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# An evaluation of the characteristics of the gear used by the Cook Island and Japan trawl vessels within the SIOFA area

Delegations of Cook Islands and Japan

Stephen Brouwer<sup>3</sup>, Takehiro Okuda<sup>4</sup>, Charles Heaphy<sup>5</sup> and Lualua Tua-Trood<sup>3</sup>

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<b>Abstract</b>	
<p>This analysis evaluated the classification of trawl types using operational variables collected during trawl sets from Cook Island and Japanese trawl vessels operating in the SIOFA area. Clear operational signatures of mid-water, benthopelagic and bottom trawling were determined. There are clear distinctions between trawl set types and it is recommended that each be considered separate gear for use in stock assessment models. Benthopelagic and bottom trawling are the most similar and importantly the net height above the bottom indicated that the vast majority of benthopelagic sets come into close proximity to the seabed. As a result of this it is recommended that benthopelagic trawls be considered to be bottom fishing gear. In order to provide some clarity to trawl operators, any mid-water set where the net drops below 50m above the seabed, or the tow speed is more than three knots or active fishing tow duration is less than 30 minutes should be classified as benthopelagic.</p>	

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<sup>3</sup>Ministry of Marine Resources Cook Islands

<sup>4</sup>Japan Fisheries Research and Education Agency

<sup>5</sup>SIOFA

**Recommendations (for proposals and working papers only)**

1. Recommended that mid-water, benthopelagic and bottom trawl gear be considered separate trawl types and should be treated as such in stock assessment models.
2. Recommended that in future all Cook Islands mid-water trawls be considered to be benthopelagic trawls.

## 1. Introduction

Commercial fishing operations in the Southern Indian Ocean Fisheries Agreement (SIOFA) area target a variety of deep-sea species including splendid alfonsino (*Beryx splendens*) and orange roughy (*Hoplostethus atlanticus*). These fisheries are prosecuted primarily by Cook Islands and Japanese trawl vessels operating across a range of depths and using different trawling techniques (Shotton, 2006). Accurate characterisation of fishing gear types and their operational parameters is essential for effective fisheries management, stock assessment, and minimizing environmental impacts on vulnerable marine ecosystems (Clark et al., 2016; Pitcher et al., 2017). Stock assessment models require accurate fishing gear characteristics in order to effectively standardise catch and effort data.

Within SIOFA, trawl fishing has been undertaken since the early 1970s, but effort has been and continues to be relatively low and primarily conducted by vessels from the Cook Islands and Japan. Since the inception of this fishery the Cook Islands has had a maximum of three vessels operating, and Japan has had a maximum of two (Delegation of the Cook Islands, 2025; Delegation of Japan, 2025). But in the most recent years both have only fished with one vessel. Despite this these two Contracting and Cooperating Parties (CCPs) account for most of the catch of alfonsino and orange roughy (SIOFA Secretariat, 2025a; SIOFA Secretariat, 2025b) within the SIOFA area.

Trawl fishing in deep-sea environments employs three primary gear configurations: mid-water trawls that fish in the water column well above the seabed, bottom trawls that maintain contact with the seabed, and benthopelagic trawls that operate in close proximity to the bottom without making sustained contact (Koslow et al., 2000; Morato et al., 2006). The classification of these gear types has traditionally relied on fisher declarations at the time of deployment. However, the operational distinction between these categories, particularly between benthopelagic and mid-water trawling, is not always clear-cut and may vary between fleets with different fishing traditions and target species (Branch, 2001; Walmsley et al., 2007).

The need for objective gear classification is particularly acute in Regional Fisheries Management Organizations (RFMOs) such as SIOFA, where CCPs are required to submit detailed operational data to support science-based management decisions (Rogers and Gianni, 2010; Wright et al., 2015). These data can be used when standardising Catch per Unit Effort (CPUE) data. Misclassification or ambiguous categorization of trawl types can lead to inaccurate assessments of fishing impacts on benthic habitats, improper effort allocation, and difficulties in implementing gear-specific management measures (Auster and Langton, 1999; Thrush and Dayton, 2002). Furthermore, different trawl types are associated with distinct catch compositions and size selectivities, making accurate gear characterisation critical for understanding fish population dynamics and ecosystem effects (Jennings et al., 2001; Shephard et al., 2012).

Previous studies have demonstrated that operational parameters such as tow speed, duration, net depth and bottom clearance can provide objective indicators of fishing gear behaviour (O'Neill et al., 2003; Eigaard et al., 2014). However, comprehensive analyses integrating multiple operational variables to classify trawl types have been limited, particularly for deep-sea fisheries in the Indian Ocean (Clark and Dunn, 2012). The advent of detailed observer programs and electronic monitoring has created new opportunities to develop data-driven classification systems based on actual fishing behaviour rather than fisher declarations alone (Mangi et al., 2015; Van Helmond et al., 2020).

The objectives of this study were threefold: first, to characterise the operational parameters of different trawl types used by Cook Islands and Japanese vessels targeting alfonsino and orange

roughly in the SIOFA area. Secondly, to identify the key variables that distinguish mid-water, benthopelagic, and bottom trawling operations. Finally, to develop and validate a predictive model capable of classifying trawl type based on operational and environmental variables. By establishing objective criteria for gear classification, this work aims to support improved fisheries management and provide a framework for standardising trawl type reporting across fleets operating in the SIOFA area.

## 2. Methods

Within SIOFA CCPs are required to submit data to the secretariat. These data are stored in a database. The data for the Cook Islands and the Japanese trawl vessels were extracted for analysis. The data for Japan and the Cook Islands were analysed separately using the same analysis code and the results pooled for the final analysis. The data were collated and cleaned in R (R Core Team, 2013) prior to the analyses being conducted in R.

The data consisted of data aggregated by year, as well as logsheet and observer data which are fine scale set by set data. The aggregated data were largely uninformative and were dropped from further analysis. The observer data proved the most useful and were used for the remaining analyses. Both the Cook Islands and Japanese fleets have 100% observer coverage (Delegation of the Cook Islands, 2025; Delegation of Japan, 2025).

At the time of the set, the vessel declares that set type as mid-water or bottom trawling. While the Japanese fleet undertakes true mid-water trawls, the mid-water trawl sets undertaken by the Cook Islands are more correctly classed as benthopelagic trawls (Shotton and Heaphy, 2024). Trawl sets were grouped into mid-water, benthopelagic and bottom trawling.

The data were then assessed by trawl speed, tow duration, distance travelled, bottom depth, net depth, change in depth, height of net above the seabed, species composition of the set and fish size. Then these data were used in a prediction model.

A multinomial logistic regression model was developed to predict trawl type (mid-water, benthopelagic or bottom) using operational and environmental variables recorded during fishing operations. The model was fitted using the multinom function from the nnet package in R. Predictor variables included: target species as a categorical factor, depth measurements at the start and end of tows for both the seabed and the net, operational metrics including tow distance, duration, and speed, net height measurements at the beginning and end of each tow, and depth change variables for both the bottom topography and net position. The multinomial model was formulated as follows:

*Trawl type* ~ *factor(target species) + start depth + end depth + net start depth + net end depth + distance + tow duration + tow speed + net height end + net height start + depth change bottom + depth change net*

The dataset was partitioned into training and testing subsets, with model parameters estimated from the training data.

Model performance was evaluated on the testing dataset using a confusion matrix to assess overall accuracy, class-specific sensitivity and specificity, and Cohen's kappa statistic for agreement beyond chance. This modelling approach allowed for simultaneous estimation of the probability of each trawl type category based on the combination of predictor variables.

Model predictions were generated for the test dataset by applying the fitted multinomial logistic regression model. For each observation, the model calculated predicted probabilities for all three trawl type categories (mid-water, benthopelagic and bottom), with each observation classified into the category with the highest predicted probability. Model performance was evaluated using a confusion matrix comparing predicted versus observed trawl types. Performance metrics included overall classification accuracy with 95% confidence intervals, Cohen's kappa statistic, and class-specific measures of sensitivity, specificity, positive predictive value, and negative predictive value for each trawl type. This evaluation approach allowed for comprehensive assessment of model performance across all categories and identification of potential classification biases.

### 3. Results

Since 2007 most of the trawl fishing effort within SIOFA has been undertaken by the Cook Islands and Japan. The trawl catch data reflect this and these two countries account for the bulk of the catch of both alfonsino and orange roughy.

Assessing the species composition of the catch showed that alfonsino (*Beryx splendens*) were caught in mid-water, benthopelagic and bottom trawl sets (Figure 1). Whereas, violet warehou (*Schedophilus velaini*), bluenose warehou (*Schedophilus velaini*), escolar (*Lepidocybium flavobrunneum*) and hapuka (*Polyprion oxygeneios*) were not caught in bottom trawls. Orange roughy (*Hoplostethus atlanticus*) and spiky oreo (*Neocyttus rhomboidalis*) are exclusively caught in bottom trawls (Figure 1).

The data show that for alfonsino are presented in Figure 2. These data show that smaller alfonsino (fish below 35cm) are caught in mid-water trawls.

Generally, mid-water trawls occur in shallower water with starting depths shallower than 550m (Figure 3). Bottom trawls are almost always deeper than 850m at the start and over 1000m at the end. Mid-water trawls tend to have the smallest change in net depth. Whereas, bottom trawls have the deepest net depth change. Benthopelagic trawls sit between the two but are skewed towards the bottom trawls.

Net clearance shows clear trends where bottom trawl sets are in contact with the bottom with zero net clearance, mid-water sets have a high clearance with benthopelagic sets normally below 50m off the bottom (Figure 4). Mid-water trawl sets are normally above 50m above the bottom at the start and end of the sets.

Bottom trawl and benthopelagic trawls have a short travel distance normally below 1nm, whereas mid-water trawls are often over 3nm. Bottom and benthopelagic trawls are always shorter than one hour, and mostly shorter than 30 minutes (Figure 5). Mid-water trawls are normally longer than one hour. Mid-water trawls have slow speeds normally less than two knots most bottom and benthopelagic sets occur at speed of two knots or more.

The model results showed that target species, net height above the seabed, tow duration and tow speed are very influential (Figure 6). In the model, model accuracy and factor importance identify these factors as being the leading elements in identifying set types. In summary the model clearly identified set types (Figure 7), with mid-water trawls classified with net depths shallower than 625m, tow speeds less than 3 knots and long tow durations of more than 30 minutes. Benthopelagic trawls fish with net depths from 750 to about 900m deep, have faster tow speeds (2.5-2.75 knots) and short fishing duration (up to 30 minutes). Bottom trawls are deep

usually 1,000m or more, with fast tow speeds (over 2.5 knots), have a change in net depth during the active fishing period of more than 250m and a very short duration less than 30 minutes of active fishing (although the total trawl time is longer due to the time taken to get the net to fishing depths and back to the surface after fishing) (Figure 7).

The confusion matrix shows excellent model performance with clear actual vs predicted classifications. The classification showed that 519 mid-water tows were correctly predicted as mid-water; 994 benthopelagic tows correctly predicted as benthopelagic; and 226 bottom tows were correctly predicted as bottom trawls. There were only 29 misclassifications out of 1,768 observations.

The model predicted an accuracy of 98.36% correctly with 95% CI: (97.65%, 98.90%). The Kappa statistic of 0.9711 is a measure of agreement beyond chance, anything above 0.8 is considered to be excellent. The P-value < 0.0001 shows that the model performs significantly better than random chance.

#### 4. Discussion

This study successfully developed and validated a highly accurate predictive model for classifying trawl types in the SIOFA deep-sea fisheries, achieving 98.36% classification accuracy with only 29 misclassifications out of 1,768 observations. Some of these misclassifications could be a result of the tow being misspecified in the observer data set. The exceptional model performance demonstrates that operational and environmental variables can reliably distinguish between mid-water, benthopelagic, and bottom trawling operations, providing an objective alternative to fisher declarations alone. This level of accuracy exceeds that reported in similar gear classification studies in other fisheries (Matic-Skoko et al., 2011; Maina et al., 2018).

The analysis revealed clear and consistent operational signatures for each trawl type. Mid-water trawls operated in relatively shallow waters (net depths <625m), employed slow tow speeds (<2 knots), and conducted extended fishing operations (>1 hour) covering substantial distances (often >3 nautical miles). These characteristics reflect the pursuit of pelagic and semi-pelagic target species such as alfonso across broad areas of the water column. The long tow durations and slow speeds are consistent with search patterns designed to encounter patchily distributed schools of mid-water fish (Freon and Misund, 1999; Klages et al., 2014).

In contrast, bottom trawls operated in deep water (typically >1,000m), used faster tow speeds (>2.5 knots), and conducted very short active fishing periods (<30 minutes). The substantial changes in net depth (>250m) during bottom trawl operations reflect the topography and fishing method where bottom trawls are conducted down the slopes of the seabed with high profile relief. These characteristics align with targeting aggregations of demersal species such as orange roughy and spiky oreo that form dense concentrations over specific seabed features (Clark, 1996; Tracey et al., 2004; Dunn et al., 2009).

Benthopelagic trawling emerged as a distinct intermediate category, operating at moderate depths (750-900m), employing moderate-to-fast tow speeds (2.5-2.75 knots), and maintaining short fishing durations (up to 30 minutes). Critically, these operations maintained close proximity to the bottom (typically within 20m) without sustained seabed contact, but periodic unintended seabed contact can occur. This classification validates the operational reality of Cook Islands fishing practices, which the fishers themselves distinguish from true mid-water trawling despite deploying similar gear configurations (Smith and Brown, 1983; Koslow et al., 2000). This arises

from the method of targeting alfoncino where the large fish aggregate close to seamounts and to catch them successfully the fishing gear needs to be flown over and down the side of a seamount, but within the water column.

The strong association between trawl type and catch composition provides both validation of the classification system and insights into species ecology. The exclusive capture of orange roughy and spiky oreo in bottom trawls confirms their strictly demersal behaviour and association with specific seabed habitats (Clark et al., 2000; Tracey and Horn, 1999). Conversely, the absence of violet warehou, bluenose warehou, escolar, and hapuku from bottom trawls indicates these species occupy mid-water or benthopelagic zones and do not form fishable aggregations on the seabed in SIOFA waters (Stewart and Smith, 1994; Roberts, 2002).

The occurrence of alfoncino across all three trawl types reflects the species' vertical distribution and behavioural plasticity. Alfoncino are known to exhibit diel vertical migrations and can form aggregations at various depths depending on local oceanographic conditions and seabed topography (Shotton, 2016). This broad distribution makes alfoncino a valuable indicator species for distinguishing fishing strategies but also highlights the importance of gear-specific catch reporting for accurate stock assessment (Branch, 2001; Shotton, 2014). In particular the smallest alfoncino are landed in mid-water sets, this is to be expected as juvenile alfoncino are pelagic, while the adults are suprabenthic and associated with marine topographic features like seamounts (Widdrington et al., 2026b and Widdrington et al., 2026a).

From a management perspective, these species-specific associations have important implications for spatial planning and ecosystem-based management. Bottom trawling, which makes direct contact with the seabed, carries the highest risk of impact to benthic habitats and vulnerable marine ecosystems (VMEs). The concentration of this gear type in deeper waters (>850m) and its association with specific target species allows for more precise spatial management measures. Benthopelagic fishing, operating just above the bottom, represents an intermediate impact category that merits separate consideration in impact assessments and management frameworks (Fennessy, 1994; Lokkeborg, 2005).

The variable importance analysis identified target species, net height, tow duration, and tow speed as the most influential predictors of trawl type. The primacy of target species reflects the fundamental relationship between fishing strategy and target catch, with fishers deploying gear configurations optimized for specific species assemblages (Sainsbury, 2004; Hilborn and Walters, 1992). However, the strong predictive power of operational variables (net height above the seabed, tow duration and speed) demonstrates that actual fishing behaviour provides reliable classification even in cases where target species declarations may be ambiguous or when mixed-species strategies are employed (Pelletier and Ferraris, 2000).

The high classification accuracy across all three categories, with minimal confusion between classes, indicates that the operational signatures of each trawl type are distinct and consistent across the combined Cook Islands and Japanese fleets. This consistency despite different vessel origins and fishing traditions suggests that the physical and biological constraints of fishing at different depths for different target species impose similar operational requirements regardless of fleet nationality (Pitcher et al., 2009; Eigaard et al., 2014).

The few misclassifications that did occur (n=29) warrant investigation to identify potential transitional operations or unusual circumstances. These edge cases may represent genuine intermediate fishing behaviours, data recording errors, or situations where operational parameters fell outside typical ranges due to environmental conditions or gear malfunctions (Watson et al., 2006).

The development of an objective classification system for trawl types has several immediate management applications within SIOFA. First, it can serve as a quality control mechanism for fisher-reported data, flagging potential misclassifications or inconsistencies that may require investigation or correction (Kelleher, 2005; Branch et al., 2006). Second, it enables retrospective reclassification of historical data where trawl type declarations may have been inconsistent or ambiguous, improving the quality of long-term datasets used for stock assessment and ecosystem modelling (Caddy and Cochrane, 2001; Maunder and Punt, 2004).

Third, and perhaps most importantly, the model provides a framework for standardising trawl type reporting across CCPs with different fishing traditions and reporting practices. The distinction between benthopelagic and mid-water trawling, for example, may not be uniformly recognized or reported by all fleets, yet our analysis demonstrates it represents a real operational and ecological distinction. Adoption of objective classification criteria based on operational parameters could harmonize reporting and improve the comparability of data across fleets (Agnew et al., 2009).

For impact assessment purposes, the clear differentiation of bottom trawling from benthopelagic and mid-water operations allow for more accurate estimation of seabed contact and potential impacts on benthic communities. This is particularly relevant for implementing SIOFA's obligations to protect VMEs and manage bottom fishing activities in accordance with international guidelines. The model could support the development of gear-specific management measures, such as spatial closures or effort limits, tailored to the actual footprint and impact profile of each trawl type (Hilborn et al., 2004; Shotton and Patchell, 2008).

## 5. Conclusions

This study demonstrates that objective classification of trawl types in SIOFA deep-sea fisheries is achievable with high accuracy using operational and topographic variables readily available from existing data collection programs. The clear operational signatures of mid-water, benthopelagic, and bottom trawling, combined with their distinct catch compositions, validate the ecological and management relevance of maintaining these as separate categories. There are clear distinctions between trawl set types and it is recommended that each be considered separate gear and should be treated as such in CPUE analyses and stock assessment models. Noting that benthopelagic and bottom trawling are the most similar in almost all respects, in particular for tow speed, tow duration and importantly the net height above the bottom, where the vast majority of benthopelagic sets come into close contact with the seabed. As a result of this it is recommended that benthopelagic trawls be considered to be bottom fishing gear, as they are likely to touch the seabed in some cases when undertaking their normal operations, despite their best efforts to avoid touching the bottom and damaging the nets. It is also recommended that in order to provide some clarity to trawl operators, any mid-water set where the net drops below 50m above the seabed should be classified as a benthopelagic set.

The predictive model developed here provides a valuable tool for quality assurance, data standardization, and science-based management of these important fisheries. Implementation of objective gear classification systems should be considered as a best practice for RFMOs seeking to improve the accuracy and consistency of fisheries data in support of sustainable management and ecosystem protection.

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## Tables

**Table 1: Model prediction statistics by trawl gear from the multinom model predicting trawl type by gear characteristics.**

Model prediction statistic	Mid-water	Benthopelagic	Bottom
Sensitivity	0.9811	0.9861	0.9784
Specificity	0.9919	0.9803	0.9974
Pos Pred Value	0.9811	0.9851	0.9826
Neg Pred Value	0.9919	0.9816	0.9967
Prevalence	0.2992	0.5701	0.1307
Detection Rate	0.2936	0.5622	0.1278
Detection Prevalence	0.2992	0.5707	0.1301
Balanced Accuracy	0.9865	0.9832	0.9879

Figures

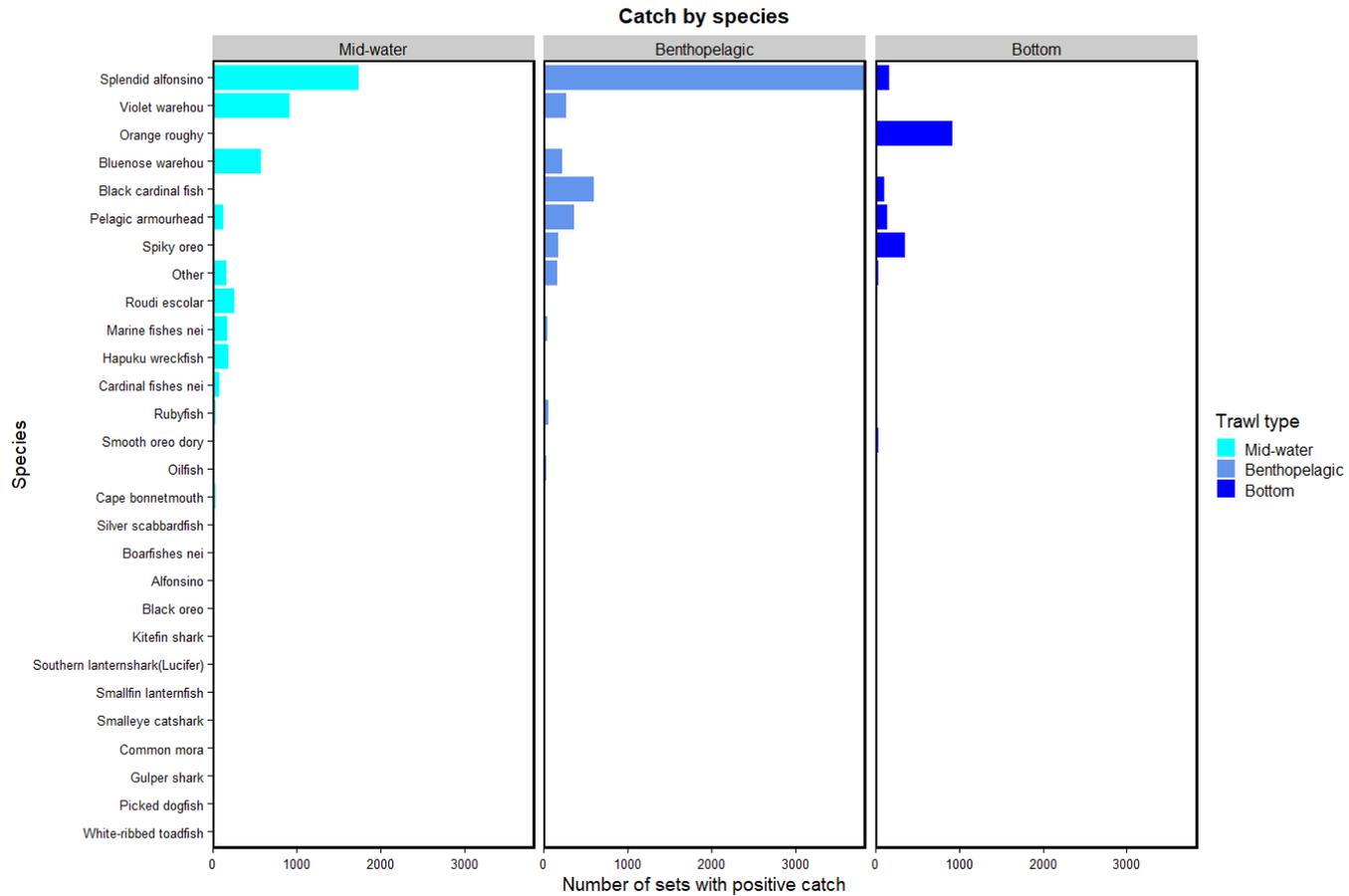


Figure 1: The species composition of the catch from the Cook Island and Japanese trawl fisheries within the SIOFA area by trawl tow type.

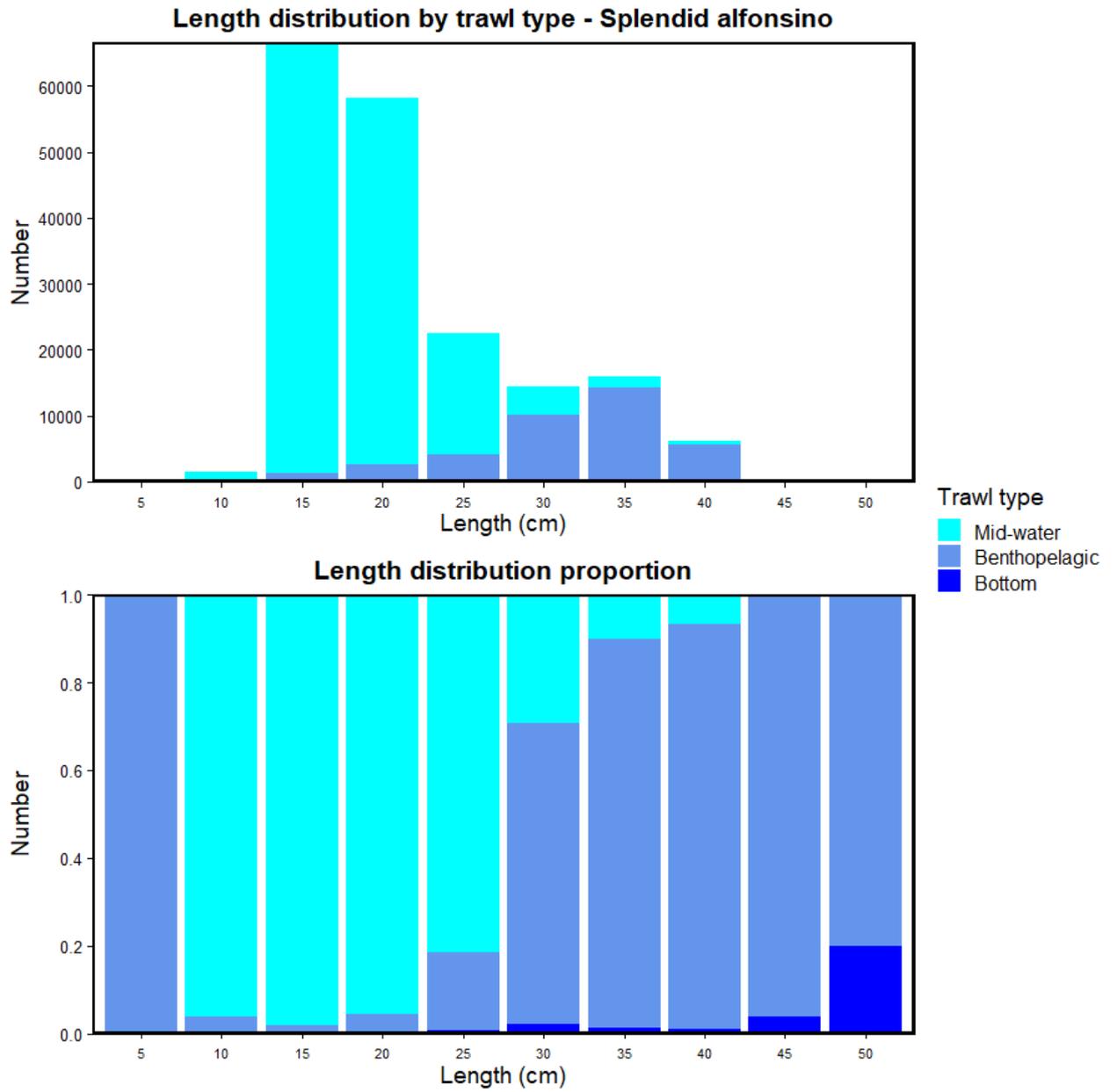


Figure 2: The size of alfonsino caught in the Cook Island and Japanese trawl fisheries within the SIOFA area by trawl tow type.

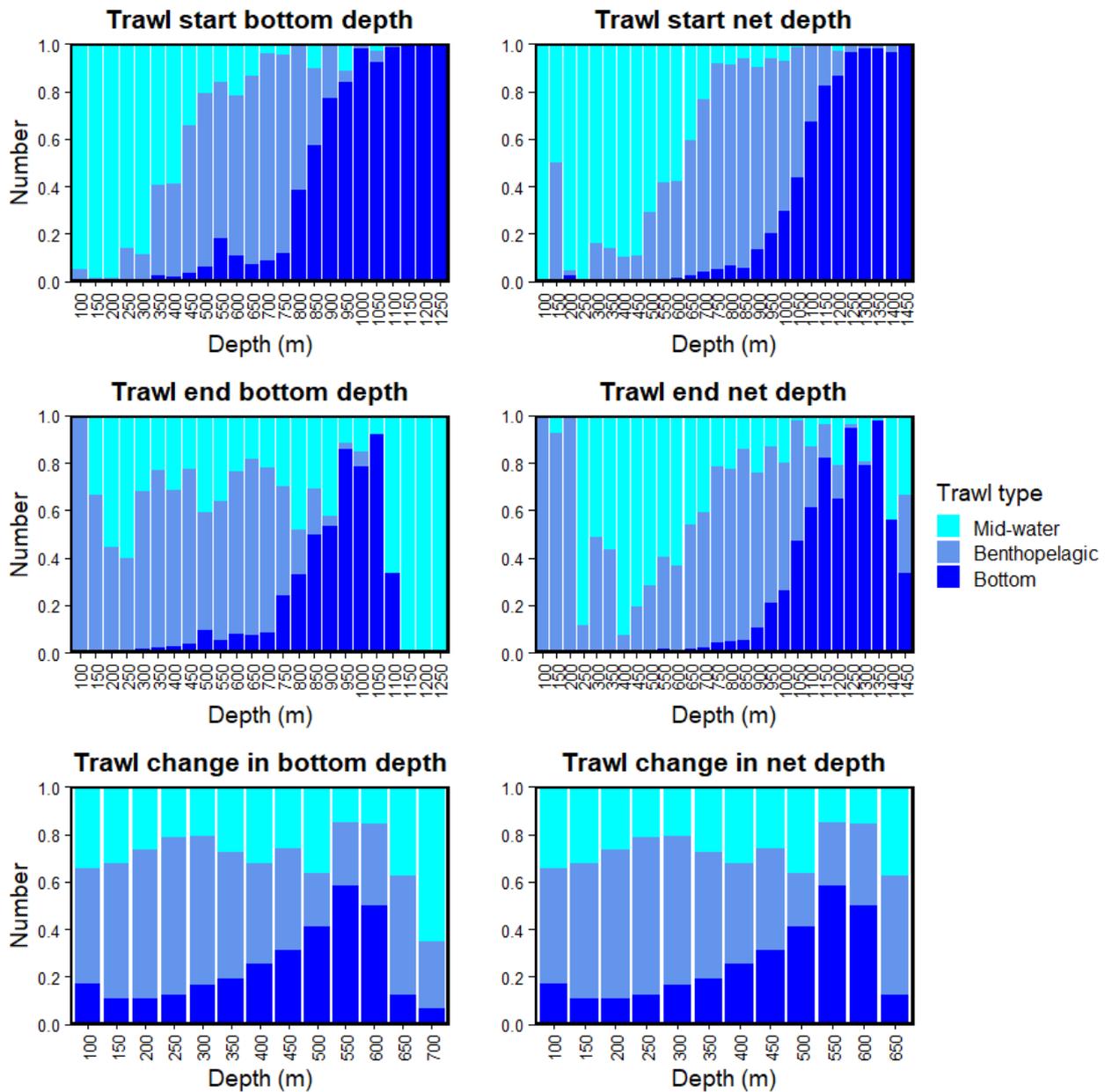


Figure 3: The start and end depth at the time of fishing of the topography and the trawl net as well as the change in net depth from the Cook Island and Japanese trawl fisheries within the SIOFA area by trawl tow type.

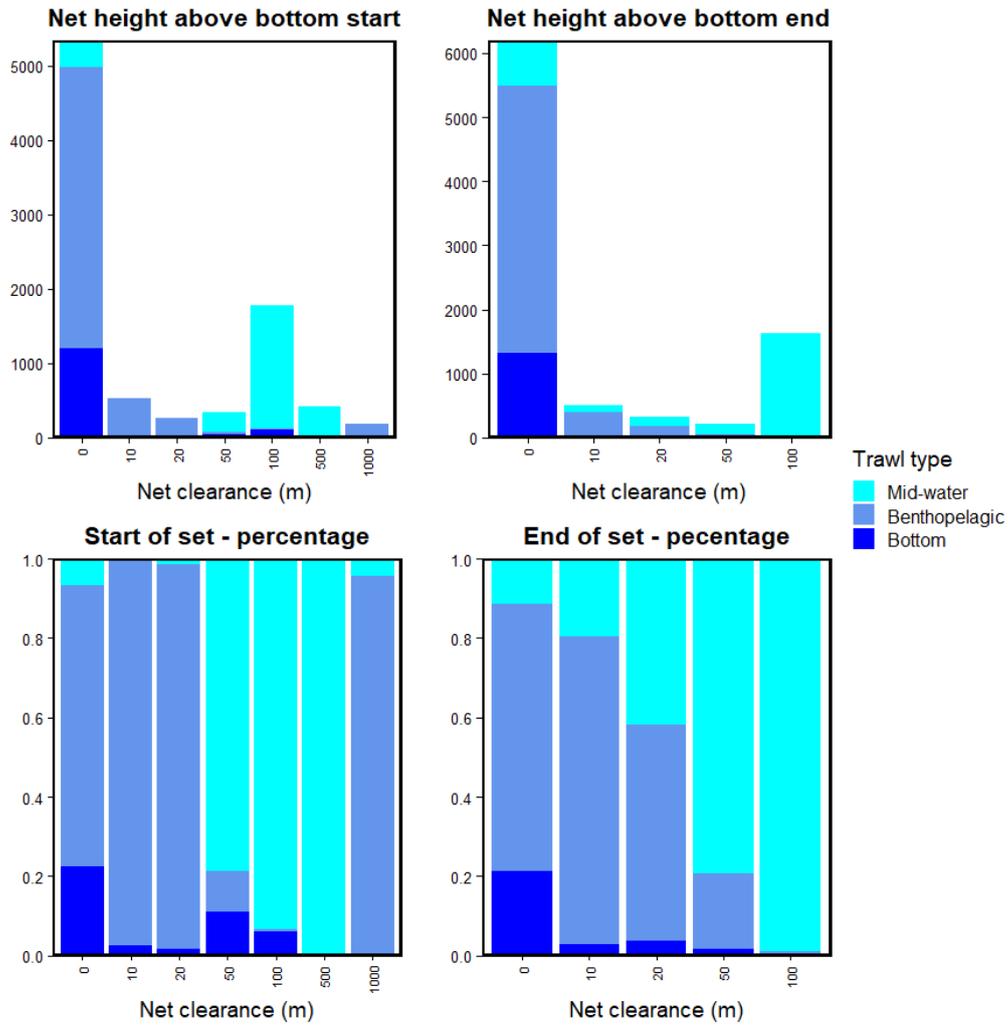


Figure 4: The net height above the seabed at the start and end of set from the Cook Island and Japanese trawl fisheries within the SIOFA area by trawl tow type.

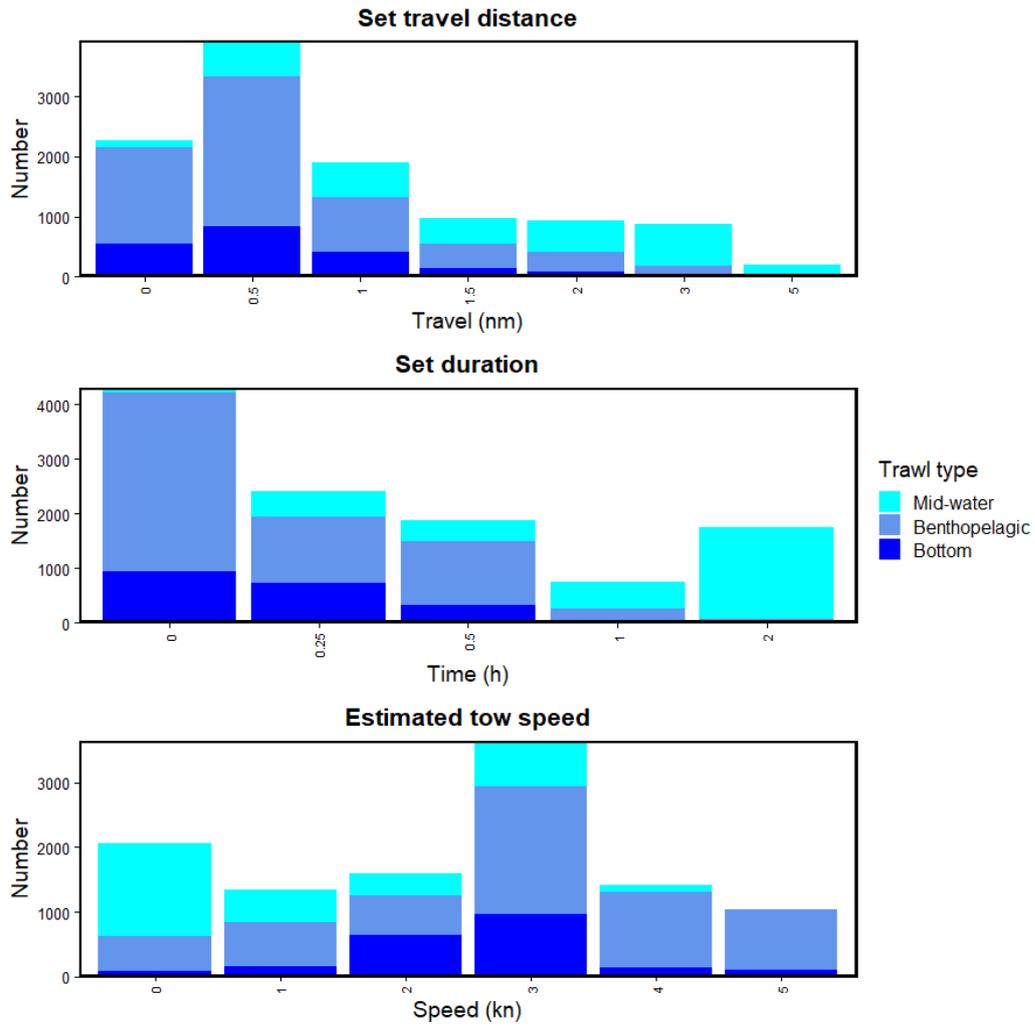
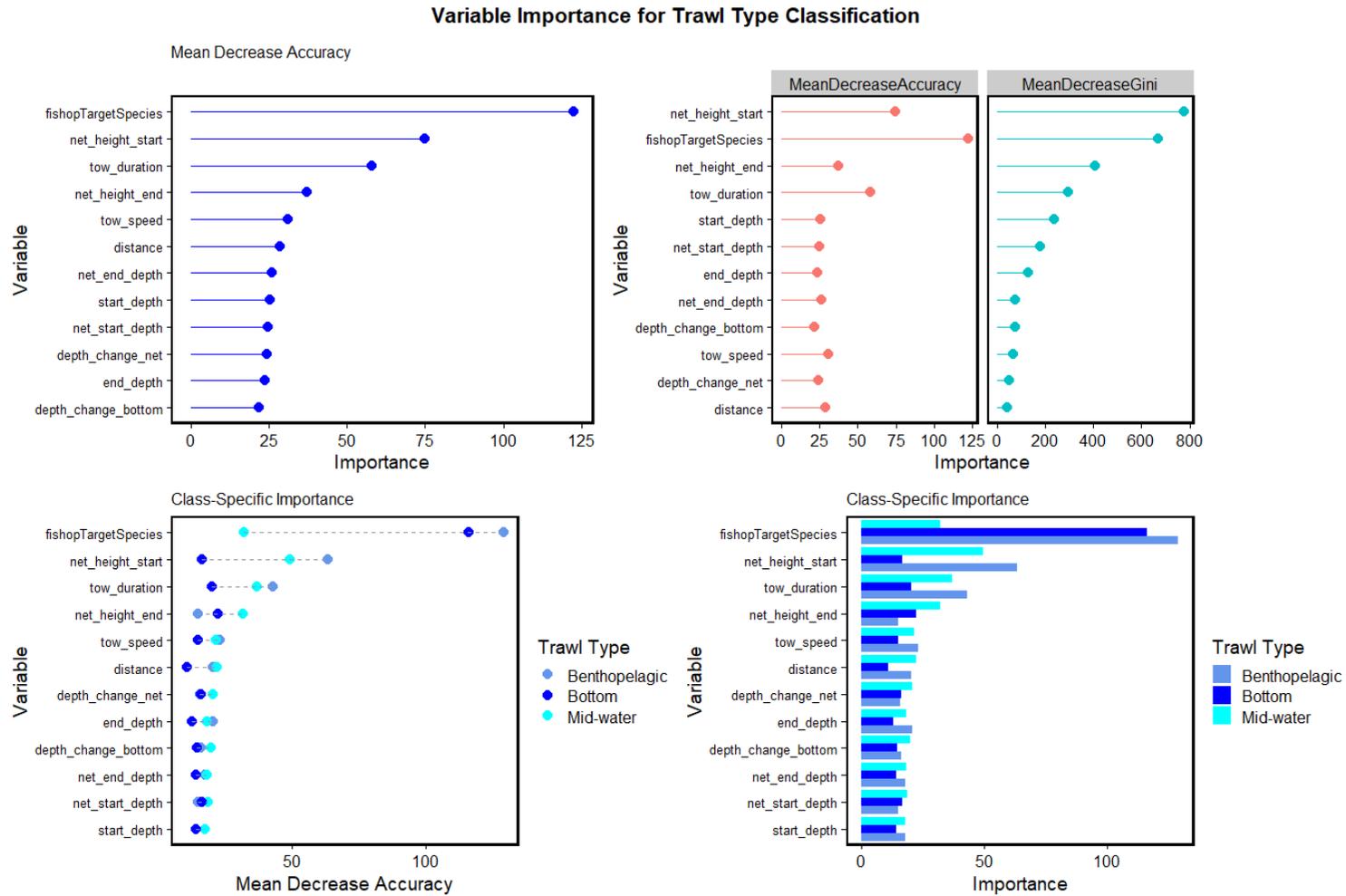


Figure 5: Trawl tow travel distance, tow duration and vessel speed from the Cook Island and Japanese trawl fisheries within the SIOFA area by trawl tow type.



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Figure 6: Model outputs from the multinomial logistic regression model showing the accuracy and importance of the factors within the model.

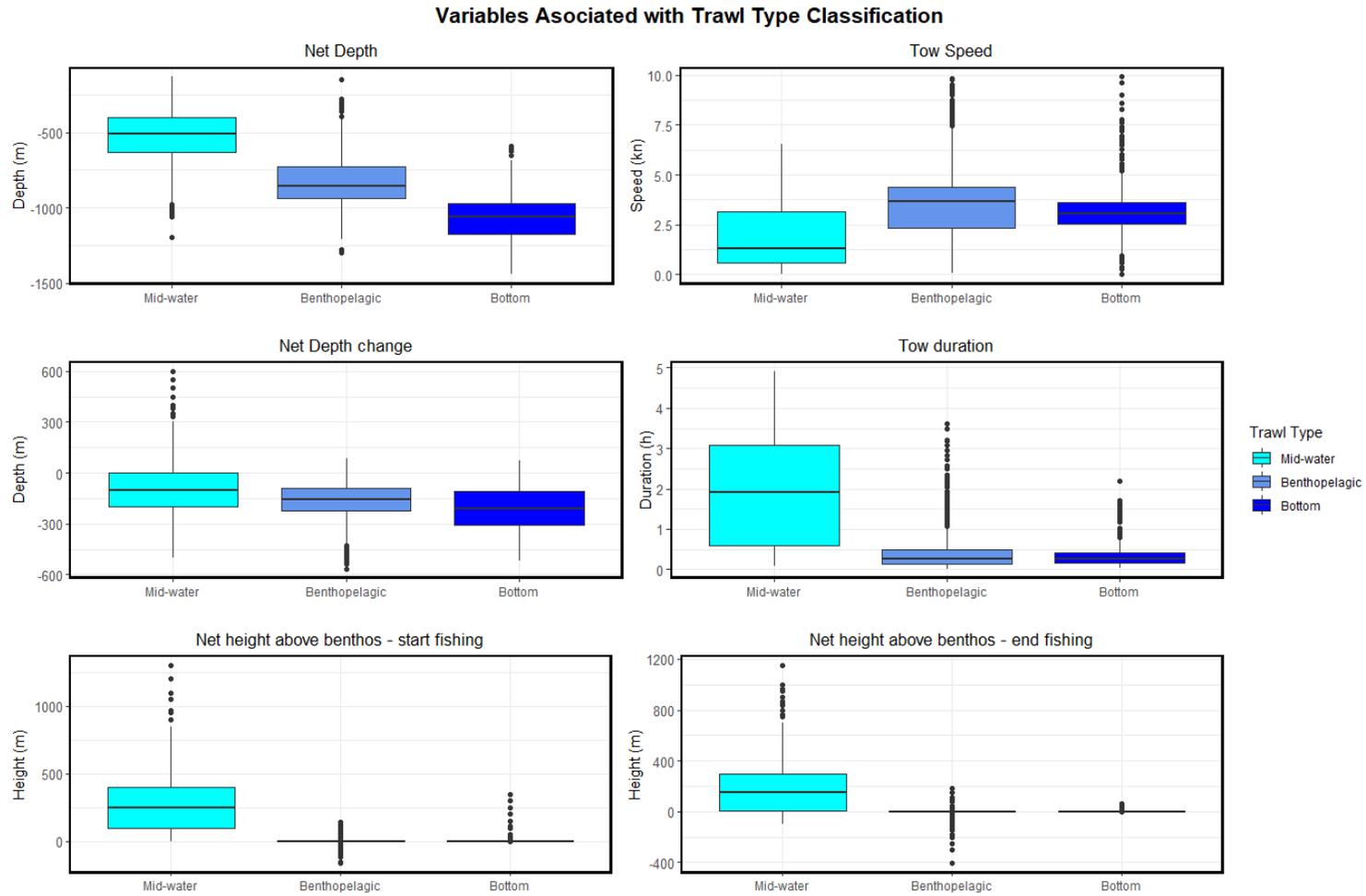


Figure 7: Model prediction summaries from the Cook Island and Japanese trawl fisheries within the SIOFA area by trawl tow type.