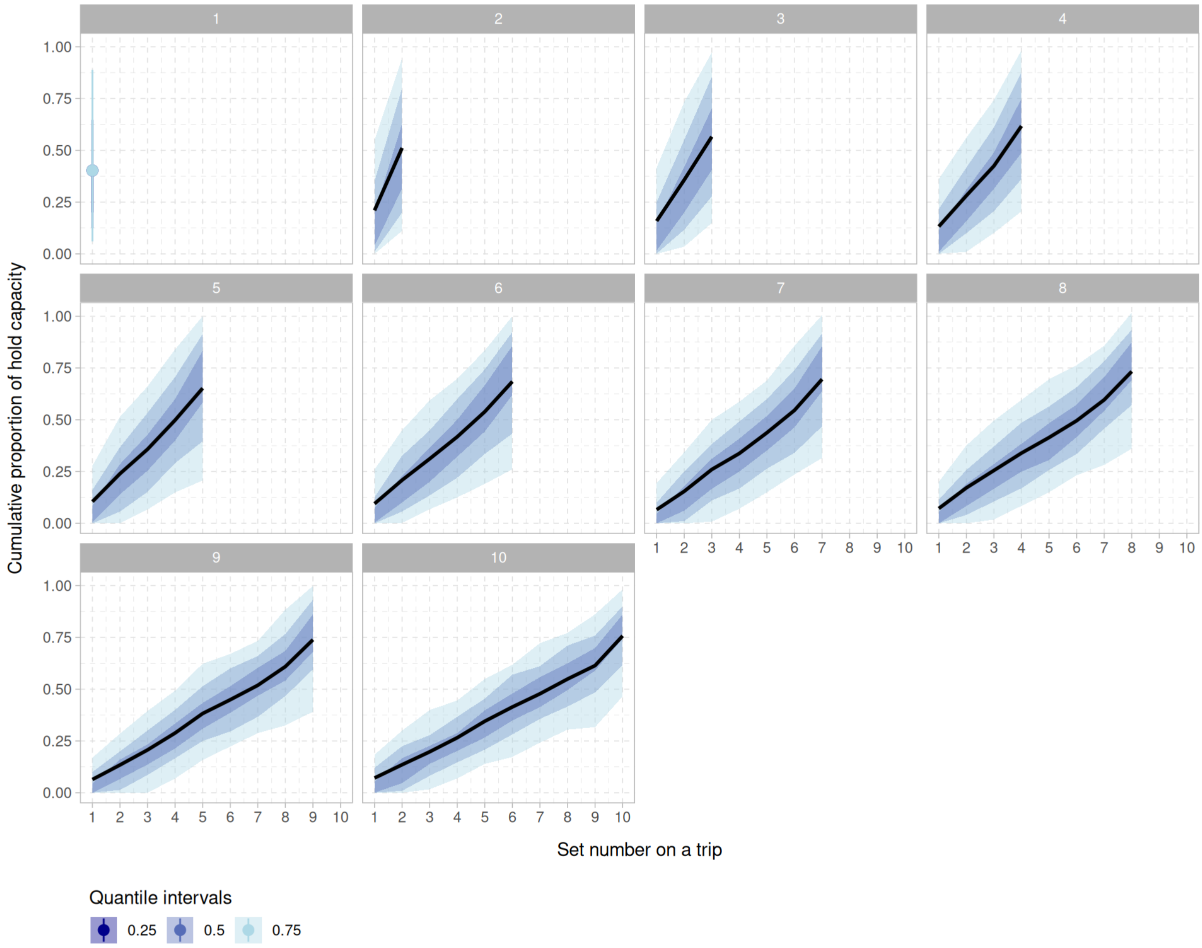

Figure 19: Cumulative proportion of catch relative to vessel fish hold capacity, shown by total number of sets on a trip, for trips that had 10 or fewer sets in a trip (black line is the mean across vessels and years, blue shades show inter-quartile, 75% and 90% intervals).

3.5 Vessel track analysis

Vessel track data have the potential to provide information on vessel searching activity. These data are currently collected from commercial fishing vessels in New Zealand under the Fisheries (Geospatial Position Reporting) Regulations 2017,[5] and referred to as GPR data. International studies, and older New Zealand studies, refer to Vessel Monitoring System (VMS) data, which are essentially equivalent to GPR data. In both cases, a unit on the vessel is responsible for sending position reports, usually via satellite. Automatic Identification System (AIS) data, which are broadcast from vessels by VHF radio but can be picked up by satellites, provide similar information but with less certainty of continuous tracks.

A number of studies have categorised track data from purse seine vessels. These are reviewed in Appendix B. In general, these studies aimed to classify vessel activity into a limited number of activities, and often focus on the identification of fishing activity in the first instance. Bertrand et al. (2008) and Joo et al. (2011) aimed to classify data from the Peruvian anchovy fishery into either fishing set or non-fishing categories, although a later study separated the non-fishing activity into 'searching' and 'cruising' classes (Joo et al. 2015). The same three states were also used in a study of purse seine fishing in the Indian Ocean (Bez et al. 2011). In a study of the Bay of Biscay small pelagic trawl fishery Vermard et al. (2010) also assigned VMS data to three states: Steaming, Fishing and Stopping.

Zhang et al. (2021) recognised that purse seine vessel activity could be categorised into at least four states, including transiting, searching for fish, fishing operations, and transshipment. However, in their analysis of AIS data from the WCPFC tuna purse seine fleet they focused on separating fishing activity from 'high-speed transiting'.

In the case of the New Zealand purse seine fishery, fishing activity is known, because it is reported in the catch and effort data. The main interest in analyses of GPR data is in categorising vessel activity in the non-fishing periods. In particular, it is of interest to separate periods spent searching for fish from periods where the vessel is simply transiting.

The studies reviewed (Appendix B) all used vessel speed as a key variable for categorising vessel activity, with several also considering turning behaviour, defined as the change in direction between consecutive position reports. The highest frequency of position data in the reviewed studies was hourly; the 10 min interval between position reports available for the New Zealand purse seine vessels under the GPR regime has the potential to allow a finer scale classification of vessel activities.

Here we investigate features of vessel tracks for some illustrative trips in August 2022; this period was selected because of the concurrent availability of spotter plane track data (considered below).

3.5.1 Interpretation of GPR data

The current GPR requirements[6] allow for either a fixed or moderated frequency of position reporting. The inshore purse seine vessels considered here all use fixed-frequency reporting that provides position reports at a ten-minute interval (except when the vessel is in port, when the frequency is reduced).

In the examples below, we extracted GPR data for vessels during the period of a fishing trip, as defined by the trip start and end times from the Electronic Reporting (ER) data. The vessel was considered to be at sea whenever the interval between position reports was between 1 and 700 seconds, and for the first position report received on a trip. In addition to a time and position, the GPR data include vessel speed over ground and course over ground. We derived one further variable: the minimum turning angle (to port or starboard) between the current course and the course reported in the previous position report.

[5] https://legislation.govt.nz/regulation/public/2017/0155/latest/DLM7330540.html
[6] https://www.mpi.govt.nz/dmsdocument/37985-Fisheries-Geospatial-Position-Reporting-Devices-Circular-2019

Position reports were labelled as ‘Fishing’ if they were reported during a fishing event reported in the ER data. Non-fishing positions were labelled as ‘Stationary’ if the speed over ground was less than or equal to 0.1 knots.

3.5.2 Exploration of GPR data from a trip

GPR data from a purse seine fishing trip in August 2022 are illustrated in Figure 20. The four sets undertaken on the trip are apparent as periods when the vessel was moving slowly, and it is clear that the vessel anchored on two occasions to the south of Mayor Island/Tuhua.

During fishing events the vessel speed was always less than 2.5 kn, and usually less than 1 kn, with a wide range of changes in course between position reports (Figure 21). When classified as stationary, the vessel heading did not typically change between position reports, but occasionally reversed. In non-fishing periods, the distribution of vessel speed was bimodal, with modes at near-stationary speeds and above 9 kn, but some reports across the range of intermediate speeds. Turning angles for non-fishing periods showed a large mode at small turn angles, with other reports showing a range of turning angle and evidence of modes at 90° and 180°. The faster vessel speeds are usually associated with smaller turning angles (Figure 22).

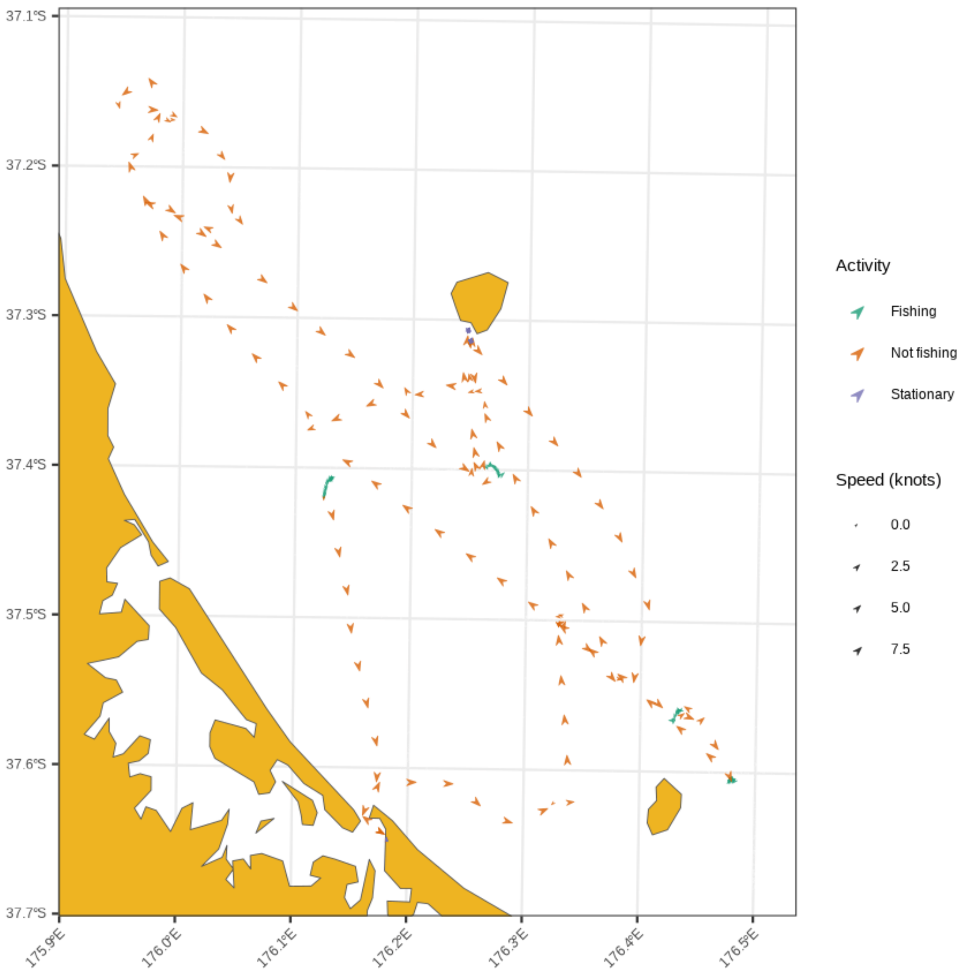

Figure 20: GPR data showing vessel speed and course for a purse seine fishing trip in August 2022. Position reports were classified as Fishing if they were reported during a fishing event, and Stationary if the vessel speed was less than or equal to 0.1 knots.

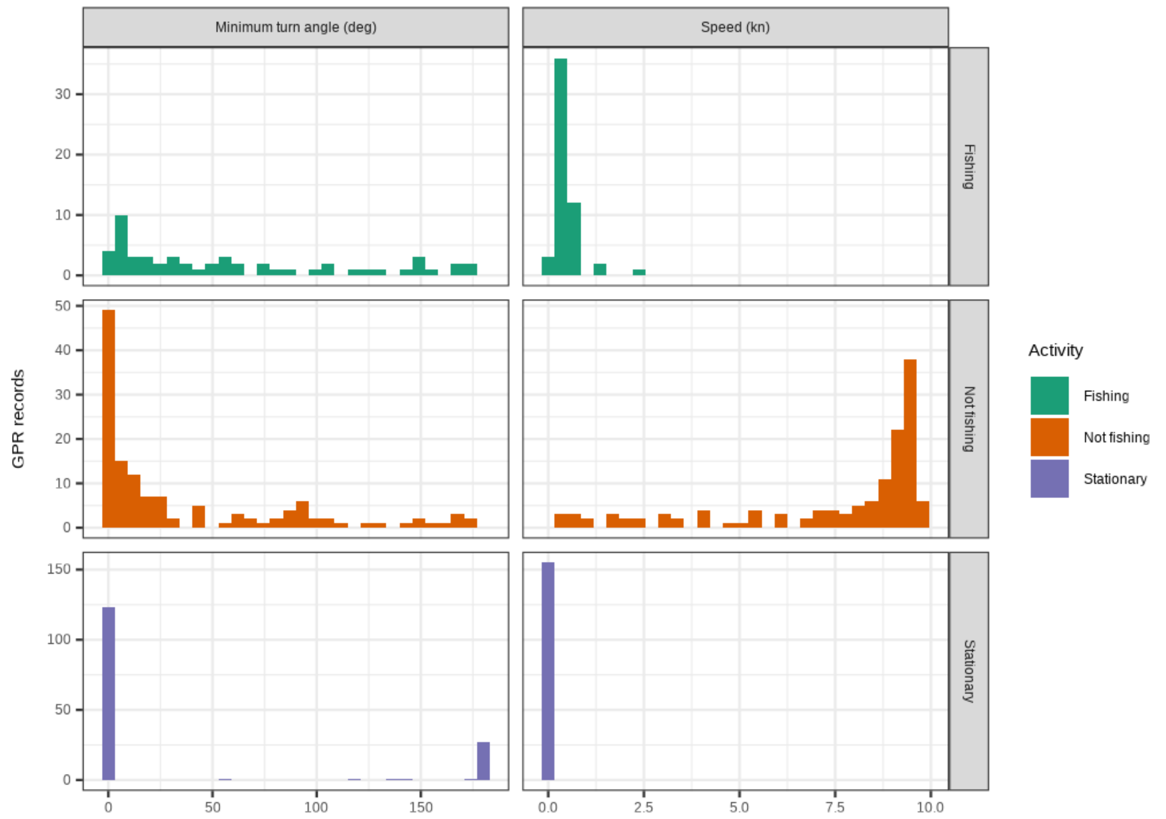

Figure 21: Histograms of vessel speed (knots) and minimum turn angle (degrees) since the previous report, for position reports during fishing events (Fishing), with a speed of $\leq$ 0.1 kn (Stationary), or otherwise (Not fishing).

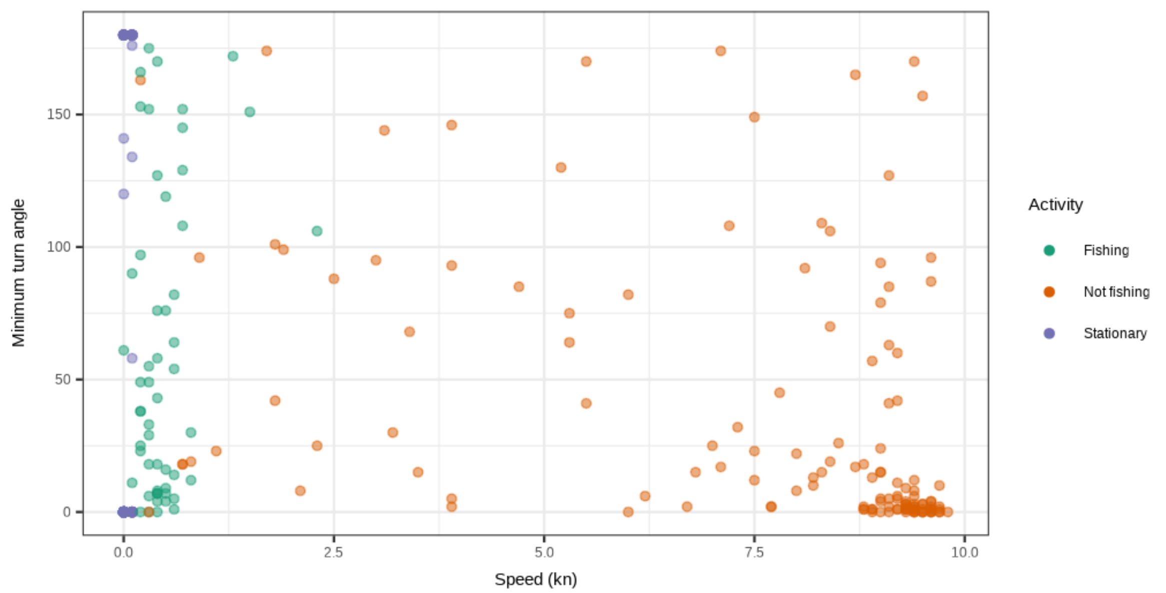

Figure 22: The relationship between vessel speed (knots) and minimum turn angle (degrees) since the previous report, for position reports during fishing events (Fishing), with a speed of $\leq$ 0.1 kn (Stationary), or otherwise (Not fishing).

An initial classification of the non-fishing (and non-stationary) position reports defined the vessel activity as 'Transiting' if the speed was greater than 5 kn and the minimum turning angle between positions was less than 10°, and 'Searching' otherwise. This simple classification results in reasonably consistent periods being defined as Transiting vs. Searching (Figure 23). It is apparent that the activity classification could be improved by taking account of port entry and exit periods, where larger course changes are inevitable, and by considering the classification assigned to previous and subsequent position reports.

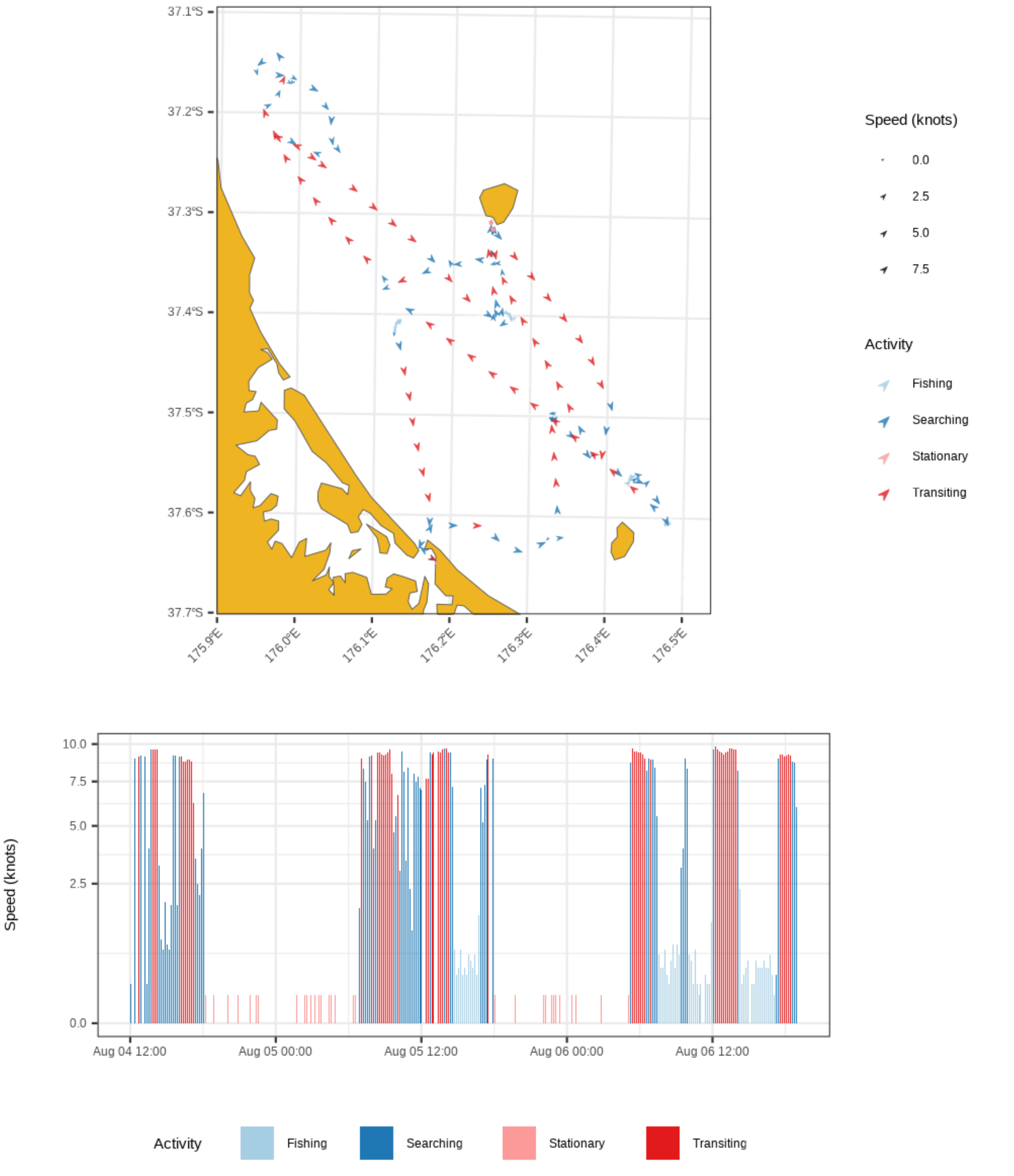

Figure 23: GPR data showing vessel speed and course for a purse seine fishing trip in August 2022. Position reports were classified as Fishing if they were reported during a fishing event, Stationary if the vessel speed was less than or equal to 0.1 knots, Transiting if vessel speed was above 5 kn with a minimum turn angle of less than 10°, and Searching otherwise.

3.5.3 Additional example trips

The same approach to classifying the non-fishing (and non-stationary) position reports is applied to two further trips in Figure 24 and Figure 25. The classification again results in reasonably consistent periods of Transiting and Searching activity but again suggests that the classification could be improved by assuming autocorrelation in activity. Fishing events are highlighted, with symbols indicating whether a spotter plane assisted in the set.

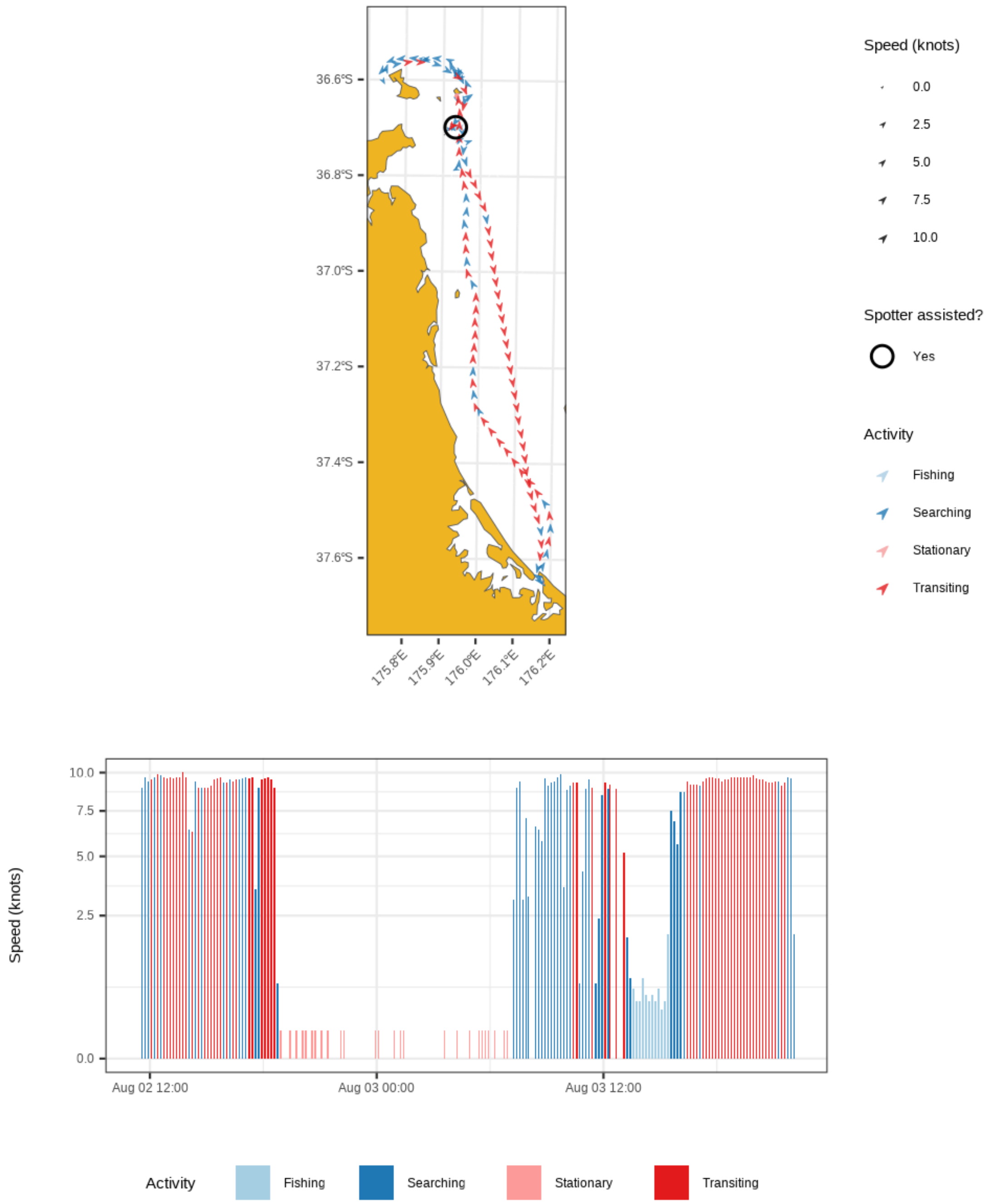

Figure 24: GPR data showing vessel speed and course for a purse seine fishing trip in August 2022, by the same vessel as illustrated in Figure 23. Position reports were classified as Fishing if they were reported during a fishing event, Stationary if the vessel speed was less than or equal to 0.1 knots, Transiting if vessel speed was above 5 kn with a minimum turn angle of less than 10°, and Searching otherwise.

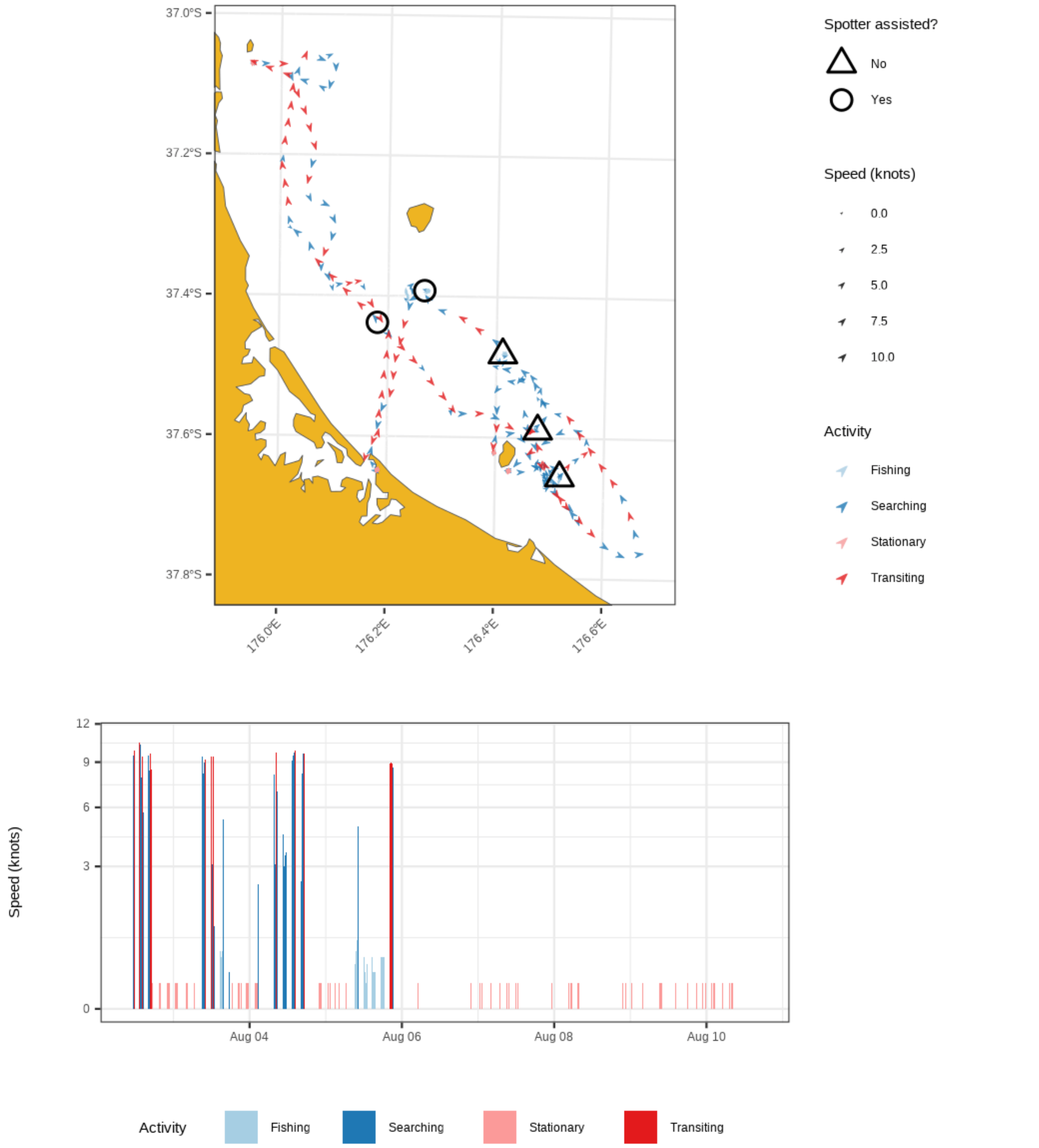

Figure 25: GPR data showing vessel speed and course for a purse seine fishing trip in August 2022, by a different vessel than illustrated in Figure 23 and Figure 24. Position reports were classified as Fishing if they were reported during a fishing event, Stationary if the vessel speed was less than or equal to 0.1 knots, Transiting if vessel speed was above 5 kn with a minimum turn angle of less than 10°, and Searching otherwise.

3.6 Spotter plane flight paths

While the exploratory analysis of GPR data suggests that it should be possible to partition vessel activity between periods spent searching for fish and periods when the vessel is simply transiting the area, the use of spotter planes to assist in some sets highlights that the vessel activity only represents a part of the search effort associated with the catch from a particular trip.

In addition to the recording of whether a spotter plane assisted with a set as part of data from a fishing event, two other sources of information on spotter plane activity are potentially available. Aircraft track data information are available from the Automatic Dependent Surveillance-Broadcast (ADS-B) system, where aircraft broadcast their position similarly to the AIS system employed on vessels, with additional positions estimated by multilateration (MLAT) calculations when an aircraft is detected by multiple ground stations.

Spotter plane pilots in the inshore purse seine fishery also complete data forms on the flights undertaken and schools sighted, in the same format as data previously compiled in the Fisheries New Zealand `aer_sight` database (Fisher & Taylor 2015).

Not all spotter planes used in the purse seine fishery broadcast ADS-B data. However, in early August 2022 only one spotter plane was used in the inshore purse seine fishery (Figure 26), and both flight track data and the pilot's sightings data for this period were obtained. Flight tracks, during the period of the same three illustrative trips considered above, demonstrate that the spotter planes can provide extensive search effort over the same area in which the vessels operated, in addition to specific assistance during the setting operations (Figure 27).

Observed fish schools (limited here to single species schools) recorded by the spotter plane pilots, together with the pilot's estimate of school biomass, are illustrated for the three example trips in Figure 28. While there are caveats around the current aerial sightings data that have limited their use in quantitative analyses, these plots serve to illustrate that the catch data from purse seine operations only provide a partial picture of the schools available in the area, with the spotter planes often identifying schools that are not targeted. Conversely, some schools fished are not recorded in the spotter plane observations.

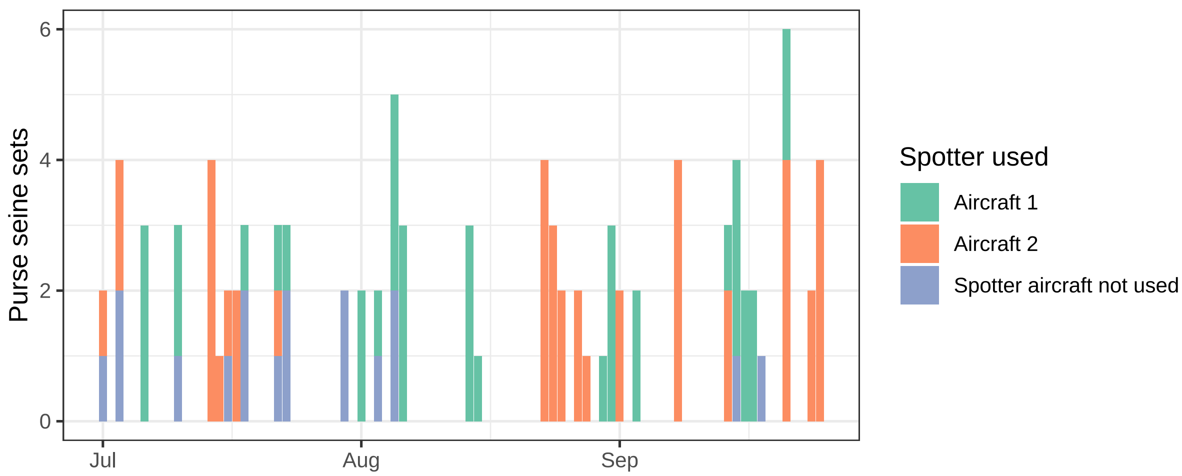

Figure 26: Spotter plane use on purse seine sets from July to September 2022.

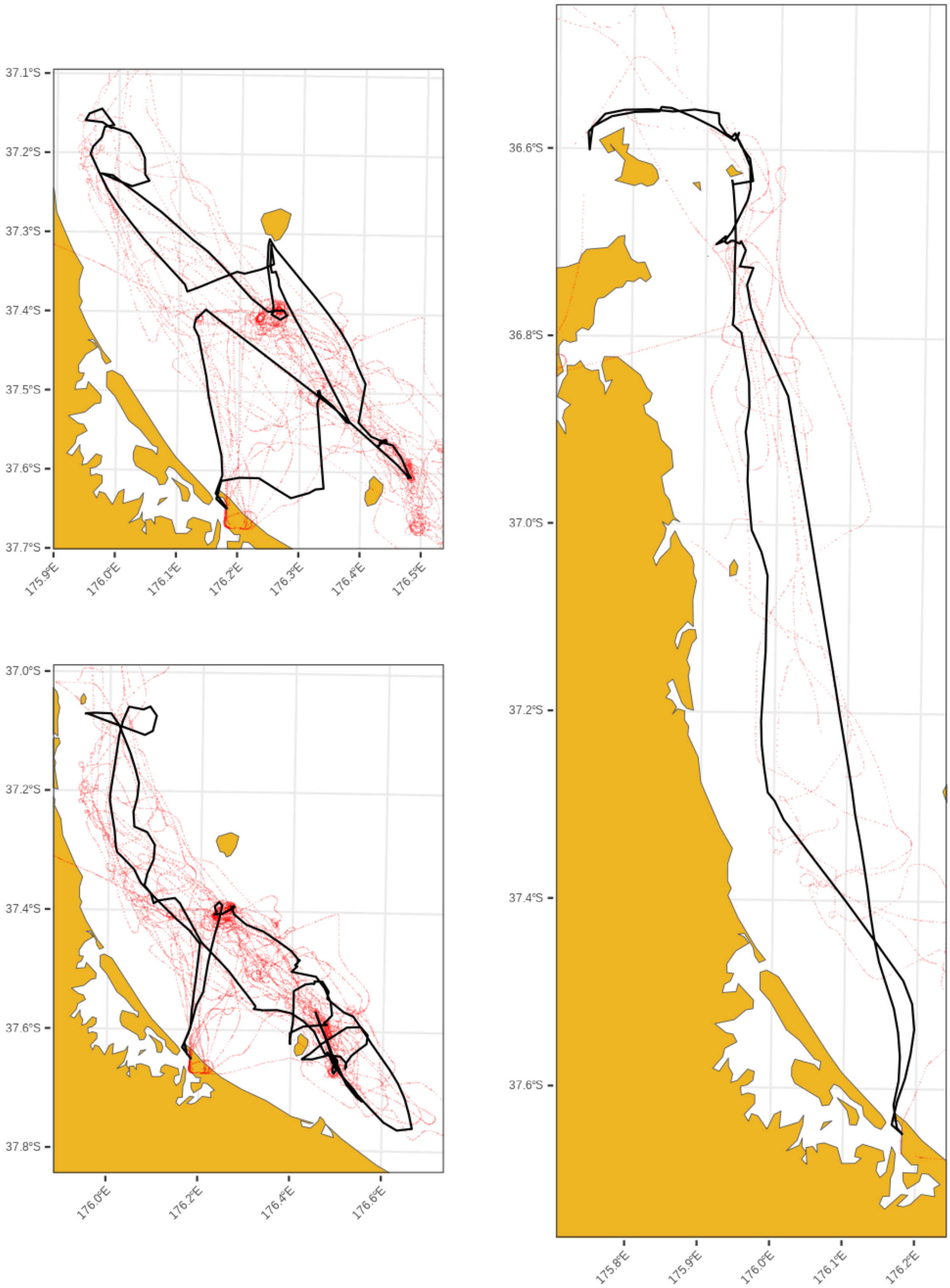

Figure 27: Black line: purse seine vessel tracks for three trips in August 2022; red points: spotter plane locations during the period of the fishing trips. Trip start and end from trip reports in the Fisheries New Zealand Electronic Reporting data.

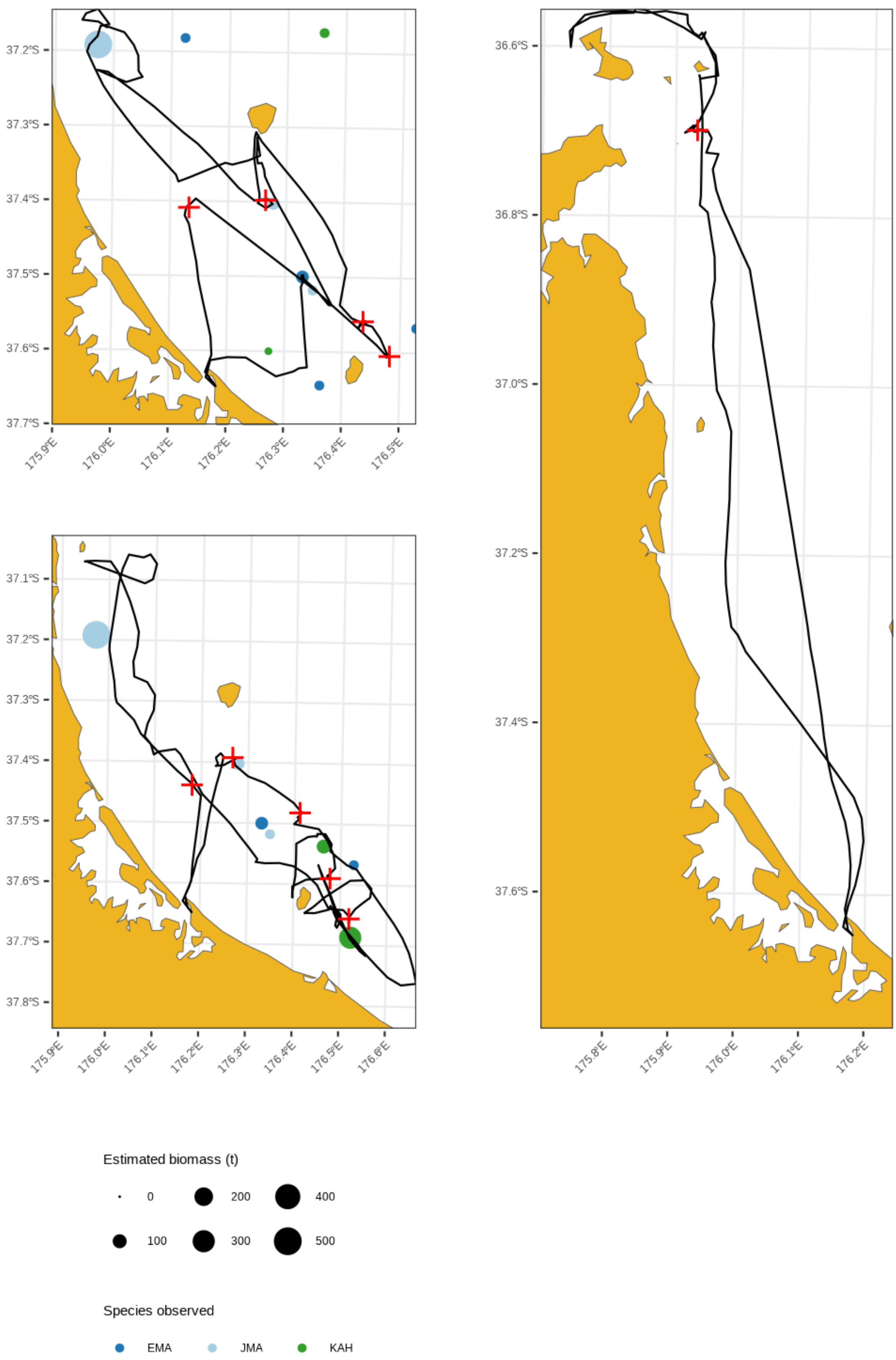

Figure 28: Black line: purse seine vessel tracks for three trips in August 2022; red crosses: purse seine set positions; coloured circles: spotter plane school observations during the period of the fishing trips. Trip start and end from trip reports in the Fisheries New Zealand Electronic Reporting data.

The combination of data from spotter planes that identify the search coverage, patterns, durations and observations/detections identify opportunity to better characterise the search efforts of these aircraft. Notable in the visualisations are the areas of concentrated flying (that generate a circular pattern) in locations they assisted the vessel setting upon, and catching fish. This flight pattern differs to that of the spotter plane when exploring areas away from vessel tracks, which presumably indicate searching activity (Figure 27). Therefore, based on similar classification metrics applied to vessel activity in the previous section, different activity states of spotter planes could readily be inferred. In addition, knowledge of the observations recorded by spotter pilots (and presumably relayed to the vessels) that result in activity changes of the vessels (i.e. from searching to transiting) could better inform interpretations of vessel activity and overall searching behaviours.

4. DISCUSSION

4.1 Stable catches with evidence of operational change

The most notable feature of the current dataset and characterisation is the relative stability of catches in the fishery since the early 2000s, and the respective introduction of each species into the quota management system. These stable catches have occurred despite the reduction in the number of vessels and spotter planes in the fishery. Like catches, Total Allowable Commercial Catch (TACC) limits have also remained stable. This is due to a combination of successful management settings (e.g., KAH 1 and TRE 1) and the difficulty in determining stock estimates of the highly mobile and large populations of mackerel species (e.g., JMA 1 and EMA 1).

Shifts in the geographical spread of catches are noticeable in the dataset. Catches of blue mackerel off East Northland have shown a gradual decline, matched by a gradual increase in catches from the Bay of Plenty region from the 2000s. This shift has been particularly marked since 2020 with catches of blue mackerel primarily coming from the Bay of Plenty region. Whether this represents a southern range shift of blue mackerel stocks is a valid question worth further investigation.

Jack mackerel show a concentration in the geographical spread of catches, with a relative absence of catches in the East Coast North Island and East Northland regions in recent decades. This pattern can be explained by the shift in the storage media used for jack mackerel on board the vessels. The transition from brine storage media to refrigerated seawater (RSW) during 2010–2015 has reduced the storage life of fish on board the vessel. In consequence, once jack mackerel are caught they will be scheduled for unloading at their home port within 24–48 hours, acting to measurably limit the fishable range of these vessels.

The transition from the CELR reporting framework to the current ERS, and the recent consolidation of the fishery to a single operator, are two most recent features, both having occurred in 2019. While the shift to the ERS has not resulted in any major changes in the catch and effort data, it has assisted with removing erroneous entries, especially those associated with the spotter plane callsign. Industry consolidation has led to further reductions in the number of spotter planes used in the fishery, and a relative decrease in catches of jack mackerels. It is considered that these reductions in jack mackerel catches are associated with the lower processing efficiencies of this species compared to others in the fishery. All catches of the small pelagics fishery are now processed through a single factory rather than the two factories in operation prior to 2019; this has placed greater demands on the remaining processing infrastructure. On water observations have also described changes in jack mackerel behaviour in recent years, with a lower proportion of fish showing surface schooling behaviours and sonars being increasingly used when conducting sets. This is arguably reflected by the relative reduction in spotter plane use in the Bay of Plenty in recent years and emerging differences in catch rates with and without spotter plane assistance, when targeting jack mackerels. The influence of the apparent increase in catches of blue mackerel on the jack mackerel stocks in the Bay of Plenty is also uncertain and raises the possibility that interspecies competition may now be occurring.

4.2 Catch rates and catchability in the small pelagics fishery

The current investigation demonstrates that a successful characterisation of the SPF fishery can be performed utilizing existing statutory datasets. However, indices of catch rates (CPUE) in the fishery should be considered uninformative of the abundance of the key SPF species. Firstly, this is because the current analysis investigates all key target SPF fisheries in combination rather than independently and does not consider differences in catchability between the different species or the differences in the relative contribution of each species to the aggregated annual catch rate. Secondly, catch rates in the fishery are simplistically defined by the catch achieved in a set or day (i.e., catch per day or catch per set) and poorly reflect the activity undertaken prior to the capture of fish.

Several of the concerns previously, and rightly, raised about the use of CPUE as an index of abundance for pelagic species in the New Zealand fishery have been investigated in the current study. These can be broadly grouped into the following factors: target switching in a mixed species fishery, the visual methods of fish detection and targeting (including selectivity biases associated with size selection of individuals, and schools), vessel constraints, the behavioural dynamics of the species (including their environmental responses, and spatial/vertical mobility), and the proportionality of CPUE and population abundance.

As the SPF is a mixed species fishery, the possibility that the fleet is able to switch targets independent of the abundance of a given species would influence any determination of CPUE. The present investigation identified that the phenomenon of target switching can be readily identified from the available catch data. More than half of voyages in the fleet only target a single species during voyages, and more than 90% of voyages target less than two species. Catches typically primarily comprise the declared target species, with fewer than 20% of catch events containing other key target species from the fishery. The observation that low levels of mixed catch in the fishery occur throughout the year in the KAH and JMA fishery suggest that targeting of mixed schools is a typical occurrence. The inability to record more than one target species in the current reporting system for any catch event is likely to have masked the fact that mixed catches can be an intended, and not incidental, feature of the fishery, and further suggest that mixed species schooling is a common phenomenon for these species. As target switching and mixed catches can be readily identified, there is potential to account for these phenomena in CPUE standardisation.

The visual method of targeting fish in the SPF fishery, both by the vessel itself and by the spotter planes that support purse seine fishing activity, is another feature that violates common assumptions imposed on the calculation of CPUE. However, the catchability of fish in any fishery should never be considered naive, as fishers' experience (often considered statistically as the 'skipper effect') and technological assistance (i.e., sonar, on-water communications) are both common features of all fishing methods. Purse seine fishing simply differs from many other methods as visual signals influence catchability, decision making, and successful outcomes in the fishery. With respect to the use of spotter planes, the collection of information identifying their use when conducting a set is readily identifiable and has further benefitted from the recent introduction of ERS. While this provides an additional factor that assists in the determination of catch rates, it only partly explains the nature of support they provide. By indicating that a spotter plane was used in the catch event, skippers declare that the identified aircraft assisted in the search for fish. However, no information is provided on the period of time that the pilot of the plane assisted in search activities. Work to gain a more detailed understanding of these search activities is described further in the following sections.

An additional factor investigated in this report is whether the size of schools targeted by vessels is influenced by their holding capacity. Foremost, results identify that the schools caught by the purse seiners rarely saturate the hold volume of the vessel. This observation suggests that these fishes do not have a tendency to form large (200 t to 300 t) aggregations that are readily caught by the fleet, which would arguably contribute towards a hyperstable CPUE index. If catch decisions were regularly based upon the need to meet the holding constraints of the vessel, and independently of the relative availability of fish, this would lead to erroneous interpretations of the relative abundance of fish in the region. While the selection of schools that are larger in volume than the vessel's hold capacity are obviously precluded, there is no additional evidence of an interaction between the size of schools selected by the vessel and the number of sets conducted in a voyage. Similar investigations could readily investigate whether this phenomenon exists for each target fishery when determining species-specific CPUE indices.

Other factors affecting catchability including the behavioural dynamics of the species, selectivity biases associated with fish size, market dynamics, and the proportionality of CPUE and abundance are discussed in later sections.

4.3 Next steps to a better understanding of effort in the SPF

4.3.1 Better utilisation of geospatial tracking data in the fishery

In the present investigation the utility of GPS data for determinations of the searching behaviours of spotter planes, and vessels, was investigated. In combination with the catch records collected by the fishing vessels, and the observation notes collected by the pilots, this data collection showed that the search areas, search behaviours, and the detection frequencies, of both craft can be readily inferred. Opportunities to classify search, catch and transit behaviour of both vessels and spotter planes can be estimated from their turning behaviours and speeds (and potentially altitude for spotter planes), as has been done elsewhere (Joo et al. 2015). Validation of these inferred and classified activity patterns would be a worthwhile undertaking. Investigations that use statistical classification models (e.g., random forests) are also recommended, as these have been used within investigations into the use of dFADS as a mechanism for fishery independent data and stock assessment (Escalle et al. 2021).

4.3.2 Expanding the data collected from the PS fleet

Additional data collected by the fishing fleet would overcome many of the challenges currently associated with the development of a worthwhile CPUE index. Generally speaking, this data would present as ‘non-fishing’ or ‘non-catch’ event data, as catch data is already collected by the current ERS systems. As noted above, the searching activities performed by vessels and planes could be readily validated if this data was captured during their operations. The declaration of *a priori* targeting intentions would also provide useful information in this regard. Additional information that describes all observations of target species in combination with unsuccessful (or partially successful) catch events would also support delta models that model the probability of encounter against the estimated density of fish; fish density is commonly defined as the positive catch rate in purse seine fisheries. Context provided by information on the decisions made by skippers on whether to set, or not set, upon a possible target would provide information on why a given observation of the target species is deemed worthy of catching, or not. This could include the estimated species composition of the school upon detection, the estimate of fish size in the target, or whether additional factors preclude capture of the observed schools(s) (e.g., the presence of endangered threatened or protected species, bathymetric features, or proximity to marine protected areas). Whether a school was detected by aerial, visual, or acoustic methods would provide a more thorough understanding of the different modes of searching undertaken by the vessels and also provide information on the vertical behaviours of fish (also discussed in the following section). Collectively, this information would better provide better information on the encounter rate between fish and the fishery.

4.3.3 The influence of environmental and behavioural variations on CPUE determinations

An additional challenge raised with the use of CPUE as an index of abundance is the relative lack of understanding of how environmental conditions influence species availability and/or abundance seasonally, spatially, and in their distribution through the water column. This understanding would enable standardisation of any CPUE trends, and is particularly relevant to small pelagic species and other low trophic level species for which their abundance or presence is often considered to be driven by environmental factors rather than fishing pressure (Bez et al. 2011, Hilborn et al. 2022). CPUE can be used as a primary indicator of the relative abundance (or presence) of a species in ecological niche factor analyses or habitat suitability models, highlighting the usefulness of the index for reasons beyond stock assessment purposes. Furthermore, remotely sensed and in situ environmental datasets are routinely used to standardise CPUE time series affected by natural variability, both in the New Zealand setting, and elsewhere. Collectively the utility of CPUE for both investigating environmental influences on the fishery, and the ability to account for differing environmental conditions, should not dissuade further efforts to develop a CPUE metric for the purse seine fleet.

4.3.4 The proportionality of CPUE and abundance

Efforts to identify whether the abundance of a population and a CPUE metric are linear or non-linear is no trivial task for most fisheries. Generally speaking, it is recognised that operational characteristics of a fishery tend towards hyperstability in the CPUE relationship, while distributional factors tend towards hyperdepletion (Gaertner & Dreyfus-Leon 2004). With respect to operational features, non-random search effort and information sharing are two key factors that will contribute to hyperstability and are particularly relevant to purse seine fisheries. Indeed, investigations into the sharing of information by purse seine vessels (and its association with non-random searching) have identified a stronger non-linear relationship between CPUE and abundance in the skipjack fishery than in vessels that operate individually (Gaertner & Dreyfus-Leon 2004). Other investigations have explored how the use of technological aids (fish aggregating devices, FADs) assist catch outcomes and influence the relationship between CPUE and abundance, again in the skipjack tuna purse seine fishery (Nooteboom et al. 2023). These have showed that, while non-linear relationships can be detected, these can switch between hyper-deplete and hyper-stable states depending on different circumstances, and typically represent fairly small deviations from a linear CPUE-abundance relationship. Investigations into how distributional factors of fish populations influence the relationship between CPUE and abundance also exist (Alós et al. 2019). As a result of these, and other evaluations, it is now commonly accepted that, in tropical tuna purse seine fisheries, the 'effective' CPUE achieved by vessels is primarily attributable to the technologies employed by the fishers including oceanographic sensing technologies, digital FADs, and communication networks.

While it is not the intention of this report to understand the relationship between CPUE and population abundance in New Zealand's SPF it is highlighted that both the operational characteristics of the fishery, and the incompletely understood spatial distributions of the fish populations in question, will influence whether the CPUE-abundance relationship of the population in question is linear, or non linear. It is therefore likely that further consideration is required before a satisfactory understanding of this relationship is agreed, for each relevant species. Based upon the information provided in the previous paragraph, a suggested initial start point for assessing the linearity of the CPUE-abundance relationship in the New Zealand SPF would be the assumption that the distributional behaviours of SPF species tend towards hyperdepletion scenarios. Whereas fishing technologies, primarily including spotter planes, but also including acoustic (on-board sonar technologies) and communication networks, lend a tendency towards hyperstability. The 'next steps' outlined in this report will help to clarify the nature of how technologies and communication influence catchability and support standardsation of any CPUE metric, whereas other investigations are required to identify how the spatiotemporal patterns of these fishes influence catchability.

4.3.5 Analytical approaches for assessing population abundance using CPUE

Pelagic fish present a challenging case for any assessment as their range is large, the distribution within their range often patchy (due to their gregarious nature), and their movement throughout this range is highly dynamic. Moreover, the availability of these fish to fishing fleets is non-random, with vessels generally only able to capture fish when their locations and behaviours support successful and efficient capture by the vessels. Due to these two factors the catches of fish (or fishery dependent sampling) is non-random and preferential in nature. These same factors also mean than fishery independent surveys are generally not practical due to the necessarily high sampling requirements (e.g., coverage area, temporal repetition). To account for these factors, spatio-temporal models of fisheries-dependent CPUE data, that inherently account for the spatial and temporal variability of the species, are considered the most appropriate method to assess the status of a pelagic fishery stock. This is the approach widely adopted for tropical tuna purse seine fisheries, as utilised by the WCPFC, IATTC and ICCAT Regional Fisheries Management Organisations. The potential to incorporate seasonal environmental covariates, and to account for operational and systematic changes in the fishing fleet (effort creep), are provided for in spatio-temporal models much like other assessment approaches.

4.4 Summary

Determining the population status of small pelagic fishes caught solely by the purse seine fishing method is challenging. Inferring the relative abundance of these populations by modelling catch per unit effort presents one potential method by which the population status of these species can be measured. However, before undertaking such an analysis, key limitations of the CPUE metric for purse seine vessels (that have been highlighted in past attempts to generate a CPUE index) must be addressed.

Currently available information from the purse seine fleet provides a generally sound basis for ongoing research to establish CPUE based indices of abundance in the SPF fishery. Key advantages presented by currently available data include:

- a predictable and well characterised fleet of vessels, of which many have been operating throughout the time period investigated;
- a small number of fleet operators, providing for ready adoption of new analysis approaches and data collection methods;
- a stable geographical range of catch events, with well described and detectable geographic shifts over time;
- detectable changes in fishing practices and technology adoption (e.g., sonar use, spotter plane use) that can both be inferred, and better accounted for; and
- improved understanding of how vessel related factors influence catch levels (e.g., hold volumes).

Whereas, key constraints limiting further investigations include:

- a lack of information on the search and effort undertaken by pilots during their spotting activities;
- little information available on what drives the catch decisions of skippers when on the water; and
- a poor understanding of environmental drivers on school availability/catchability to the purse seine fleet.

To address these current constraints, the following activities could be considered:

- a focus on data capture processes that enable an improved understanding of the spotter plane search/effort patterns and the observations made by pilots, and how these influence the catch decisions of the fishing fleet. This would ideally be incorporated into existing, or complementary, electronic reporting systems currently utilized by vessels in the fleet;
- The recording of non-fishing event data capture aboard vessels,
  - including the availability, encounter rates, and biological/behavioural characteristics of the target species (and other key SPF species) during trips;
  - the prevalence and nature of information sharing occurring between vessels and spotter planes; and
  - environmental or ecological factors that influence catch decisions.

5. ACKNOWLEDGEMENTS

Many thanks to Marc Griffiths for helpful discussion on the past efforts associated with the development of the sightings per unit effort index for the purse seine fishery, and to Paul Starr for discussion on these past efforts and the opportunities and challenges associated with the future developments identified in this report. Review by the Inshore Fisheries Assessment Working Group is gratefully acknowledged. Helpful science and editorial reviews were provided by Marc Griffiths and Marianne Vignaux.

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APPENDIX A: SUPPLEMENTAL ANALYSES

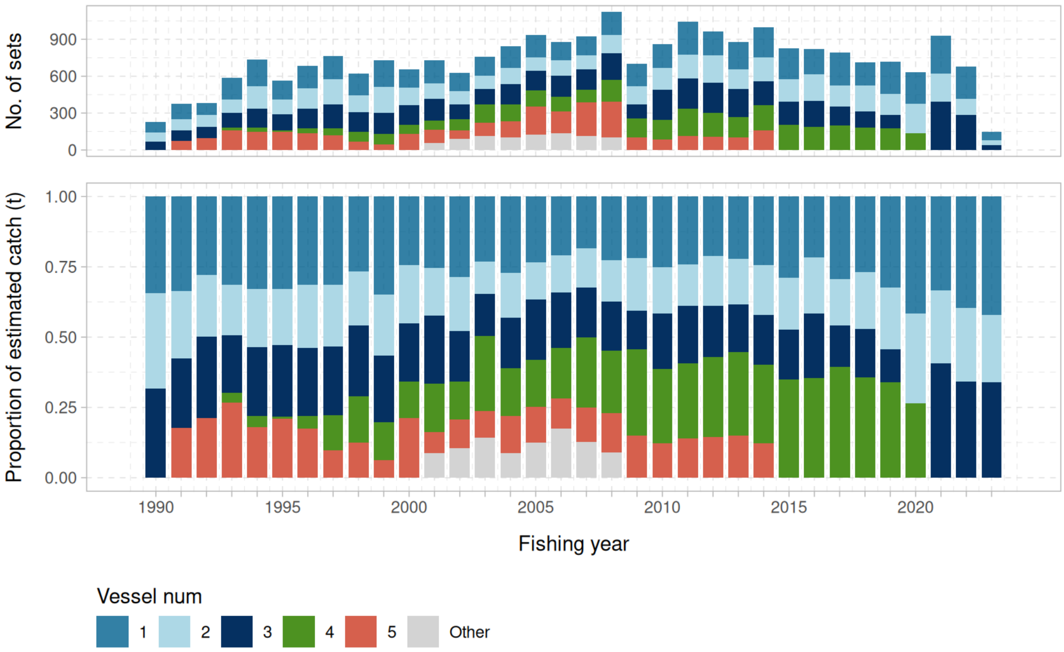

Figure A-1: The number of sets (top) and proportion of estimated catch (bottom) by fishing year and the purse seine fleet vessels (colours).

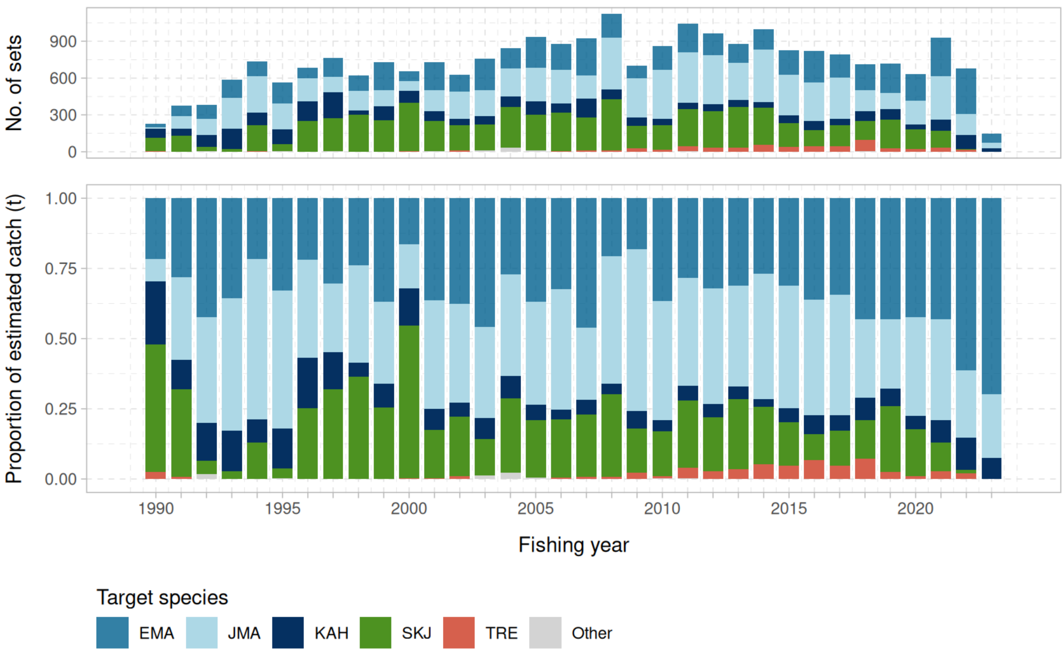

Figure A-2: The number of sets (top) and proportion of estimated catch (bottom) by fishing year and target species (colours); blue mackerel (EMA), jack mackerel (JMA), kahawai (KAH), skipjack (SKJ), and trevally (TRE). The remaining target species are grouped as Other.

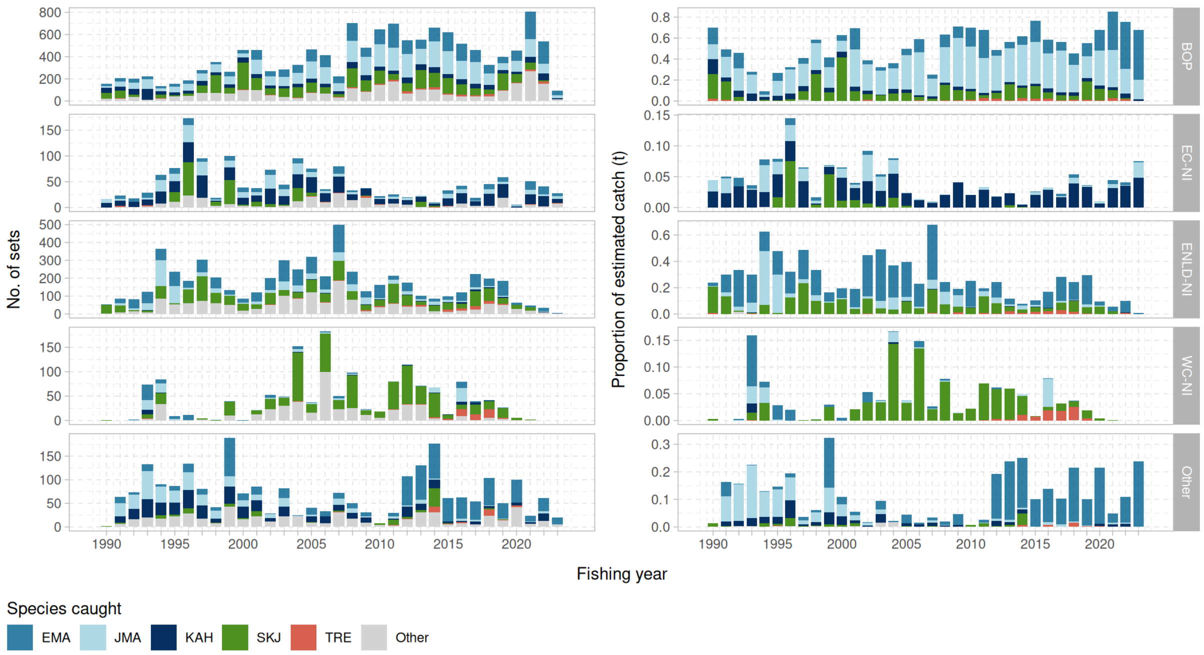

Figure A-3: The number of sets (top) and proportion of estimated catch (bottom) by fishing year, area, and species caught (colours); blue mackerel (EMA), jack mackerel (JMA), kahawai (KAH), skipjack (SKJ), and trevally (TRE). The remaining species caught are grouped as Other.

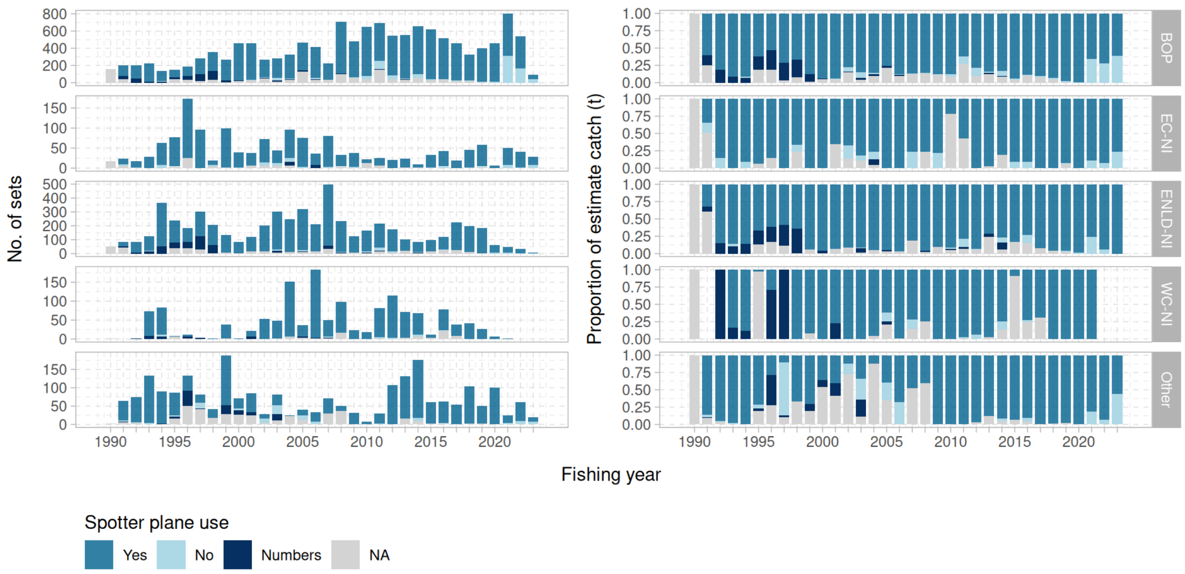

Figure A-4: The number of sets (left) and proportion of estimated catch (right) over time by spotter plane use (colours) and area.

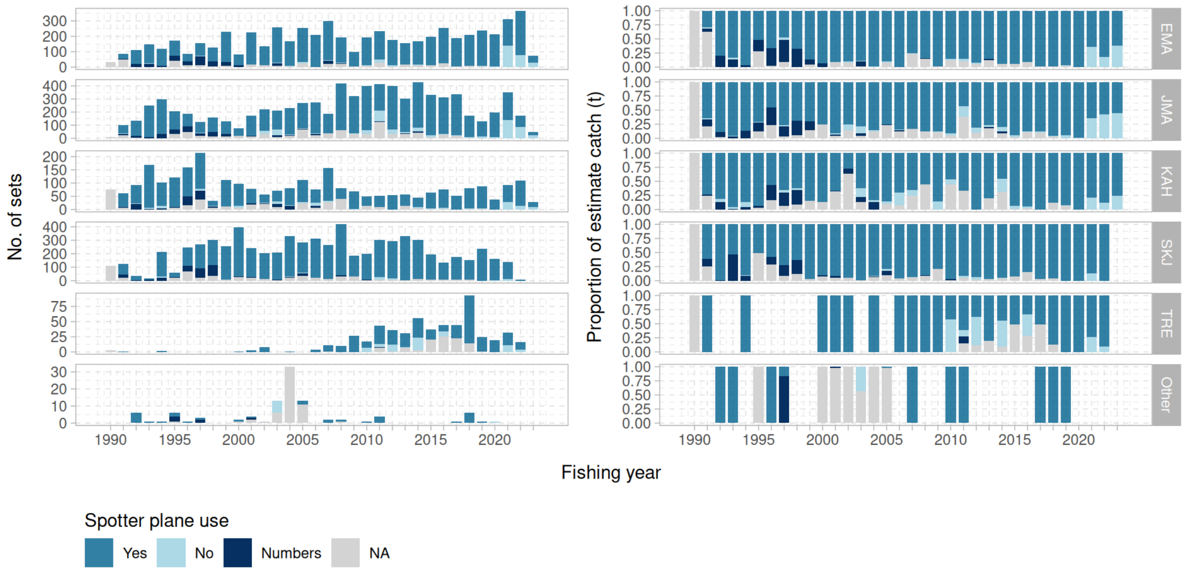

Figure A-5: The number of sets (left) and proportion of estimated catch (right) by spotter plane use (colours, see legend below), species and fishing year.

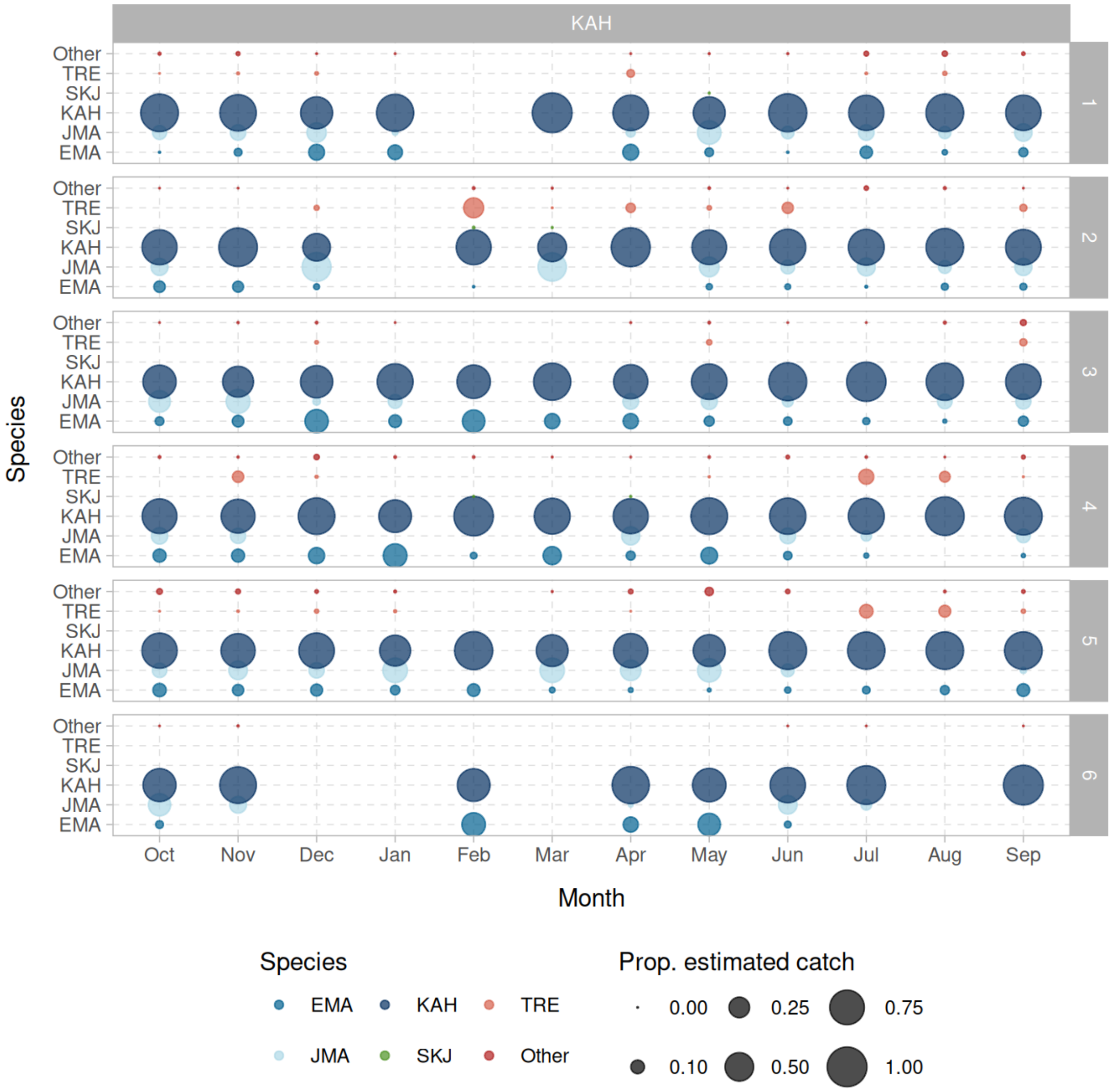

Figure A-6: Seasonal patterns in the proportion of species caught when targeting kahawai (KAH) for all fishing vessels.

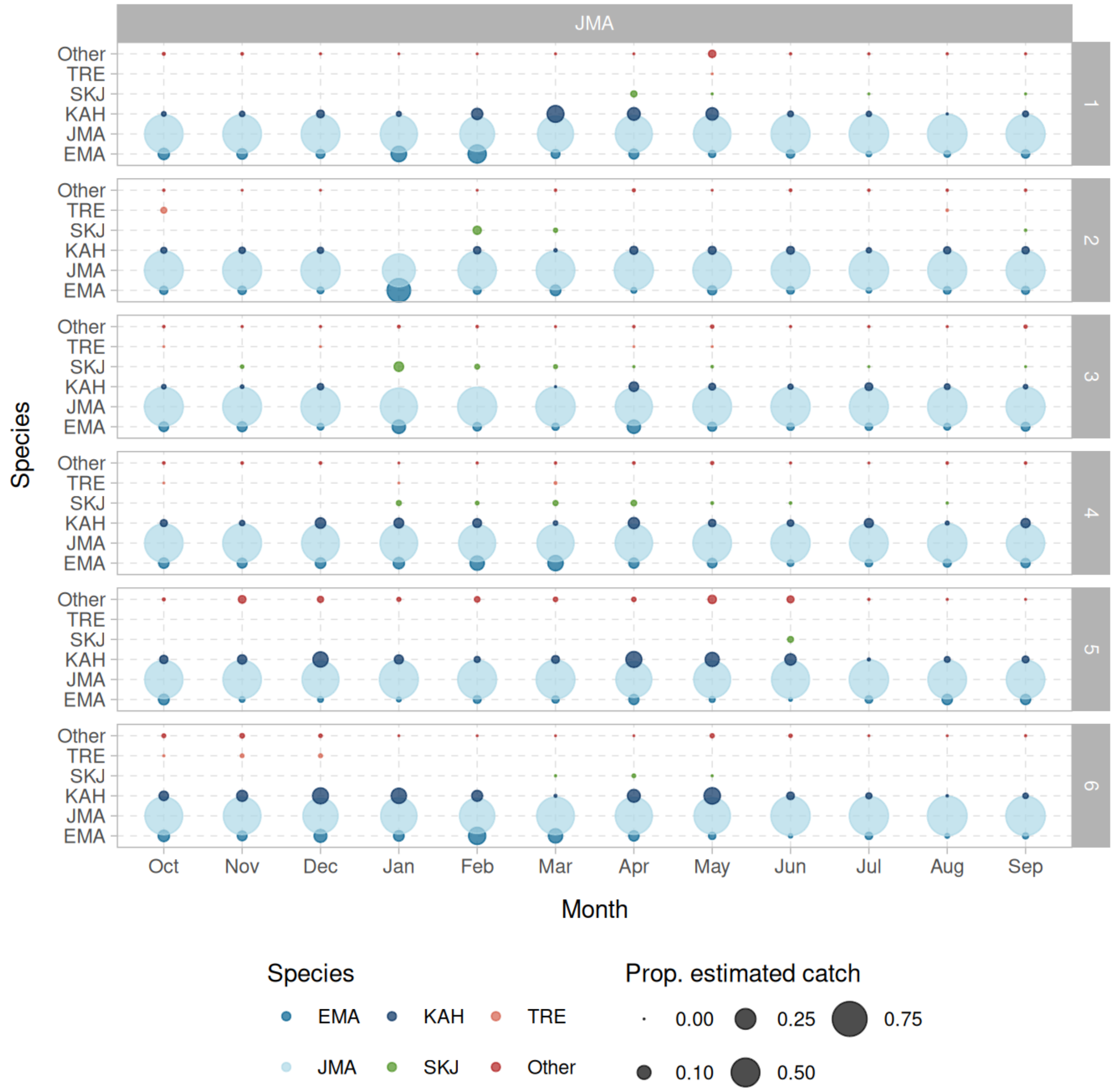

Figure A-7: Seasonal patterns in the proportion of species caught when targeting jack mackerel (JMA) for all fishing vessels.

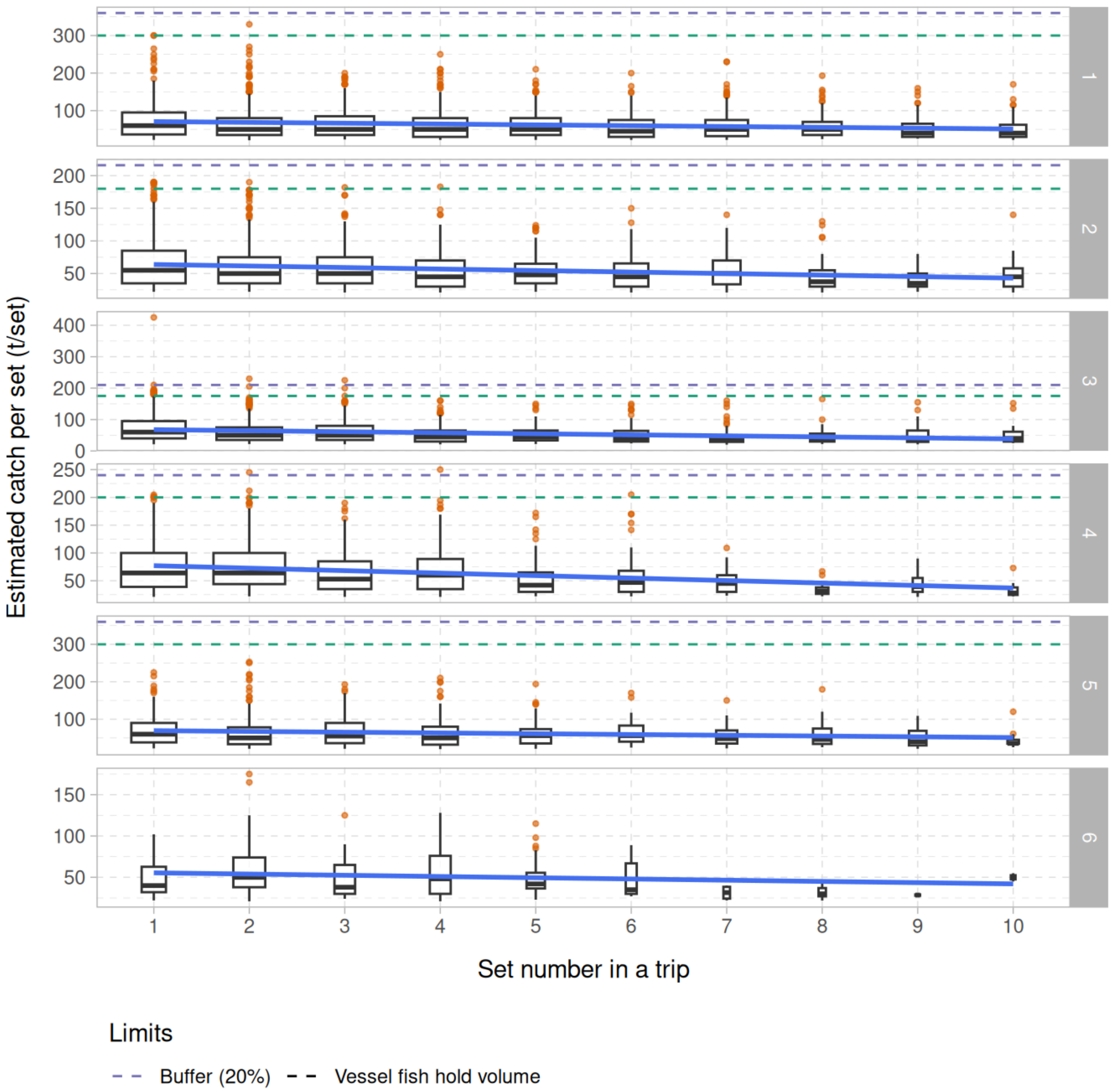

Figure A-8: Estimated catch by set number along small pelagic purse seine trips relative to each vessel's hold capacity (green dashed line) and 1.2× hold capacity (black dashed line), with each panel representing individual (anonymised) vessels to account for vessel specific hold-sizes.

Table A-1: Changes in the purse seine fishing fleet and techonologies between 1990 – 2022. All fleet specification values are presented as mean values. Sonar technologies are denoted by: I - Scanning sonars without tracking funcitonality, II - Searchlight sonars with tracking functionality, III - Early omni sonars with tracking functionality, IV - Contemporary omni sonars with tracking functionality. All sonar types described operate at mid-frequency (50–80 kHz). Storage technologies described include brine and RSW (refrigerated sea water). The early transition of some vessels to RSW storage is described by the form ∼RSW. Note RSW storage is generally only applicable to JMA and TRE catches

		Mean specifications								Technologies	
Year	No. vessels	Gross tonnage (t)	Length (m)	Age (years)	Power (hp)	No. crew	Total hold volume (t)	No. holds	Skiff power (hp)	Sonar	Storage
1990	3	268.0	32.9	9.7	957.8	7.3	218.3	5.3	273.3	I	Brine
1991	3	268.0	32.9	10.7	957.8	7.3	218.3	5.3	273.3	I	Brine
1992	4	288.0	33.4	13.5	918.4	7.2	238.8	5.5	205.0	I	Brine
1993	5	289.4	33.8	14.6	1014.7	7.4	231.0	6.2	212.0	I	Brine
1994	5	289.4	33.8	15.6	1014.7	7.4	231.0	6.2	212.0	I	Brine
1995	5	289.4	33.8	16.6	1014.7	7.4	231.0	6.2	212.0	I, II	Brine
1996	5	289.4	33.8	17.6	1014.7	7.4	231.0	6.2	212.0	I, II	Brine
1997	5	289.4	33.8	18.6	1014.7	7.4	231.0	6.2	212.0	I, II	Brine
1998	5	289.4	33.8	19.6	1014.7	7.4	231.0	6.2	212.0	I, II	Brine
1999	5	289.4	33.8	20.6	1014.7	7.4	231.0	6.2	212.0	I, II	Brine
2000	6	289.4	33.8	21.6	1014.7	7.4	231.0	6.2	212.0	I, II	Brine
2001	6	289.4	33.8	22.6	1014.7	7.4	231.0	6.2	212.0	I, II	Brine
2002	6	289.4	33.8	23.6	1014.7	7.4	231.0	6.2	212.0	I, II	Brine
2003	6	289.4	33.8	24.6	1014.7	7.4	231.0	6.2	212.0	I, II	Brine
2004	6	289.4	33.8	25.6	1014.7	7.4	231.0	6.2	212.0	I, II	Brine
2005	6	289.4	33.8	26.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine
2006	6	289.4	33.8	27.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine
2007	6	289.4	33.8	28.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine
2008	6	289.4	33.8	29.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine
2009	5	289.4	33.8	30.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine, ~RSW
2010	5	289.4	33.8	31.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine, ~RSW
2011	5	289.4	33.8	32.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine, ~RSW
2012	5	289.4	33.8	33.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine, ~RSW
2013	5	289.4	33.8	34.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine, ~RSW
2014	5	289.4	33.8	35.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine, ~RSW
2015	5	289.4	33.8	36.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine, RSW
2016	5	289.4	33.8	37.6	1014.7	7.4	231.0	6.2	212.0	II, III	Brine, RSW
2017	4	274.8	33.6	37.2	1068.4	7.5	213.8	6.2	265.0	II, III	Brine, RSW
2018	4	274.8	33.6	38.2	1068.4	7.5	213.8	6.2	265.0	II, III	Brine, RSW
2019	3	268.0	32.9	38.7	957.8	7.3	218.3	5.3	273.3	II, III	Brine, RSW
2020	3	268.0	32.9	39.7	957.8	7.3	218.3	5.3	273.3	II, III	Brine, RSW
2021	3	268.0	32.9	40.7	957.8	7.3	218.3	5.3	273.3	II, III	Brine, RSW
2022	3	268.0	32.9	41.7	957.8	7.3	218.3	5.3	273.3	II, IV	Brine, RSW

APPENDIX B: REVIEW OF VESSEL TRACK CATEGORISATION

B.1 Peruvian Anchovy Fishery

The use of Vessel Monitoring System (VMS) data to investigate spatial use strategies and estimate fishing activity has been investigated in the Eastern Pacific anchovy purse seine fishery—the largest single species fishery in the world. Initial efforts used VMS data from 1350 vessels collected between 2000 and 2002 to estimate the position of fishing operations and estimate the extent of anchovy distributions (Bertrand et al. 2008). VMS data included vessel ID, date, hour, latitude, and longitude, with a resolution of 100 m and sampling intervals of 60 min from which derived variables including velocity, speed variation, and change of direction were calculated. An artificial neural network (ANN) of the multilayer perceptron (MLP) type was utilised. A three neural layer (input, output and one 'hidden' layer) topology was utilised. The input layer comprised neurons defined by: speed and hour of move, speed variation between current and next move, speed variation between current and previous move, and the change in heading between the last and previous move. The output layer comprised of two classifications: fishing set, or no fishing set. Bias neurons were included.

The ANN was trained from reference data collected by onboard observers aboard during 142 fishing trips (494 operations), or approximately 1.5% of the total number of trips investigated in this study. A back propagation procedure was used to train the network; this included an early stopping procedure that divided the training data into three subsets (training, validation, and test subsets), employed to achieve balance between data-fitting and model complexity. Outputs from the ANN were able to predict 83% of fishing sets, with 0.5% overestimation. Attempts to use a simple speed threshold on raw VMS data led to an overestimation of the number of fishing sets of 182%. Similarly, a general linear regression modelling approach (GLM) identified 65% of true positives and 16% of false positives, leading to a global underestimation of the total number of fishing sets of 19%.

The initial work of Bertrand et al. (2008) was expanded by Joo et al. (2011) with an optimised ANN. Using the same model architecture as the earlier study, the internal structure of the training algorithm and the rules dictating the size and composition of the training and inference datasets were evaluated using a trial-and-error sensitivity analysis. The intention of these analyses was to optimise and increase the robustness of the ANN in the context of the eastern Pacific anchovy fishery, including how (i) the use of two different vessel types (steel and wooden hull) and (ii) different management rules in separate regions of the fishery, influence predictions. Sensitivity analysis proved highly informative, with the thresholds applied to the output value, and the MSEmax (the maximum acceptance value for MSE) being the two most important parameters to optimise the percentage of correct classifications (i.e., ensuring that the number of observed, and identified, fishing sets are as similar as possible). The third most important parameter was the number of internal nodes within the ANN, with lower numbers of nodes producing more parsimonious outcomes. Partition sizes of the training database (i.e., training, validation and test subset partitions) were next most important, particularly when the size of the training database were small. The optimised ANN achieved an average of 76% correct classification of fishing sets, with 1% estimation error across a larger dataset than earlier work (7 years vs 2 years). Finally, opportunities for using these tools to calculate CPUE were highlighted.

To investigate the fishing strategies of the Peruvian anchovy fleet, Joo et al. (2015) evaluated the use of HMMs (Hidden Markov models) and Hidden semi-Markov models (HSMMs) alongside discriminative models including random forests (RF), ANNs and support vector machines (SVMs). Strategic fishing states: fishing, tracking and cruising were determined from the GPS data (and associated derived variables described above) of 50 vessels over a one-year period of operation. 200 of the voyages evaluated were simultaneously measured by GPS and onboard observers. HSMMs were the first approach considered as (compared to HMMs) they incorporate the time element by explicitly modelling the durations of states. All models estimated the fishing states with an accuracy between 75–80.3%, with HSMMs accuracy the highest (by a small statistical margin). HSMMs outperformed all other models detecting the different fishing states, based on a F1 metric that combined recall and precision. Cruising was the easiest mode to identify and searching the hardest (with confusion between both fishing and cruising states) in all models.

B.2 Indian Ocean Tuna Purse Seine

Using Vessel Monitoring System (VMS) data, Bez et al. (2011) investigated the fishing effort of the French fleet in the tropical tuna purse seine fishery of the Indian Ocean. A Bayesian State-Space model allowed the classification of operational fishing activities into the three strategies or states described above for Joo et al. (2015): fishing, tracking, and cruising. States were defined according to the vessels speed and turning angles (Table B-1).

Table B-1: Characteristics of the three vessel activities defined by Bez et al. (2011)

State	Turning Behaviour	Vessel Speed	Characteristics
Fishing	Low	Low (~0 knot) but still allowing for tidal drift	Vessel holding still while observing fish before setting, or holding still while fishing
Tracking	Widely distributed around 360° / 2π	Lower mean velocities, with high instantaneous speeds	Sinuous, and often random changes in vessel direction with schools appearing either side of vessel and at various distances away
Cruising	Predominantly 0°/ rad	High	Moving quickly though abundance poor areas

Spatial data was collected from a two-year period of fishing operations, with VMS information at hourly intervals over 131 different voyages of 14–17 vessels per year. Approximately 140 000 waypoints were analysed. Each activity was aggregated according to the hours spent in that activity then pooled in monthly intervals. Spatial pixels were 0.2° × 0.2°. Spatial extent of activity was expressed as the number of positive pixels, and homogeneity of distributions was quantified by Gini's index.

The analysis framework consisted of a state-space Bayesian Hidden Markov model initially validated using observer data from 10 trips. Compositional data of the three operational states were investigated with histograms that assessed levels of variation in each state across the duration of observations. They were then represented in simplex with significant effects of a linear model (including vessel and seasonal effects) plotted alongside. Importantly, model predictions were validated with observer observations recorded on 10% of the trips. Fishing strategies associated with the targeting of free swimming schools, or the use of Floating Aggregation Devices (FADs), were not addressed in this study.

B.3 Bay of Biscay Small Pelagic Trawl Fishery

Vermard et al. (2010) also used Bayesian Hierarchical Models using a Hidden Markov process to investigate the behavioural modes of pelagic trawl vessels using VMS data. VMS data was collected at a (nominal) two-hour sampling rate, with positional accuracy of 500 m. Instantaneous speed was also logged. Time intervals were not always regular. Three fishing modes: Steaming, Fishing and Stopping were defined by speed, at 4, 11, and 0, knots respectively. Turning angles defining each mode were distributed *a priori* as a wrapped-Cauchy distribution. A simulation-estimation approach was used to assess the sensitivity of the model to differences associated with the behavioural state definitions, time lags, missing values, and the number of observations, before the model was applied to a true dataset.

Outcomes of the study identify numerous insights into how this Bayesian method performed with the test dataset. Notable was the discussion on the importance of the VMS sampling frequency and its ability to capture changes in the fishing operation that are of a shorter duration than the sampling frequency.

B.4 The WCPFC tuna purse seine fleet

Spatial data from the Automatic Identification System (AIS) of 130 purse seiners collected between July 2017 and May 2018 were investigated using data mining approaches (Zhang et al. 2021). Data including timestamp information (year, month, day, hour, minute, second), latitude, longitude course, speed and MMSI (Maritime Mobile Service Identity) numbers were utilised. Fishing modes including fishing and searching behaviour / high speed transiting were identified based on day/night and speed thresholds (< 2.5kn for fishing, and >2.5kn for searching). Effort was defined as the time spent searching and chasing schools, while fishing intensity was defined as the time spent by all seiners in each grid unit (5° × 5°). Catch (production) statistics were used at the 5° × 5° spatial resolution with CPUE calculated at the same spatial scale by dividing the cumulative catch by the number of nets (assumed to be the number of sets).

Spatial autocorrelation and the global Moran Index parameter was used to investigate global distribution patterns, while local spatial distribution patterns were investigated using hot spot analyses and spatial autocorrelation. Correlations between catch, time spent fishing, CPUE, and fishing intensity were investigated. Results included spatial characterisations of the speed, heading and fishing intensity, the distributions of speed and course, time series and spatial analysis of fishing effort (i.e., high-speed transiting and low speed setting operations). Spatial representations of cumulative fishing effort, monthly effort, and a depiction of the hot spot analysis were presented alongside a suite of descriptive statistics describing the distributions of fishing effort. Correlation analysis and the resulting coefficients were also tabulated.

Overall, findings provide a thorough characterisation of the fishing behaviour of purse seine vessels as it relates to catches, as determined by AIS data. Effort was highly correlated with catch volumes and setting (low speed) behaviours, and moderately correlated with CPUE.