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A PRELIMINARY ANALYSIS OF VMS DATA FROM THE EQUATORIAL PURSE-SEINE FLEET – THE POTENTIAL APPLICATION OF VMS DATA IN THE ANALYSIS OF PURSE-SEINE CATCH AND EFFORT DATA

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A preliminary analysis of VMS data from the equatorial purse-seine fleet – the potential application of VMS data in the analysis of purse-seine catch and effort data.

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Executive Summary

The analysis of Vessel Monitoring System (VMS) data from the equatorial purse-seine fleet has the potential to increase the understanding of the operation of the fishery and lead to the quantification of the effective fishing effort expended by the fleet. In turn, this may enable the development of metrics that provide indicators of the performance of the fishery and, potentially, a method for monitoring the relative abundance of the principal target species (skipjack tuna) through the analysis of logsheet and other data. This paper presents a preliminary analysis of VMS data from fishing trips that primarily fished on unassociated tuna schools. The analysis applies a modelling approach developed for processing animal tracking data to characterise a range of vessel behaviours that are related to active searching and fishing. A number of recommendations are made to extend the study to a point where stronger conclusions can be made regarding the utility of the VMS data in stock monitoring and assessment.

Introduction

Vessel Monitoring System (VMS) data are somewhat analogous to animal tracking data as they provide a record of location (and distance and direction travelled) at regular intervals. There is a growing body of literature that has applied Hidden Markov Models to infer foraging behaviour from animal tracking data (e.g. Jonsen et al 2007). Similar approaches are now being applied to the analysis of VMS data from fishing vessels to define different modes of operation (e.g. fishing and steaming) (Walker & Bez 2010, Vermard et al 2010).

A recent analysis of the VMS data from the New Zealand purse-seine vessels operating in the equatorial Pacific fishery investigated the utility of applying statistical techniques developed for analysing animal tracking data to characterise different modes of operation and specifically examine the behaviour of the vessel related to different types of fishing (e.g. fishing on associated or unassociated fish schools) (Langley in prep.). The type of fishing was defined from the information recorded on the corresponding vessel logsheet (e.g. frequency of purse-seine sets and set type).

While preliminary in nature, the analysis highlighted the utility of using VMS to discriminate between different modes of vessel activity. Four principal activities were defined based on the movement patterns of the vessel and the associated fishing activity: 1) steaming/searching, 2) fishing on unassociated schools, 3) searching and fishing on associated schools, and 4) directed fishing on FAD associated schools (Langley in prep.). The study revealed that the proportion of the fleet's activity assigned to the latter category had increased from 2004 to 2009 with a corresponding decline in the proportion of vessel time assigned to steaming/searching.

Currently, nominal (and standardised) CPUE indices derived from catch and effort data from the equatorial purse-seine fishery (and the method generally) are not considered to be informative regarding trends in the relative abundance of the target tuna species. This conclusion is broadly accepted due to the nature of the fishing operation, principally the fishing on aggregated surface schools, increased efficiency of the purse-seine vessels operating in the fishery, the increased reliance on fishing on schools associated with artificial FADs, and the increased reliance on GPS and remote sensing technology.

The performance of a purse-seine vessel is largely dependent on the vessel's ability to locate surface schools of tuna. Fishing directed at FAD associated schools is guided by the accurate location of

FADs from GPS tracking and, potentially, the magnitude of tuna associated with individual FADs through sonar detection. The ability of a vessel to locate unassociated schools of tuna is more reliant on visual searching by the purse-seine vessel complimented by remote sensing products, other "code group" vessels, helicopter spotter flights and electronic searching devices (sonar, bird radar, etc).

A measure of the searching activity of the purse-seine vessels engaged in fishing on unassociated tuna schools is likely to represent a more informative measure of the effective fishing effort for the fleet compared to simple effort metrics such as number of fishing days and number of purse-seine sets. Correspondingly, the encounter rates of tuna schools are likely to be more informative regarding the availability of tuna schools to the purse-seine fleet and, hence, the performance of the fishery, although the underlying relationship between fishery performance and tuna stock abundance is likely to remain uncertain.

A simple measure of the searching activity by a vessel is the distance steamed (proportional to area searched) by a vessel during daylight hours while engaged in fishing activities (excluding transiting between fishing locations). The data collected from the fishery via vessel logsheets (and by fishery observers) is not adequate to reliably quantify the searching activity of a purse-seine vessel. VMS data provides highly resolved spatial and temporal (usually hourly or every two hours) observations of the vessel activity and enable the continuous mapping of a vessel throughout a fishing trip, thereby, improving the interpretation of the range of activities (steaming, searching, fishing, etc) and potentially improving the estimation of searching activity (and, thereby, encounter rate).

The objective of this study was to conduct an exploratory analysis of the VMS data from purse-seine fishing trips that primarily conducted fishing on unassociated tuna schools. The analysis is intended to identify current issues associated with the VMS data and the associated logsheet data and conduct a preliminary analysis of the VMS data using the statistical techniques applied to the analysis of the New Zealand VMS data. The analytical approach is intended to elucidate different modes of vessel operation, in particular periods of vessel activity that can be associated with searching activity. The study is not intended to provide a definitive analysis of purse-seine searching activity but represents an initial scoping study that could be used to develop a more comprehensive project.

Data sets

Data collected by the Forum Fisheries Agency (FFA) Vessel Monitoring System (VMS) were available for 250 purse-seine vessels operating during 2008 to 2010. The VMS records the vessel location and speed at regular intervals, usually every 1 or 2 hours. Date and time are recorded as New Zealand Standard Time (NZST) and Coordinated Universal Time (UTC). The VMS data were assigned to a total of 6,958 individual fishing trips (defined as the period between successive port visits and referred to hereafter as an individual *VMS trip*).

The regional purse-seine logsheet records the date, time and location for a range of activities, including fishing, searching and steaming. A logsheet record is completed for each fishing event (start of set) and the set type and estimates of the catch of the main species are recorded. If a purse-seine set is not completed during a day, then the location of the vessel at about midday (0100 UTC) and the main activity for the day (searching or steaming) is recorded. The instructions for the completion of logsheets specify that all dates and times are recorded as UTC. Unfortunately, there is inconsistency (among vessels and trips) in the recording of date and time. A review of these data indicates that local time is frequently reported instead of UTC and for many trips it is not possible to ascertain the format of the date/time recorded (Peter Williams pers. comm.). The current analysis was limited to trips where it could be ascertained that date/time was recorded as UTC.

Five main set types have been defined based on the fish school type: free school (unassociated), feeding on bait fish, associated with floating logs, associated with drifting fish aggregation devices (FADs), and associated with anchored FADs. The first two categories are generally categorized as “unassociated sets” and log, anchoured and drifting FAD sets were considered collectively as “associated sets”.

Individual logsheet records for a purse-seine vessel were assigned to a specific VMS trip if the date/time of the logsheet record was bracketed by the start and end date of the VMS trip. For 2008 and 2009, approximately 65% of the VMS trips had associated logsheet records (Table 1). Logsheet data were available for a smaller proportion of the trips from 2010 (50%), because of lower logsheet coverage at the time of the analysis.

Most (87%) of the corresponding logsheet records for a trip included at least five (5) fishing records (sets) (Table 1).

Almost all of the qualifying trips (97%) had an hourly or two hourly VMS transmission rate (Table 1). Of these trips there is a reasonable correspondence between the trip duration (number of days) from the VMS and logsheet data sets (Figure 1), although for a significant proportion of trips there are a larger number of days included within the VMS data set. Many of the additional VMS days appear to correspond to days when a vessel was in port either for discharge of fish or for longer periods that are assumed to be related to maintenance (days in port were excluded in later analyses). However, for some trips, there were periods when the vessel was active within the equatorial region, presumably related to fishing, for which limited logsheet data were available. In some cases, logsheet data were missing for discrete periods of a trip, while in other cases logsheet records were only available for fishing activities and no data were recorded for steaming/searching.

The pilot study focussed specifically on fishing trips that predominantly conducted purse-seine sets on unassociated schools. Overall, unassociated sets represented at least half of all sets for 60% of the qualifying fishing trips (Table 1). The resulting 1,841 trips were dominated by Korean, Taiwanese, Vanuatu, United States and Japanese flagged vessels. For most trips, there was a close correspondence between the vessel locations transmitted by the VMS and the reported position from the vessel logsheets (Figure 2).

The subsequent analyses partition individual fishing trips into relatively short periods (typically 1-3 days) of comparable vessel activity based on the VMS data. These partitions were then characterised by the corresponding fishing activity (from logsheet data). Given the level of temporal resolution of the VMS data, it is necessary to ensure the logsheet data is reported (or corrected) at the equivalent time zone to the VMS data (UTC). Only 16% and 20% of the trips from 2008 and 2009 were deemed (by SPC/OFP) to have logsheet data that were reported using UTC and only a very small proportion of 2010 fishing trips met the criterion (it may be that the assignation had not been completed for the 2010 logsheet data) (Table 1).

As a result, the final data set was limited to a small (231 trips, 8.6% of the 2,699 “unassociated trips”) proportion of the total purse-seine trips. Hence, the final data set cannot be considered representative of the unassociated fishing activity of the fleet and the results of the study are not applicable to the entire fishery. Instead, the analysis should be viewed only as a pilot study to investigate the utility of VMS data and the potential application of a range of analytical techniques to condense and summarise these data.

The final groomed data set of 231 trips from 76 individual vessels included approximately 110,000 individual VMS records.

Table 1. Summary of the number of purse-seine fishing trips available for inclusion in the VMS data analysis at each step in the data grooming process.

Step	Data criteria	Year			Total
		2008	2009	2010	
1	Total PS trips with VMS data	2,154	2,341	2,463	6,958
1	Number of PS vessels in VMS data set	224	227	237	250
2	VMS trips of 5 to 365 days duration	1,888	2,054	2,075	6,017
2	Total VMS days in data set	59,598	58,540	62,120	180,258
2	Total number of logsheet days in VMS data set	33,807	32,932	25,099	91,838
3	VMS trips with corresponding logsheet data	1,244	1,338	1,053	3,635
4	Trips with at least 5 purse-seine sets	1,108	1,167	889	3,164
5	VMS transmit rate (each hour or two hourly).	1,059	1,134	875	3,068
6	Trips with at least one unassociated purse-seine set	911	962	826	2,699
7	Trips with fishing activity predominantly directed at unassociated schools.	643	550	648	1,841
Final	Trips with logsheet date/time recorded as UTC (OFP assignment).	103	109	19	231

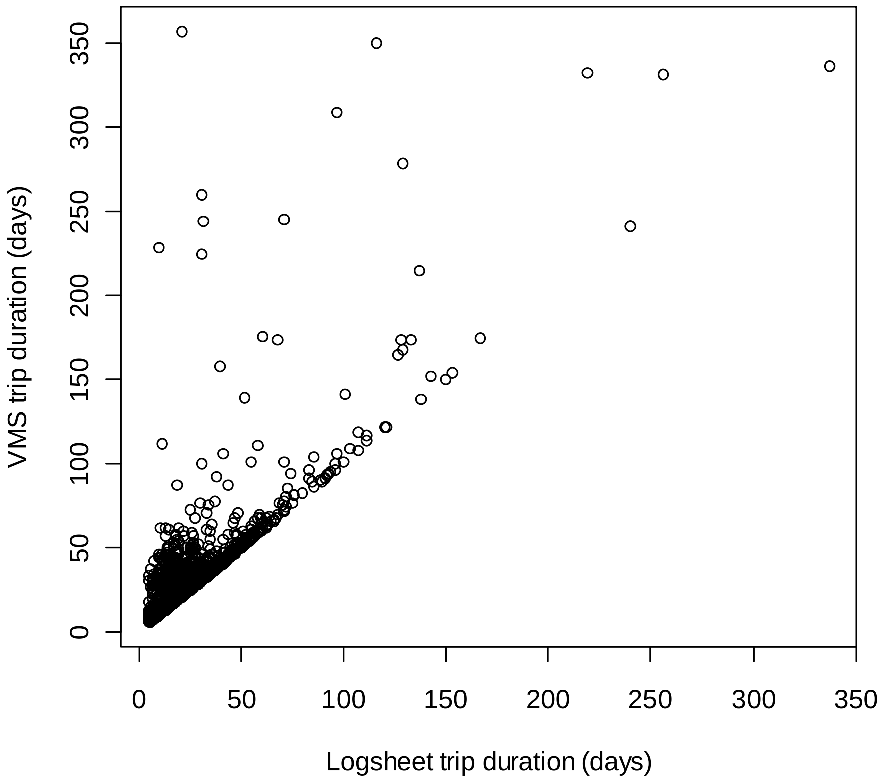

Figure 1. A comparison between the numbers of unique days recorded from VMS data and logsheet records for individual fishing trips included in the final data set.

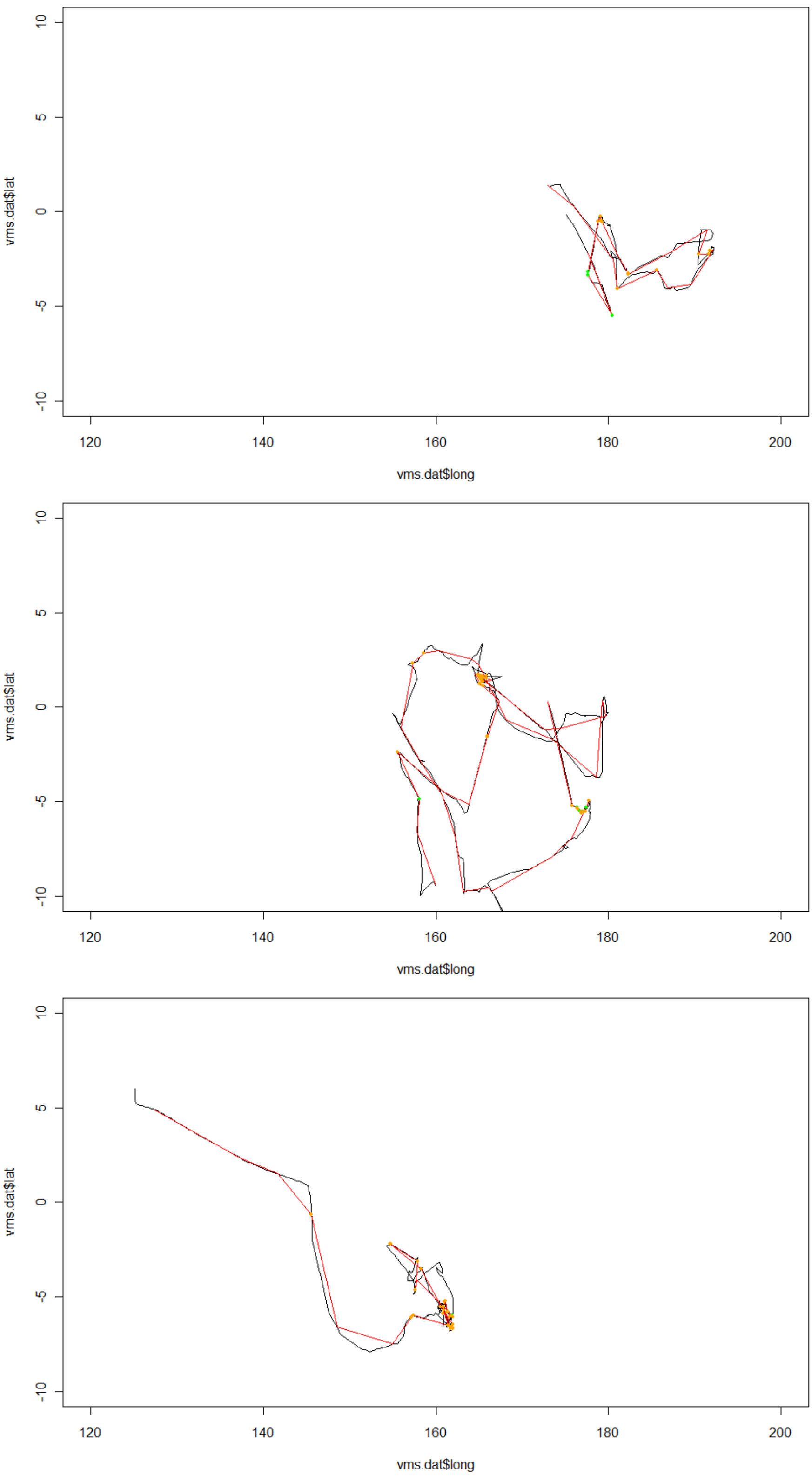

Figure 2. Comparison between vessel tracks from VMS (black) and logsheet (red) and the location of unassociated (orange) and associated (green) purse-seine sets for three individual fishing trips.

Data Analysis

The VMS data from individual fishing trips were compiled based on the trip start and end dates from the logsheet data. The distance between individual VMS locations was computed and these data were used to define sequences of comparable vessel movements by applying an algorithm developed for partitioning individual animal tracks by behavioural type (the *modpartltraj* function in the *adehabitat R* package, Calenge 2006).

The approach is based on the assumption that individual movements are defined by a Markov process; i.e., the behaviour of the vessel at the next time interval has a conditional probability distribution relative to the current behaviour (state). The approach assumes that each behaviour type is characterised by a probability distribution of movements (expressed in kilometres). For example, the behaviour of a vessel transiting between fishing grounds (steaming) might be characterised by a normal distribution with a relatively high mean and relatively low coefficient of variation. Conversely, the behaviour of a vessel searching for fish schools may be defined by a normal distribution with a lower mean distance and a higher coefficient of variation. Fishing activity is also likely to be characterised by a range of other more complex behaviours; for example a vessel may remain relatively stationary for a period and then move rapidly to a new location and recommence localised searching before moving once again. This behavioural type could be defined by a bimodal distribution with the two modes representing the localised and larger-scale movements.

The analytical approach involved defining the distribution of individual behavioural types a priori. This was conducted by examining the movement patterns of individual vessel trajectories and generalising the distribution of a range of different movement patterns. The aggregated set of VMS records reveal successive movements can be categorised in three main classes: local scale movements (typically less than 3 km), movements of about 20 km and larger movements (35-45 km). The latter two movement patterns may not represent different vessel behaviours due to differences in the frequency of VMS transmission (every 1 or 2 hours) (Figure 3).

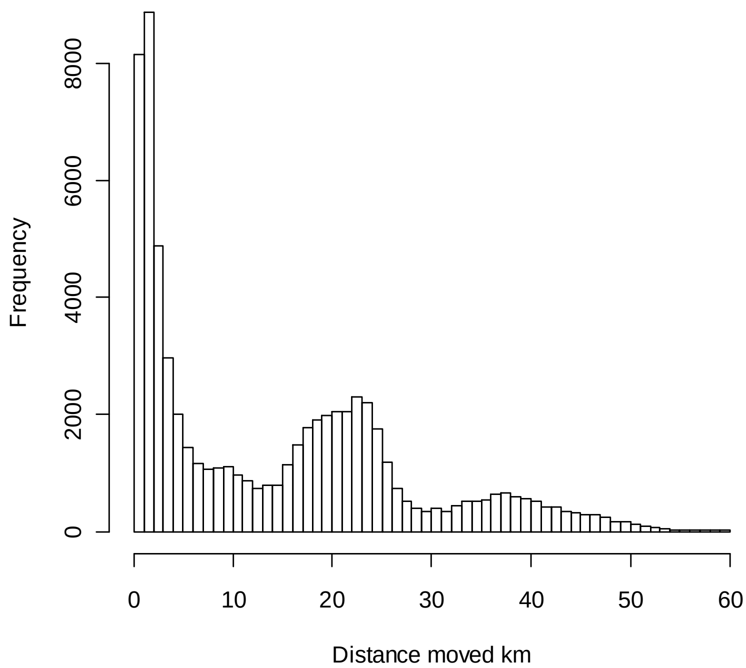

Figure 3. Frequency distribution of the distance between successive VMS locations from the final data set (all trips combined).

Individual vessel movements are relatively complex and variable among trips and among vessels. Hence, a broad range of a priori movement models were adopted to allow sufficient freedom to fit a range of different behaviours; localised movements could be categorised by three normal distributions (mean 0.5, 2.0, 2.0; s.d. 5, 1, 1), larger movements categorised by eight normal distributions (mean 20, 30, 40, 50, 20, 30, 40, 50; s.d. 2, 2, 2, 2, 5, 5, 5, 5,). More complex movement patterns were simply represented by movement models with a larger standard deviation (mean 10, 20; s.d. 5, 10), thereby, encompassing a wider range of different types of movement within the same distribution.

For each movement in a vessel trajectory, the probability density that the movement was generated by each of the a priori movement models is computed. The *modpartltraj* algorithm assigns individual segments (a sequence of vessel movements) to an individual movement model to maximise the product of the probability densities, given a specified number of segments (Calenge 2006).

For each trajectory, the appropriate number of segments can be determined by comparing the log of the probability (log-likelihood) that the trajectory is comprised of 1 to *n* segments (Calenge 2006). A preliminary analysis of a subset of individual fishing trips indicated that it was rare to achieve an optimal number of segments, indicating that individual trips were not simply composed of a limited number of specific modes of operation (as defined by movement). Nonetheless, about 15–20 segments generally accounted for most of the total variability in the vessel movements for an individual trip, corresponding to an average segment duration of approximately 1.5-2.0 days. On that basis, the number of segments per trip was determined based on an average segment duration of 1.5 days.

An example of the processing of the VMS data from an individual trip is presented in Figure 4 and Figure 5. The trip was of 24 days duration and included 568 VMS locations transmitted at one hour intervals. The VMS locations were apportioned into 15 segments; 8 of the segments were assigned to the localised movement models (representing a total of 422 hours), 2 segments were assigned to longer distance movement models (144 hours) and 5 segments (568 hours) were assigned to more complex movement behaviours that were best characterised by a high mean (20 km) and standard deviation (10 km). This movement behaviour was largely characterised by a bimodal distribution characteristic of both small and larger scale movements generally alternating over relatively short intervals.

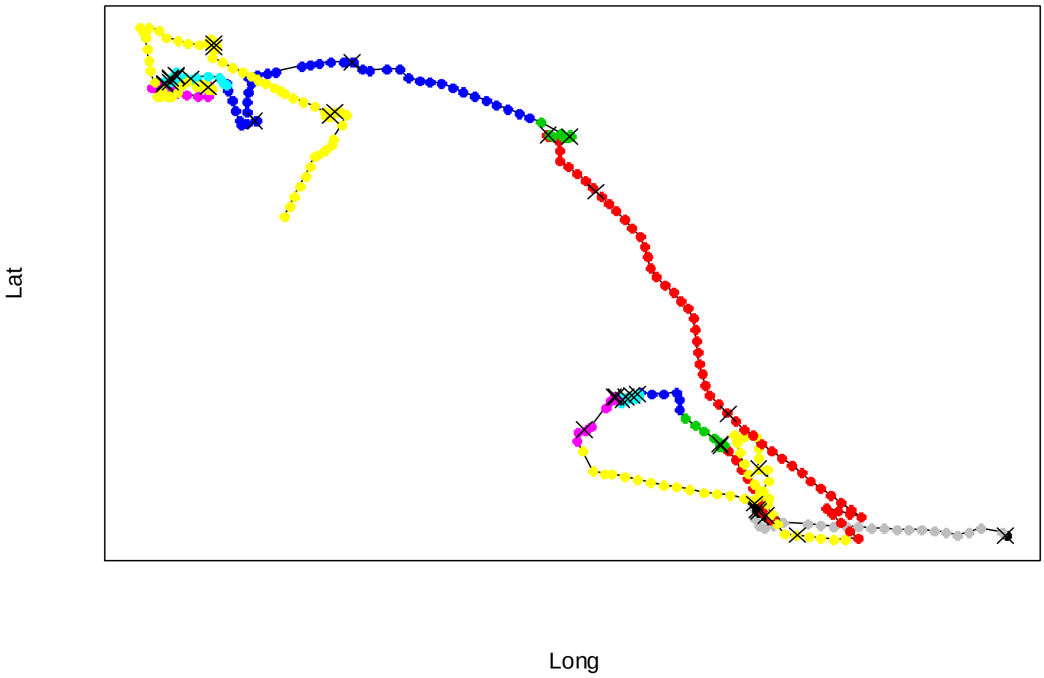

Figure 4. The assignment of individual VMS locations from a fishing trip (Trip 35638) to segments of comparable movement behaviours (partitions) (represented by different colours). The location of logsheet records are denoted by a cross.

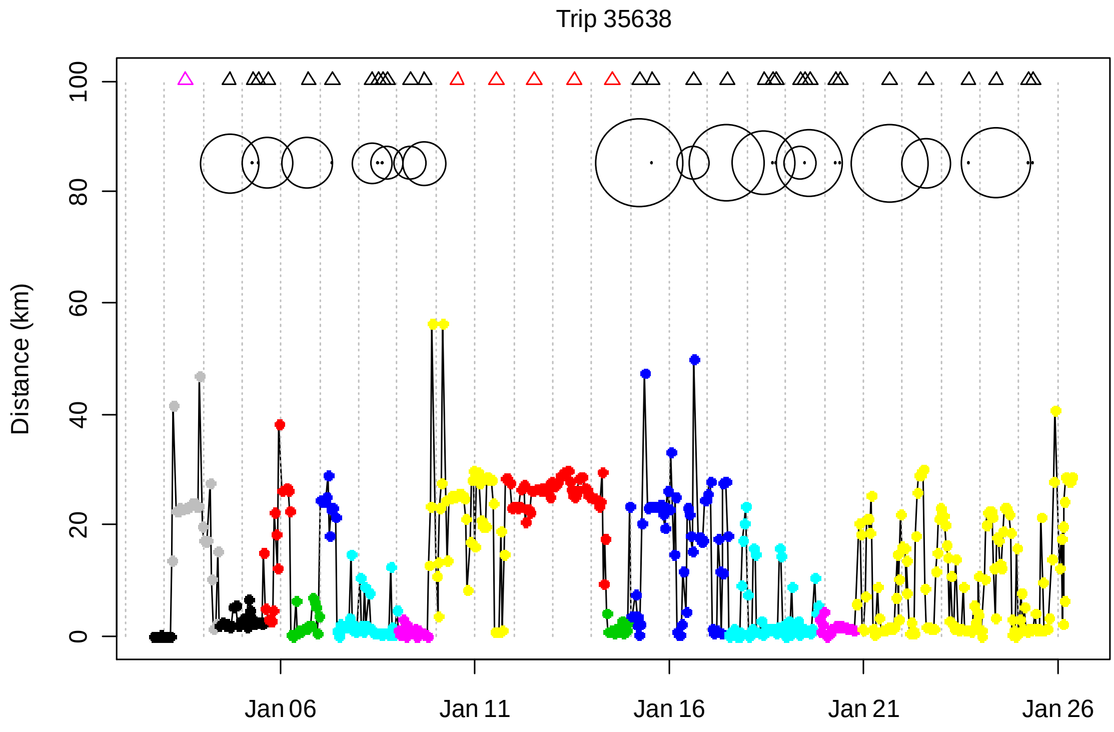

Figure 5. An example of the distance moved between individual VMS records during an individual fishing trip (black lines). The coloured points on the black line denote the individual segments of the fishing trip based on the movement dynamics defined using the VMS movement data (25 segments). The triangles represent individual activity records from the logsheet data (black, fishing; red, searching; pink, steaming). The circles are proportional to the combined catch of skipjack and yellowfin tuna from the individual purse-seine sets. Dates and times are UTC and the dashed vertical lines represent 00:00 UTC for each day of the trip.

For each fishing trip, the *modpartltraj* algorithm was applied to define the individual segments (partitions) of the VMS trajectory. A range of metrics were then determined for each partition, specifically:

- The start and end date and time of the partition in UTC.
- The duration of the partition apportioned into daytime and nightime.
- The number of VMS records in a partition.
- The total distance steamed in the partition (great circle distance, km) between individual VMS locations.
- Average vessel speed and standard deviation of the speed among records in the partition.
- The median longitude and latitude of the VMS records within the partition.
- The number of movements in a partition that involved a change in direction exceeding 90°.
- The number of VMS records with a recorded speed of less than 5 kph.
- The number of VMS records with a recorded speed exceeding 15 kph.
- The number of VMS records that were at least 20 km from the previous record.
- The maximum distance moved between successive VMS records in a partition.
- The number of logsheet records within the partition.
- The number of logsheet records within the partition that recorded fishing or searching.
- The number of logsheet records within the partition that recorded active fishing.
- The number of associated sets conducted within the partition (from logsheet).
- The number of unassociated sets conducted within the partition (from logsheet).
- The total estimated skipjack tuna catch from the partition (from logsheet).
- The total estimated yellowfin tuna catch from the partition (from logsheet).

A subset of these variables (or derived variables) was then incorporated in a cluster analysis to identify the main modes of vessel activity within the combined data set (all trips and all partitions exceeding 6 hours duration). Individual trips were excluded if there were long periods without associated logsheet data or VMS data. The final data set included 186 fishing trips and 2,258 partitions that averaged 36 hours in duration (3,387 days total).

The metrics included in the cluster analysis were as follows.

- The proportion of VMS records (per partition) with a speed exceeding 8 knots (*prop. move fast*).
- The proportion of VMS records (per partition) with a speed less than 2 knots (*prop. move slow*).
- The average speed of the vessel (per partition) (*speed*).
- The coefficient of variation of the speed of the vessel among records within the partition (*speedcv*).
- The average distance steamed from the VMS records within a partition (*amove*).
- The coefficient of variation of the distance steamed by the vessel among records within the partition (*distance cv*).
- The proportion of VMS records (per partition) that changed direction by at least 90° (*prop. change bearing*).
- The proportion of VMS records (per partition) with a movement exceeding 20 km (*nmove*).
- The proportion of the partition within the hours of daylight (between sunrise and sunset) (*prop day*).

For each of the variables in the data set, the individual observations were normalised relative to the maximum observed value. A hierarchical clustering algorithm (hclust in *R*) was applied to the data set and six clusters were defined from the resulting dendrogram. The vessel movement patterns and associated fishing activity from logsheet records were then used to characterise the mode of operation for each cluster.

Results and Discussion

The characteristics of each cluster were defined based on the variables included in the cluster analysis (Figure 7). These clusters can be interpreted as different modes of vessel activity, although some of the differences in activity are related to the frequency of VMS transmission and further standardisation of these data is required to normalise for the VMS reporting rate, principally with respect to the distance metrics. The activity from the associated logsheet records was related to the individual clusters to determine the level of fishing activity associated with each cluster. Fishing activity was expressed in terms of the number of purse-seine sets (unassociated or associated) per hour for each VMS partition.

The characteristics of each cluster are described in the following table.

Cluster/activity	**Movement characteristics**	**Associated fishing activity (from logsheet)**
Cluster 1 *Steaming, transit*	• Most movements at higher speeds; **large movements** between successive locations. • Infrequent change in direction. • Relatively constant speed and distance (low c.v.s). • Activity during day and night. • Partitions average 30 hr. Average distance steamed 600 km.	• High level of steaming/searching activity recorded. • Small number of purse-seine sets. Low overall skipjack catch.
Cluster 2 *Searching*	• Most movements at low speeds; **small movements** between successive locations. • Frequent change in direction. • Variable speed and distance (higher c.v.s). • Activity predominantly during the **day**. • Partitions average 22 hr. Average distance steamed 79 km.	• Limited steaming/searching activity recorded. • Small number of purse-seine sets. **Low** overall skipjack catch.
Cluster 3 *Fishing/Searching*	• Most movements at low speeds; **small movements** between successive locations. • Frequent change in direction. • Variable speed and distance (higher c.v.s). • Activity predominantly during the **night**. • Partitions average 31 hr. Average distance steamed 95 km.	• High level of steaming/searching activity recorded. • Highest level of purse-seine fishing activity. **Highest** level of skipjack catch.
Cluster 4 *Searching/Fishing*	• Combination of **small and large movements** between successive locations. Moderate average speed with relatively high c.v. • Frequent change in direction. • Activity during day and night. • Partitions average 67 hr. Average distance steamed 664 km.	• Moderate level of steaming/searching activity recorded. • Moderate level of purse-seine fishing activity. **Moderate** level of skipjack catch.
Cluster 5 *Searching/Steaming*	• Most movements at higher speeds; **large movements** between successive locations. • Infrequent change in direction. • Relatively constant speed and distance (low c.v.s). • Activity during day and night. • Partitions average 40 hr. Average distance steamed 626 km.	• Moderate level of steaming/searching activity recorded. • Low-moderate level of purse-seine fishing activity. **Low-moderate** level of skipjack catch.

Cluster 6 *Searching*	• Combination of **small and large movements** between successive locations. Moderate average speed and distance with relatively high c.v. • Frequent change in direction. • Activity predominantly during the **day**. • Partitions average 12 hr. Average distance steamed 133 km.	• Limited steaming/searching activity recorded. • Limited level of purse-seine fishing activity. **Low** level of skipjack catch.

Overall, there is a weak relationship between the activity of the vessel, as defined by the cluster analysis, and the associated logsheet activity (fishing and/or searching). Vessels transiting between locations are reasonably easy to delineate simply by the speed and constant direction of the vessel (cluster 1) (Figure 9).

Fishing activities tend to be associated with the smaller scale vessel movements (clusters 3 and 4). Some of these small scale movements will be related to the stationery nature of the fishing operation (setting and retrieval of the net) and therefore such a relationship would be expected.

There may also be limited movements overnight as a vessel remains at a specific location before fishing the following morning. Alternatively, the vessel may fish at a location during the day and remain in the vicinity until the next day. This may explain the high level of fishing activity and catch associated with cluster 3 despite the constituent partitions being dominated by night-time periods. Figure 10 presents an example of the vessel track assigned to cluster 3 and the associated fishing/searching activity. The vessel has fished in a localised area during the day (20 Jan, pink segment in Figure 5) and then moved a small distance over the following night. Over the subsequent five day period, the vessel undertook relatively directed movements between discrete areas and conducted fishing at a number of locations (Figure 11). This activity, encompassing active searching behaviour and fishing, was assigned to cluster 4.

Clusters 2, 5, and 6 include limited fishing activity and are characterised by different combinations of small- and larger scale movements. Broadly, these clusters could be categorised as local-scale searching activity (cluster 2), larger scale movements encompassing both steaming and searching (cluster 5), and variable searching activity (cluster 6). However, a more thorough analysis of the associated logsheet (and observer) data is required to determine the vessel activity associated with these clusters.

Clearly, most vessel behaviours cannot be simply categorised by the VMS movement data alone. The behaviours of individual vessels do not to conform to the simple set of classification rules considered in the current study and there is likely to be considerable overlap in the range of vessel behaviours. Further refinement of the analytical approach is required to more adequately define the individual segments (partitions) of the VMS data and summarise the associated vessel activity within each partition. A simple next step would be to accept that the VMS data alone is not adequate to define behaviour types and include the corresponding logsheet data in the clustering approach.

For each fishing trip, the number of segments (per trip) applied to partition the vessel movement (VMS) data was predetermined. The assigned number of segments is likely to be sub-optimal; however, the computational demands of the analysis precluded searching for an optimal number of segments for each trip. The analytical approach determines the optimal break points along the sequence of movements, rather than characterising movement types based on successive individual movements (i.e. all movements within a single partitions are simply viewed as individual observations from the same distribution of movements). Ideally, the analytical approach would be refined to accommodate more complex movement patterns as candidate movement models and/or integrate autocorrelation in the movement processes to define discrete behavioural patterns.

In addition, a more complex range of descriptive statistics could be developed to characterise periods of vessel movement. Initially, such statistics should investigate diurnal patterns in vessel activity on the basis that visual searching for unassociated tuna schools is limited to daytime. During night-time, vessel activity may be limited to either transiting between separate fishing locations or remaining “on station” until recommencing searching and/or fishing at dawn. During daytime, a vessel is likely to participate in a wider range of activities related to fishing on unassociated schools, including transiting between locations, broad scale searching activity, localised searching activity, and activity associated with setting and retrieval of the fishing gear. VMS, the associated logsheet and observer data could be utilised more extensively to assign periods of vessel activity to each of these behavioural categories.

In turn, these categories could form the basis for developing a range of performance indicators for the unassociated purse-seine fishery. Such indicators could include:

- The frequency that a vessel moves between successive fishing/searching locations.
- The distance between successive fishing/searching locations.
- The duration and area searched (including by helicopter) at a new location prior to commencing fishing (setting).
- The number of successful sets conducted at a specific fishing location.
- The duration that a vessel remains at a location before moving to a new location.
- The number of other vessels actively searching/fishing in the location.
- The spatial scale of the unassociated purse-seine fishery relative to the entire equatorial purse-seine fishery.

A review of these metrics would enable a more comprehensive consideration of the utility of such “searching based” measures of fishing effort and fishery performance of the purse-seine fishery. However, this would also require an understanding of the dynamics (ocean condition, location, regulatory constraints, etc) that influence the switching of the mode of fishing between targeting unassociated and associated (FAD based) tuna schools.

Conclusions

This study is exploratory in nature and was primarily conducted to stimulate discussion on the application of VMS data to quantify the searching component of the fishing effort in the unassociated purse-seine fishery, which is seen as a necessary pre-cursor to the development of a purse-seine-based CPUE index that might be useful for estimating relative abundance of skipjack and yellowfin tuna. VMS data are highly resolved both spatially and temporally and conceptually are informative regarding active searching behaviour of the purse-seine fleet, particularly when analysed in conjunction with other sources of data from the fishery (logsheet and observer data).

The study explored a potential approach to discriminate between searching behaviour and other vessel activities. The study is relatively novel in approach and is reliant on the identification of different patterns of movement to characterise the range vessel behaviours. However, alternative analytical approaches may improve the discrimination of the searching and fishing activity at the vessel and fleet level. Initially, it is proposed to focus further analysis on the characterisation of the range of searching behaviours that precede the active fishing on unassociated schools of tuna. These searching behaviours can then be applied to inform the processing of the VMS data to quantify the nature and duration of searching activity during individual fishing trips (or in conjunction with sectors of the fleet; i.e. “code groups”).

There is a strong correspondence between the location data from the VMS and logsheet data sets. However, further work is required to resolve discrepancies in the time recorded on vessel logsheets to enable a more direct amalgamation of the two data sources. These issues provide some challenge in the effective processing of these data, although a range of simple algorithms can be developed to improve the referencing of the VMS and logsheet data. To date, there has been limited application of the observer data and these data are likely to compliment and augment the data collected by vessel logsheets. The large volume of data collected, particularly via VMS, means that the processing of these data is computationally intensive. For this reason, it is recommended that preliminary analyses of these data are focussed on subsets of individual fishing trips that are relatively representative of the broader activity of the fleet.

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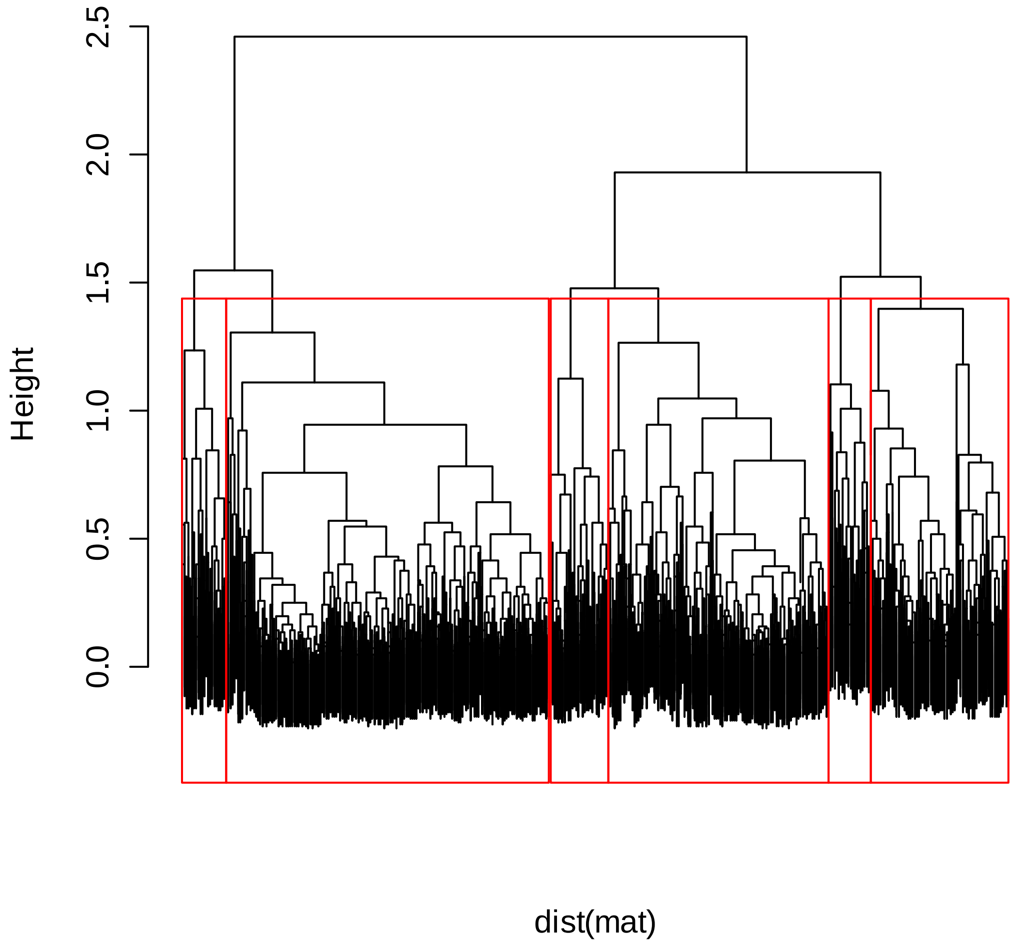

Figure 6. Cluster dendrogram from the hierarchical clustering of the variables derived for the individual VMS segments (partitions). The rectangles around the branches of a dendrogram highlight the six defined clusters.

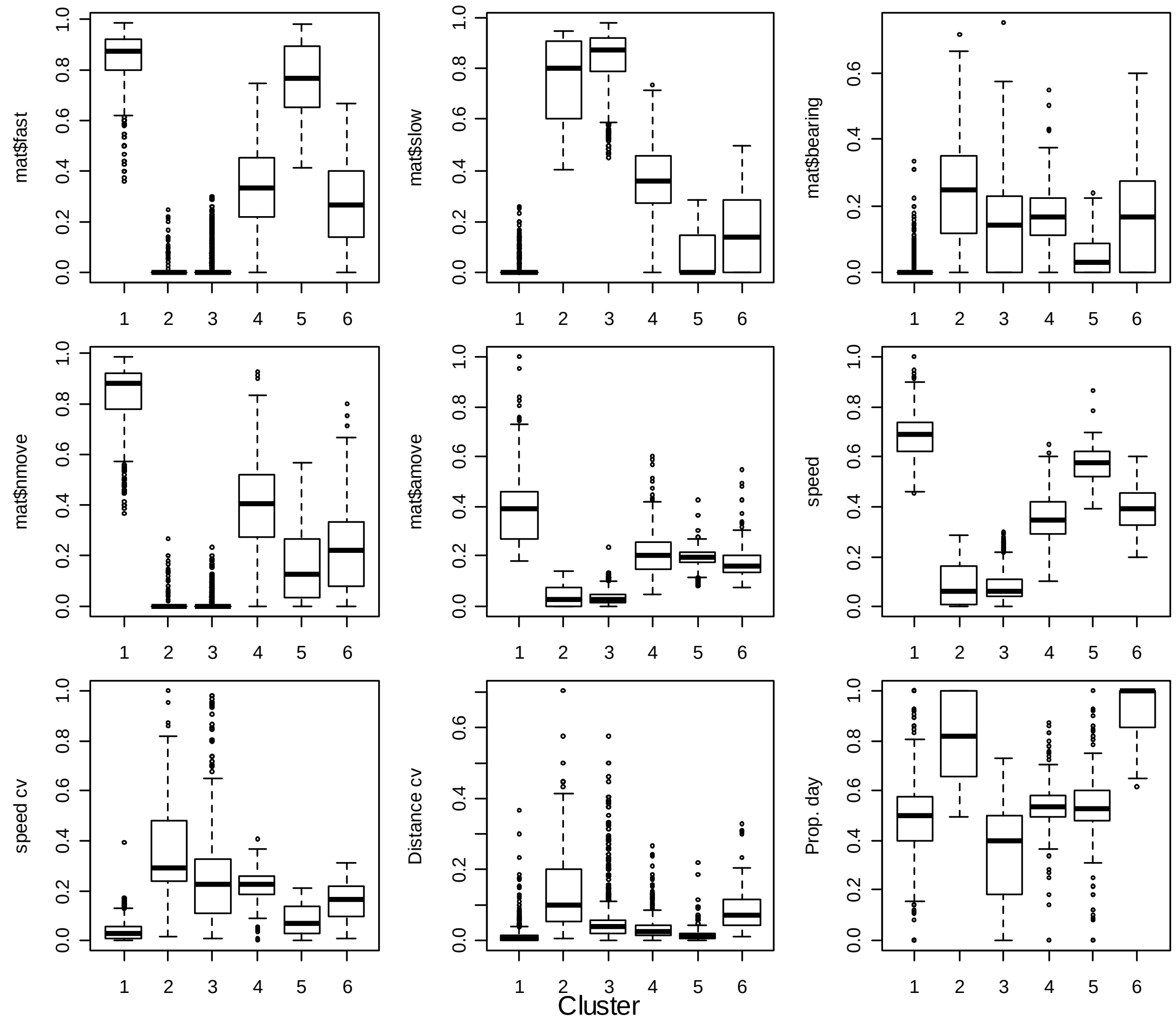

Figure 7. Boxplots (for each cluster) of the variables included in the hierarchical cluster analysis.

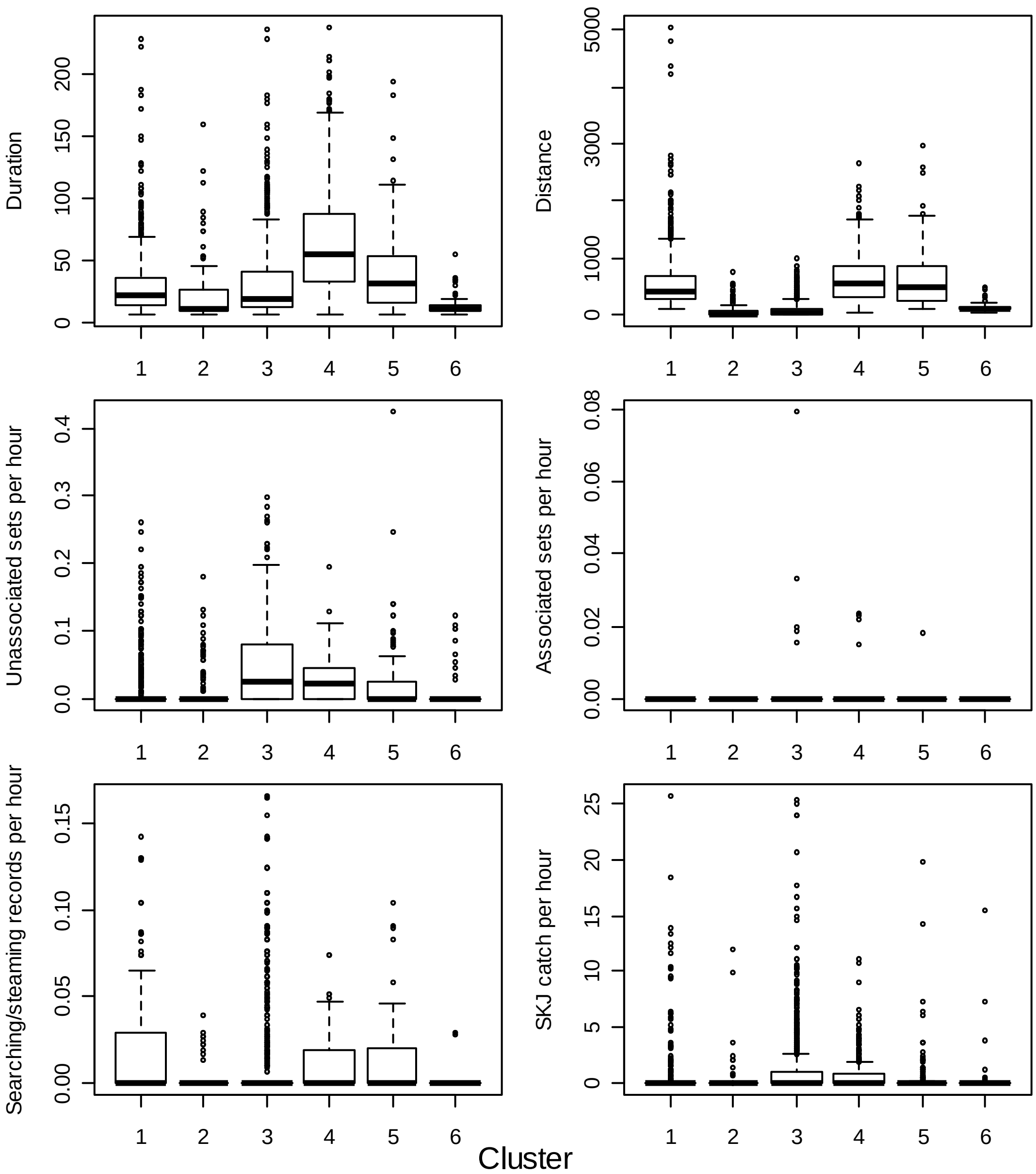

Figure 8. Boxplots of variables related to the fishing activity associated with each cluster defined from the hierarchical cluster analysis.

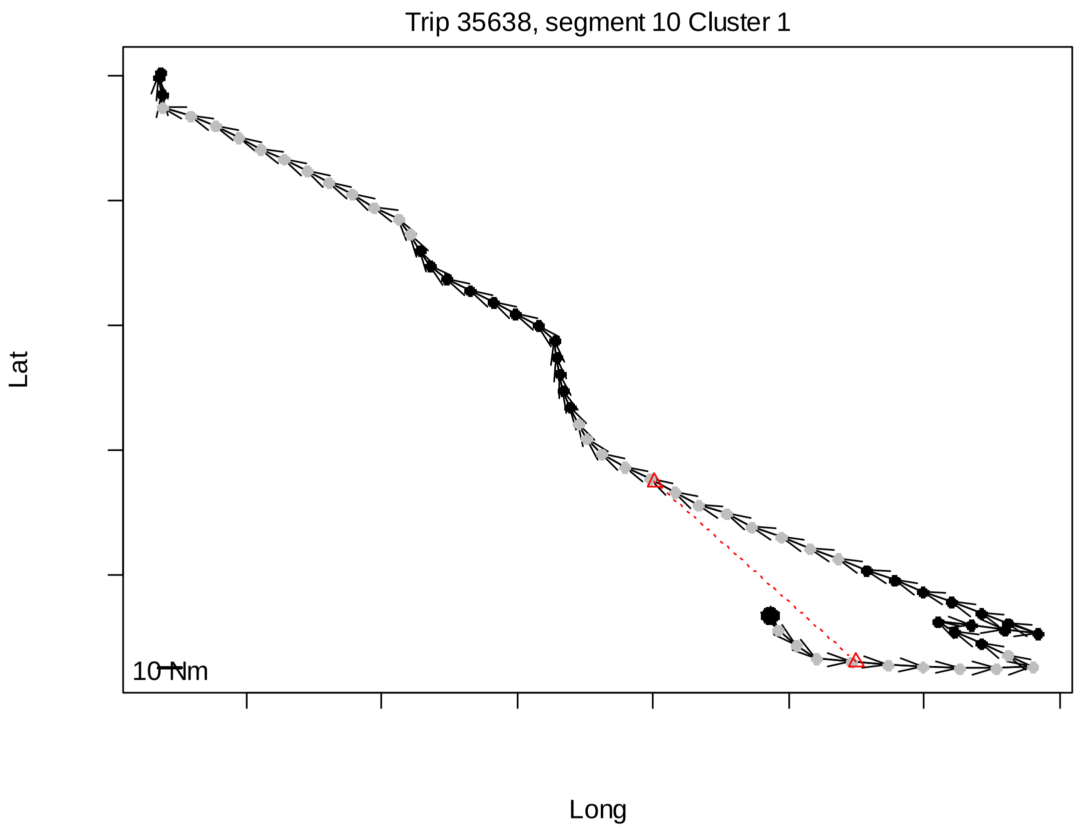

Figure 9: The location of individual VMS positions (points) from a segment of the example trip assigned to cluster 1 (steaming). The arrows represent the direction of movement between VMS locations. The black and grey points represent night and day locations, respectively. The red triangles represent the location of the vessel while steaming (from logsheet records). The scale is given in the bottom, left corner. The labels of the axes are not plotted for confidentiality reasons.

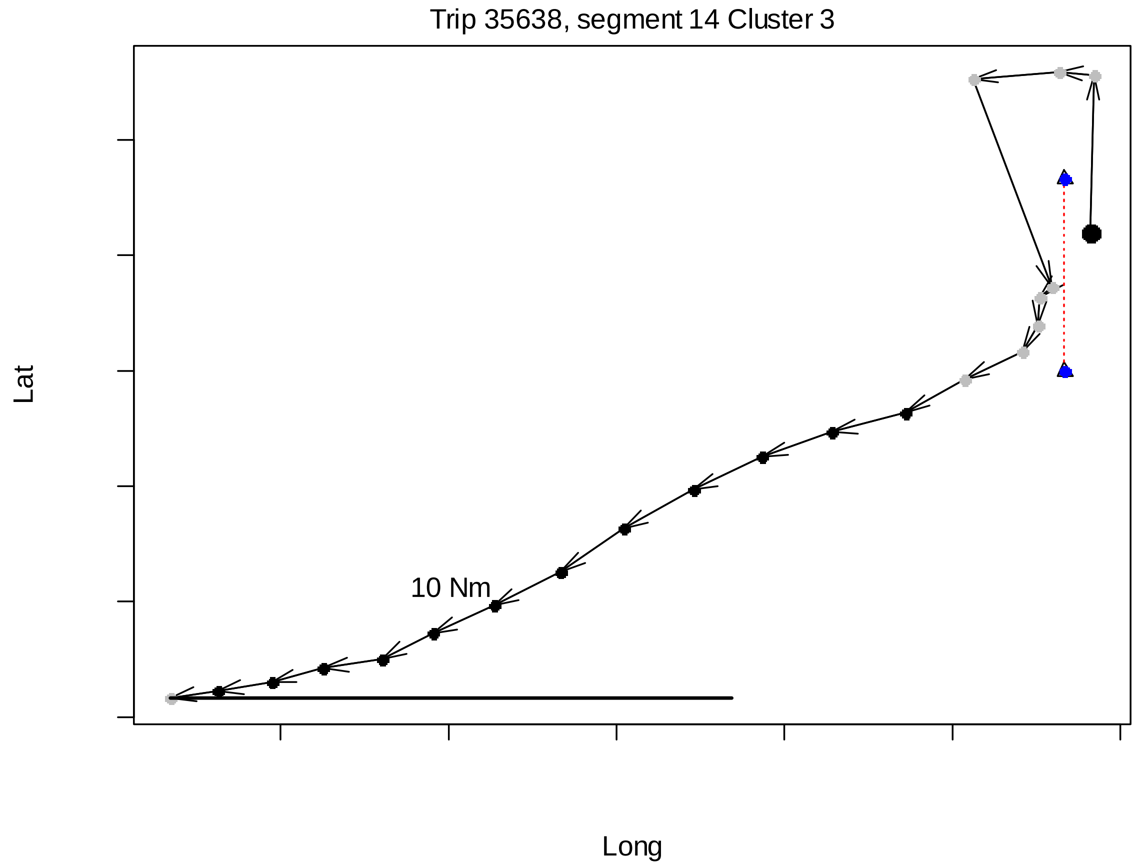

Figure 10. The location of individual VMS positions (points) from a segment of the example trip assigned to cluster 3 (fishing/searching). The arrows represent the direction of movement between VMS locations. The black and grey points represent night and day locations, respectively. The blue points represent the location of purse-seine sets on associated fish schools (from logsheet records). The scale is given in the bottom, left corner. The labels of the axes are not plotted for confidentiality reasons.

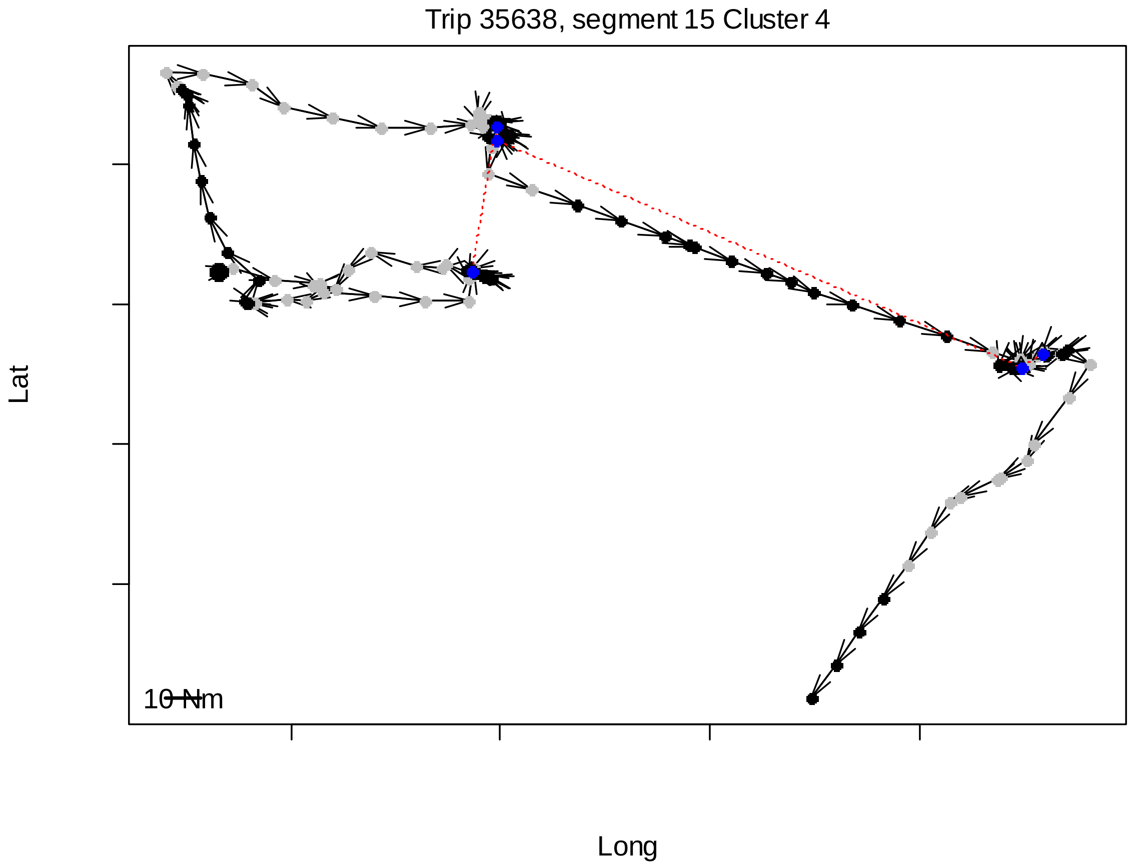

Figure 11. The location of individual VMS positions (points) from a segment of the example trip assigned to cluster 4 (searching/fishing). The arrows represent the direction of movement between VMS locations. The black and grey points represent night and day locations, respectively. The blue points represent the location of purse-seine sets on associated fish schools (from logsheet records). The scale is given in the bottom, left corner. The labels of the axes are not plotted for confidentiality reasons.