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Tini a Tangaroa

Estimation of fishing efficiency and catchability of key species on R.V. *Kaharoa* South Island trawl surveys

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EXECUTIVE SUMMARY

Holmes, S.J.[1]; Hurst, R.J.; Hamill, J. (2021). Estimation of fishing efficiency and catchability of key species on R.V. *Kaharoa* South Island trawl surveys.

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Estimates of the fishing efficiency (Q) for the R.V. *Kaharoa* South Island survey trawl gear were made from expert opinion elicited from five fishers, two net makers, and two *Kaharoa* skippers. The proportion of fish vulnerable to capture in three capture zones was estimated for seven key species (elephant fish, red gurnard, rough skate, sea perch, snapper, stargazer, and tarakihi) and six secondary species (barracouta, blue warehou, dark ghost shark, lookdown dory, red cod, and school shark). *Kaharoa* fishing efficiency was estimated to be highest for red gurnard and dark ghost shark (estimates ranging from 0.67–0.75) and lowest for tarakihi, school shark and blue warehou (estimates ranging from 0.09–0.26). It was not considered appropriate to estimate levels of confidence on these estimates, but the scoring method implied confidence intervals of at least ± 0.1. The results from this study were compared with results from other trawls in the literature. Comparison was complicated by the fact that all results from the literature gave gear efficiency between the wings whereas the results from this study were for gear efficiency between the trawl doors, and, because most studies were outside New Zealand, proxy species (or species groups) had to be used for comparisons. Between wing efficiency values from this study were generally much higher than from the comparison studies.

Estimates of the overall catchability (q) of a survey for a given species can be obtained by scaling a fishing efficiency estimate to an estimate of areal availability (u_a), i.e., the proportion of the population residing in the trawlable survey area. Estimates of areal availability were taken from generalised additive model (GAM) analyses of the survey data to derive q estimates for the seven key species. In five cases (elephant fish, red gurnard, snapper, stargazer, and tarakihi), the q values from this study could be compared with estimates from integrated stock assessment models. Agreement between q values was good for red gurnard and stargazer. The q values from this study were lower than the integrated assessment results for tarakihi and higher than the integrated assessment results for snapper and elephant fish. In the case of elephant fish, however, the credibility of the integrated assessment result was questionable. For tarakihi, the east coast South Island survey has mainly caught younger fish, but fisheries north of the Canterbury Bight/Pegasus Bay area catch a higher proportion of older fish. It is possible that the GAM predictions overestimated the geographical range of size classes predominant in the survey area and, in so doing, reduced the areal availability for this species. By contrast, the areal availability for snapper may have been over-estimated, because predictions of the extent of the species were limited to be within snapper management area SNA 7.

The approach used in this study could be extended to conform to the principles of a structured, iterative, group consensus forecast method (e.g., the ‘Delphi method’), but to do this would require a considerably larger pool of fishers and other domain experts than those who participated in this project.

[1] All authors: National Institute of Water and Atmospheric Research (NIWA), New Zealand.

1. INTRODUCTION

The overall objective of the LSP2019-02 project was to develop and implement a low information stock assessment model using spatially explicit catch, abundance, and harvest rate estimates for inshore finfish stocks. Part of the methods development for this project included estimation of catchability (q) for key species caught by R.V. *Kaharoa* stratified random trawl surveys (see Figure 1 for how estimation of q fits into the overall project approach).

In New Zealand, relative biomass is estimated using the area swept method of Francis (1981, 1989) and requires assumptions about four key components:

1. The **area swept** during each tow: for R.V. *Kaharoa* trawl surveys, the defined area swept is based on known measurements of doorspread (from sensors on the doors) and tow length.
2. The **vulnerability** (v) of the fish to capture in the volume swept by the net.
3. The **vertical availability** (u_v) of the fish to the height of the trawl (i.e., the proportion of the stock in the water column that is available to be captured between the groundrope and the headline).
4. The **areal availability** (u_a) of the fish to the survey (i.e., the proportion of the fish stock within the survey area).

Vulnerability and vertical availability can be combined as $\boldsymbol{vu_v}$ and is termed 'gear efficiency' or 'fishing efficiency'.

$$\boldsymbol{B_r = \frac{1}{q}\sum_i a_i C_i} \qquad 1$$

where a_i is the total area swept within a stratum of the survey area, C_i is the mean catch rate (tonnes per unit area) within the stratum and q is given by

$$\boldsymbol{q = vu_v u_a} \qquad 2$$

This report is divided into three main sections:

1. Estimation of fishing efficiency.
2. Estimation of areal availability.
3. Estimation of survey catchability.

The focus species of the low information project were seven considered to be inshore (or containing an inshore component): elephant fish (*Callorhinchus milii*), red gurnard (*Chelidonichthys kumu*), rough skate (*Zearaja nasuta*), snapper (*Chrysophrys auratus*), sea perch (*Helicolenus barathri*), giant stargazer (*Kathetostoma giganteum*), and tarakihi (*Nemadactylus macropterus*) and two considered to be deep water species but included because of the opportunity to compare abundance and catchability estimates with those from integrated assessments: hake (*Merluccius australis*) and ling (*Genypterus blacodes*). Because hake and ling are hardly present in the surveys conducted by the R.V. *Kaharoa*, they are not considered further in this report.

1.1 Estimation of fishing efficiency

It was proposed that estimation of gear efficiency (vulnerability and vertical availability) for key and secondary species caught by R.V. *Kaharoa* surveys would involve three components (Figure 1):

1. Literature review of gear efficiency relevant to South Island trawl surveys. This provided an opportunity to review studies that derived gear efficiency estimates making use of surveys and stock assessments.

2. Interviews with fishers and net makers. To better understand fishing efficiency of the *Kaharoa* trawl gear, expert opinions were elicited from *Kaharoa* skippers, net makers, and commercial fishers on how well they thought fish might be caught on the research surveys. In particular, approaches used by commercial fishers to either catch or avoid particular species was thought likely to be very informative.
3. Video observation of fish behaviour during bottom trawling on the east coast South Island (ECSI) survey. The aim of this component was to determine the relative vulnerability of species of interest in the path of the trawl by opportunistically attaching video cameras to selected areas of the gear on trawl surveys.

The last component of this work was not able to be carried out because the trawl survey, which was to take place from April to June 2020, had to be postponed due to the COVID-19 pandemic lockdown. A trial of the proposed cameras was undertaken prior to the lockdown, on a snapper Bay of Plenty survey in February 2020, and findings from this trial are reported here.

1.2 Estimation of areal availability and survey catchability

Areal availability of the stocks covered by the project was determined by relating survey catch rate data to environmental covariates using generalised additive models (GAMs) and then using the environmental covariate data to predict maps of species density over the full stock assessment area. Integrating the densities over the stock assessment area and over the area of the survey gave an estimate of the proportion of the stock (by weight) within the survey area, i.e., the areal availability. With estimates of the survey gear efficiency and stock areal availability, survey catchabilities were estimated through a simple multiplication of the two results (Equation 2).

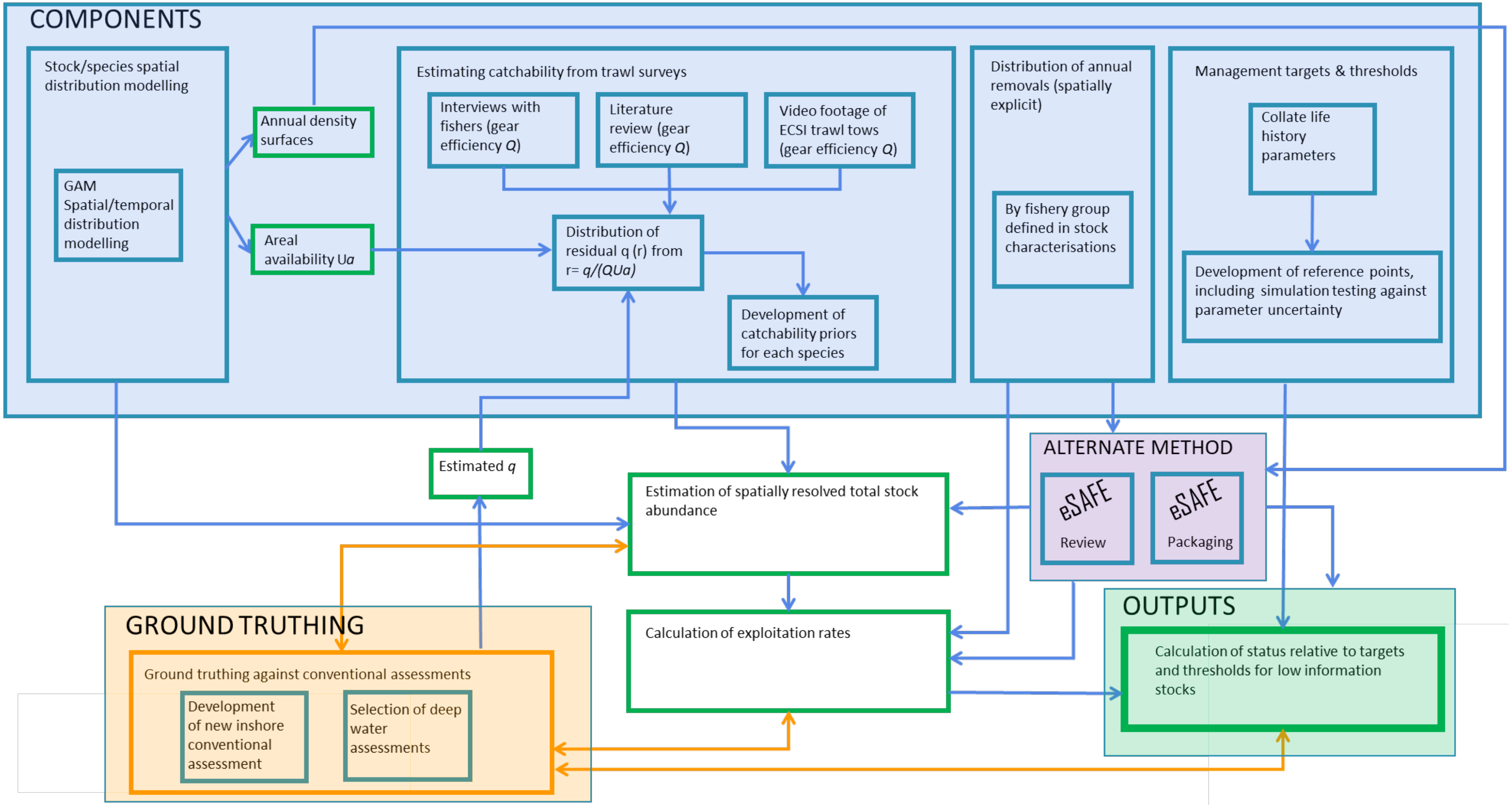

Figure 1: Schematic of the components for LSP2019-02. Research reported here on R.V. *Kaharoa* survey catchability fits is represented in the top left and middle blue boxes of the flow chart.

2. METHODS

2.1 Estimation of fishing efficiency

2.1.1 Literature review

The literature review focused on attempting to find studies that resulted in estimates of gear efficiency or overall catchability for species or species groups that could be considered relevant to the New Zealand inshore context.

Harley & Myers (2001) point out that stock assessments that assume error in the catch-at-age data estimate a single age-specific selectivity curve for each gear/vessel type s_a often standardised to a maximum of 1, and a 'bulk' catchability constant q such that $q_a = qs_a$. This study investigated the bulk q value which can be taken as the catchability at maximum selectivity. As such, studies considering size selectivity of the codend were of limited interest.

2.2.2 Interviews with fishers and netmakers

Interviews were designed to enable estimation of catchability in three main zones of the trawl: ahead of the doors, between the doors and wing ends, and at the net mouth. Zone 1 relates to vertical availability and zones 2 and 3 relate to vulnerability to capture. A conceptual view of the catching process for bottom trawls is shown in Figure 2.

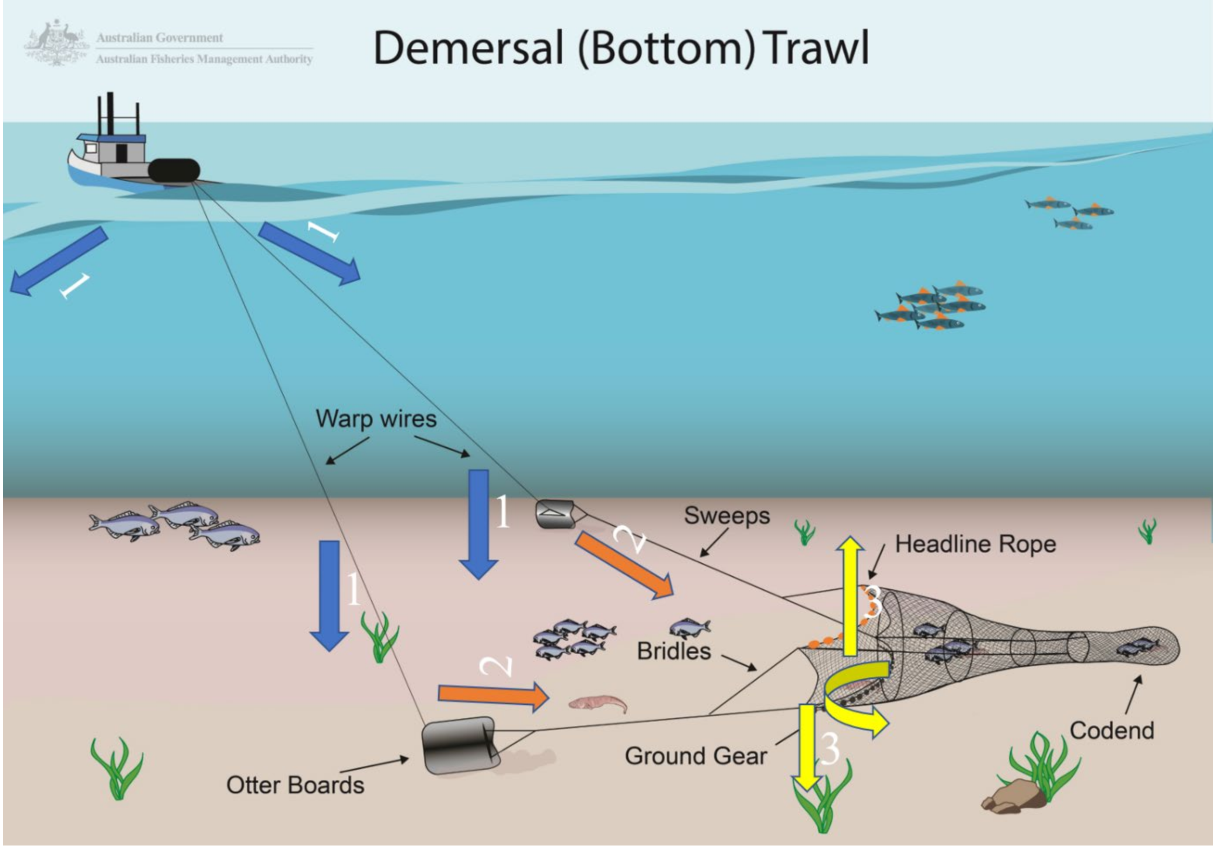

Figure 2: Schematic of the capture zones including vertical availability components 1 (ahead of the doors), vulnerability to capture components 2 (doors to wing ends), and 3 (net mouth). The underlying figure was provided by the Australian Fisheries Management Authority www.afma.gov.au/fisheries-management/methods-and-gear/trawling.

Background information supplied to interviewees included the key purpose of the interviews, which was to get a better understanding of how well the *Kaharoa* trawl survey catches a variety of species relative to each other. The interviewees were informed that, for key species, the aim was to better understand vertical availability and vulnerability of species in the path of the *Kaharoa* trawl gear, as well the effect of important environmental factors and some areal availability components (if time permitted). They were provided with the Figure 2 schematic, a list of the species of interest (Table 1) and comprehensive details and photos of *Kaharoa* gear and gear deployment specifications for the bottom trawl used on east coast and west coast South Island (ECSI and WCSI) surveys (Appendix 1). The key focus of the interviews was on the ECSI surveys, but two fishers from Tasman and Golden bays were also interviewed, with a specific focus on snapper (quota management area SNA 7), which is caught by WCSI surveys (Table 1).

Table 1: **Species (and species codes) of interest for fishing efficiency interviews.**

Key survey species	Code	Secondary species	Code
Elephant fish (*Callorhinchus milii*)	ELE	Barracouta (*Thyrsites atun*)	BAR
Red gurnard (*Chelidonichthys kumu*)	GUR	Blue warehou (*Seriolella brama*)	WAR
Sea perch (*Helicolenus barathri*)	SPE	Dark ghost shark (*Hydrolagus novaezealandiae*)	GSH
Snapper (SNA 7) (*Chrysophrys auratus*)	SNA	Lookdown dory (*Cyttus traversi*)	LDO
Giant stargazer (*Kathetostoma giganteum*)	STA	Red cod (*Pseudophycis bachus*)	RCO
Tarakihi (*Nemadactylus macropterus*)	TAR	School shark (*Galeorhinus galeus*)	SCH
Skates (rough & smooth) (*Zearaja nasuta* and *Dipturus innominatus*)	SKA		

The scope of the questions asked is described below. Questions were modified for the net maker interviews and the environmental questions were secondary and only asked if time permitted.

- Question 1. General discussion of *Kaharoa* gear characteristics and how these might differ compared with current commercial gear (in general or individual fisher's gear).
- Question 2: Vertical availability. What proportion of fish in the water column are available in the trawl path? Consider fish above the headline height during daylight hours only, fish scared sideways by the vessel and if this varies by depth or herding down by the warps. What observations are relevant?
- Question 3: Vulnerability to capture. What proportion of fish in front of the *Kaharoa* doors do you think will be herded into the path of the net? Consider the doors, doorspread and wingspread, sweeps and bridles, tow speed of 3 knots, size, and swimming ability of fish. What observations are relevant?
- Question 4: Vulnerability to capture. What proportion of fish in the path of the *Kaharoa* net mouth will be caught? Consider escapement over the top, to the side or under the groundrope. Consider headline height, escape reaction upwards or sideways or under the groundrope, power available on hauling. What observations are relevant (e.g., location of stickers)?
- Question 5: Environmental. What other factors do you consider have a major influence on catchability, aside from areal availability? For example, direction of tow, sea condition, moon phase, recent rainfall/water clarity, time of day, earthquakes, climate variability? How do you think the factor impacts catchability?

Quantifying of proportions was kept simple and split into five categories (i.e., High, Medium-High, Medium, Medium-Low, and Low). An initial attempt to quantify confidence in the estimates was not continued because it proved difficult to assign meaningful values. Scores were assigned to vertical availability (zone 1) and capture at net mouth (zone 3) (Table 2). For zone 2, scores were assigned to vulnerability to herding by:

i. assuming that all fish in the path of the wings (12.5 m wide) are available to the path of the net mouth, which gives a minimum estimate of vulnerability to capture in this zone of 0.167, based on the average doorspread of 75 m (i.e., 12.5/75, see Figure 3), and
ii. using the average area swept by the doors (75 m) to calculate the herding scores, where the five low to high herding scores are calculated based on the score (0.90, 0.70, etc.) multiplied by the proportion of potential herding area (1-0.167= 0.833). The result was added to the proportion of

wingspread area (0.167) to arrive at a final score. Thus, zero herding received the score 0.167, low herding (0.1*0.833) + 0.167 = 0.25, etc.

It is important to note that these scores have an implied confidence range of ± 0.1, which is uniform across the range, but the true uncertainty is unlikely to be uniform.

Table 2: Scores assigned to interviewee responses, by capture zone.

					Score
	High (H)	Medium-high (MH)	Medium (M)	Medium Low (ML)	Low (L)
Zones 1 & 3	0.90	0.70	0.50	0.30	0.10
Zone 2	0.92	0.75	0.58	0.42	0.25

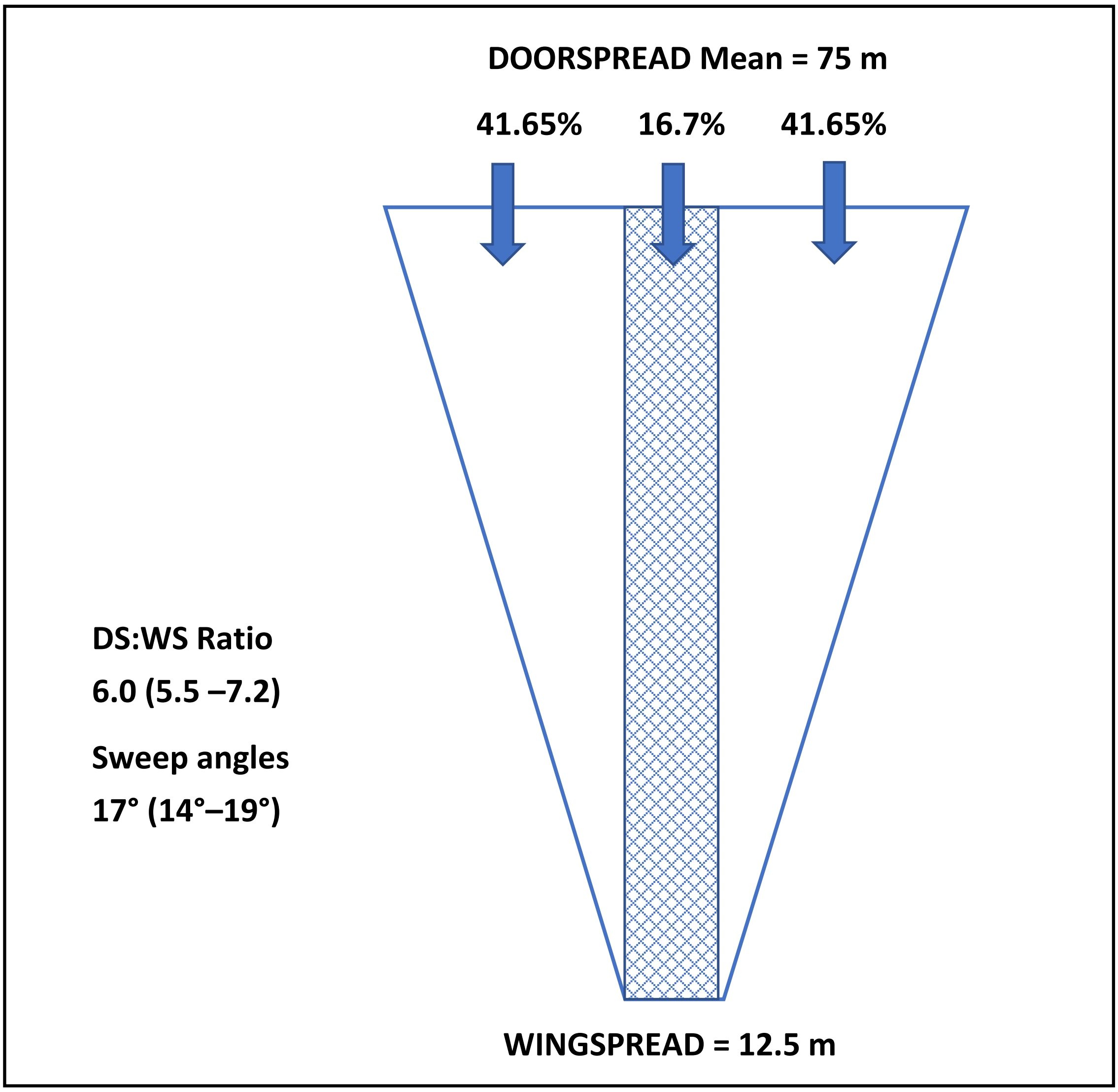

Figure 3: Wingspread (WS) and mean doorspread (DS) for ECSI surveys with the width swept by the wings as a proportion of the mean width swept by the doors (range 69–90 m), mean and range of doorspread to wingspread ratios, and sweep angles.

2.2.3 Video observations of fish behaviour during bottom trawling

To better understand and potentially quantify aspects of R.V. *Kaharoa* catching efficiency, the plan was to opportunistically attach small cameras to doors, wingends, and headropes of R.V. *Kaharoa* trawl gear on the ECSI survey in mid-2020. A pilot trial of camera placement was also planned for a snapper Bay of Plenty survey, February 2020 (with a different net to the South Island survey net), prior to the ECSI survey in April–June 2020.

In both instances, the cameras would only be attached in shallow water where lights (which will affect species catchability) are not required. Larsen et al. (2018) reported successful use of GoPro cameras in gear efficiency experiments down to 75 m depth. The size of the cameras (Figure 4), the need to place them alongside the headline transducer and on the wing close to the conductivity, temperature, depth (CTD) recorder, and the lack of lights, meant that the trial was highly unlikely to impact survey relative catchability. If the results were promising, the plan was to deploy the cameras on trawl shots on the inshore strata of the 2020 ECSI survey, allowing measurement of some species-specific reactions to the trawl gear.

The camera used was ZCam E1 (Figure 4), which was designed as an alternative to a GoPro but with the advantage of a significantly larger Micro 4/3rds sensor. The Zcam E1 also has an I/O extension port that allows the camera to easily control an external device such as infrared lights or be controlled by a microprocessor. It can also be used to do a delayed turn on.

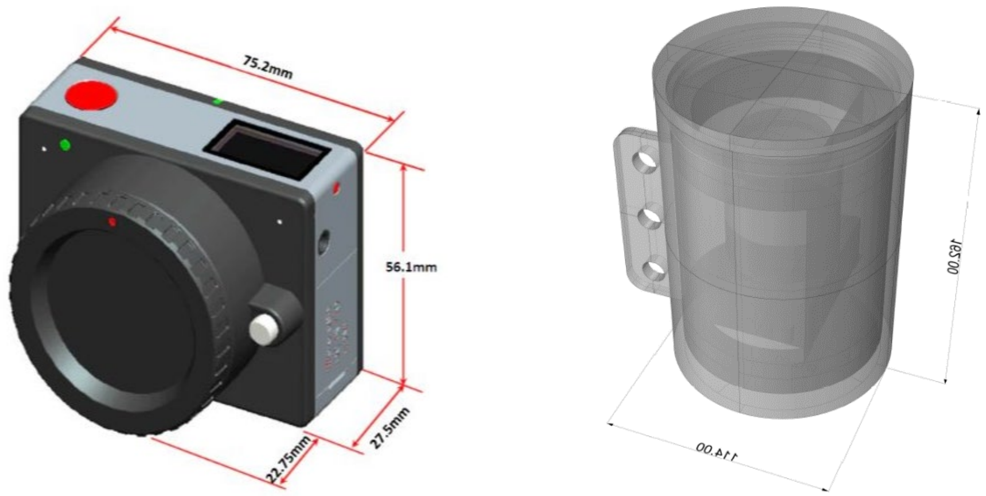

Figure 4: ZCam E1 Camera (left) and housing (right) dimensions.

If the cameras were successful in capturing footage of species of interest, fish behaviour would be quantified using the approach recommended by Reid et al. (2007). This would include recording the fish reaction to the part of the gear in the field of view, whether they were swimming steadily, swimming in bursts or gliding, turning, contacting, veering away, etc. If the fish were in the region of the groundrope, recording would include whether they entered the net mouth, changed direction to escape, or were overrun by the ground gear.

2.2 Estimation of areal availability

Areal availability of the stocks covered by the project was determined by relating survey catch rate data to environmental covariates using generalised additive models (GAMs) and then using the environmental covariate data to predict maps of species density over the full stock assessment area. Integrating the densities over the stock assessment area and over the area of the survey gave an estimate of the proportion of the stock within the survey area, i.e., the areal availability. The method produces a result for each year in which there are both survey data and covariate data. Catchability values from integrated assessments are calculated as single, time invariant, values. The mean of the annual GAM predicted results, therefore, was taken when calculating survey catchability in combination with the interview results. Full details of the GAM fitting, including cross checks on density map plausibility, can be found in Holmes et al. (in review). Two approaches to the GAM fitting were trialled. The first was a delta method approach (also known as a 'hurdle' model approach) in which the probability of a non-zero catch was modelled as a binomial distribution, then a regression against positive catch rates was made assuming a lognormal error distribution. The final estimate of catch rate was given by multiplying the two results. The second method included all catch rate data (zero and positive catches) and assumed the data conformed to a Tweedie distribution. Results from both approaches are presented.

2.3 Estimation of survey catchability and comparison to integrated assessment values

Survey catchabilities were estimated through a simple multiplication of the estimates of the survey gear efficiency from the interviews and stock areal availability results (Equation 2). Where possible the results were compared with integrated assessment results for survey catchability, i.e., the packages Stock Synthesis and CASAL estimate a catchability, q, to relate the survey index value to the survey vulnerable biomass. Integrated assessment results were available for 5 of the 7 inshore stocks. All were conducted using Stock Synthesis. For elephant fish, red gurnard, and stargazer it was necessary to use prototype assessments not yet accepted for management advice. For snapper and tarakihi, integrated assessments accepted for management advice could be used. No comparison was possible for rough skate or sea perch. The integrated assessment catchabilities were provided by the originator of the assessments (A. Langley, pers. comm.)

3. RESULTS

3.1 Estimation of fishing efficiency

3.1.1 Literature review

Only two studies could be found that provided estimates of gear efficiency for species thought to be relevant to the project species that did not involve comparison with integrated assessment results.

Reid et al. (2007) used video analysis from survey trawls to parameterise a particle tracking model for European anglerfish species (*Lophius piscatorius* and *L. budegassa*). The model was used to draw conclusions on herding of anglerfish by the trawl net and to derive a 'net efficiency' factor, i.e., a wingspread efficiency factor. Gear efficiency in the path of the net mouth was assumed to equal 1. The results from Reid et al. (2007) have been used for giant stargazer because of the similar morphology of the two species and the fact that giant stargazers also tend to partially bury in the sediment (Paul 2000). Very little evidence of herding was recorded. Observations indicated that if a fish reacted to the sweeps it was equally likely to move in a direction escaping the gear as towards the net swept area which, coupled with a short burst-swimming distance, meant few fish encountered towards the doors were likely to be herded into the path of the net. Final gear efficiency between the wings was recorded as between 1 and 1.36.

Lauth et al. (2004) compared numbers at length for thornyheads, *Sebastolobus spp.*, from a towed video camera sled with those caught in a survey trawl using paired tows. The experiment caught two species of thornyhead, *Sebastolobus alascanus* and *S. altivelis*, but did not separate them for the analysis on the grounds they have similar morphology and behaviour and hence similar trawl selectivity. Again, .on the basis that sea perch .has a similar morphology to the thornyhead species, the results were considered for sea perch in this study. Lauth et al. (2004) estimated gear efficiency for different lengths of fish ranging from 5 to 40+ cm. The efficiency values were wingspread values (the degree of herding was not quantified) with mean and confidence intervals of 0.56 (0.24–0.88).

Two studies attempted to form catchabilities for species, or species groups, by making use of integrated assessment results. The results from these studies could be used to compare to the gear efficiency estimates obtained from the fisher interviews. Harley & Myers (2001) took data from integrated assessments to form what they call 'catchability at length' estimates. Because they assumed the whole population to be contained within the survey area these are, in reality, gear efficiency estimates but, more specifically, wingspread gear efficiency estimates. Data from the assessments came in the form of catchability by age and the age data were converted to length data using a case specific von Bertalanffy growth function. A logistic curve was selected as the functional form for the catchability and the parameters for each curve were estimated using a Bayesian model. The data from the individual stocks were then combined into groups (Table 3) and a hierarchical Bayesian model was used to determine the logistic curve parameters for the groups.

Table 3: Species or species group definitions for allocating gear efficiency at length values as defined by Harley & Myers (2001). Also shown is the asymptotic *Q* value (plus 5th and 95th percentile values) from a model that assumed gear efficiency at length to be logistic with a single general shape across stocks within the group but different possible maximum efficiency.

Species Group	Group description	Asymptote *Q* value
1	Atlantic cod (*Gadus morhua*)	0.87 (0.42, 1.76)
2	Haddock (*Melanogrammus aeglefinus*)	1.50 (0.68, 2.86)
3	Demersal gadoids	0.97 (0.52, 1.83)
4	Pelagic gadoids[1]	0.58 (0.28, 1.19)
5	Ling (*Genypterus blacodes*)	1.66 (1.00, 2.72)
6	Flatfish	0.83 (0.40, 2.22)

[1] Group conditioned on 9 data sets including 3 from New Zealand hake (*Merluccius australis*).

Walker et al. (2017) used catch ratios and comparisons between survey and integrated stock assessment estimated numbers at age to estimate what they termed gear efficiency values at age Q_a for key stocks in the North Sea. In summary (and converting to the notation used in this report), for species s at length l the CPUE of gear types 1 and 2 can be compared as

$$\frac{C_{s,l,1}/E_1}{C_{s,l,2}/E_2} = \frac{a_{s,l,1}v_{s,l,1}}{a_{s,l,2}v_{s,l,2}} \tag{3}$$

Where C is catch, E effort, v vulnerability to the gear, and $a = u_a u_v$.

GAMs, with the response variable (species catch by length class by haul i, $C_{i,s,l}$) were modelled as a smoothly varying function of location and date and with gear type as a scaling factor. Following the GAM fits, for each length class, the most efficient gear had its efficiency set equal to 1 and all other gears were scaled between 0 and 1 according to their relative efficiencies. The relative efficiency values for the survey $Q_{s,l}$ were used to provide estimates of numbers at length $N_{s,l}$ using

$$N_{s,l} = \sum_r A_r \left(\frac{1}{Q_{s,l}} \overline{C_{s,l,r}/E_r} \right) \tag{4}$$

Where r and A_r are the index and area of ICES rectangles (rectangles of 30 min latitude by 1-degree longitude) and $\overline{C_{s,l,r}/E_r}$ the mean quarterly CPUE. This approach assumed fish are randomly distributed at the scale of the ICES rectangles so that areal availability is equal to unity. Numbers at length were converted to numbers at age using the inverse von Bertalanffy growth equation. The numbers at age obtained were divided by those from an integrated assessment (the assessment results were treated as true estimates of abundance) to arrive at multipliers for each year, quarter, and age. A final multiplier at age was taken as the mean among quarters and years. Multipliers at age were converted back to multipliers at length before a simple GAM model was fitted to give gear efficiency multipliers as a smooth function of fish length, providing a multiplier for every length class. Finally, the multipliers were used to adjust the initial absolute gear efficiency terms.

The gear efficiency terms are in effect age-specific estimates of vu_v (Walker et al. 2017 acknowledge they ignore the vertical component of availability). Walker et al. (2017) defined 7 species groups based on body shape, behaviour, habitat preferences, and typical position in the water column. The group descriptions are re-produced in Table 4 along with the maximum absolute gear efficiency (across all ages) estimated for the 'GOV' trawl survey gear. Estimates using the catch ratio technique were possible for species representing 5 of the 7 groups. Any species within the group was then assumed to have the same values of vu_v at age. Of the species studied in this project:

- Elephant fish, red gurnard, and giant stargazer map to species group 7 (this group included anglerfish and black-bellied anglerfish *Lophius piscatorius* and *L. budegassa*, and grey, red, and tub gurnard *Eutrigla gurnardus, Aspitrigla cuculus*, *and Trigla lucerne*).
- Rough skate maps to species group 3 (group 3 contained all skates and rays).
- Snapper, sea perch, tarakihi and hake map to group 4 (the group included European hake *Merluccius merluccius* and the Sebastes species *Sebastes marinus* and *Sebastes viviparus*).
- Ling maps to group 2 (this group included common ling *Molva molva* and blue ling *Molva dypterygia*)

Table 4: Species group definitions for allocating gear vulnerability values as defined by Walker et al. (2017).

Species group	Group description	Max *Q* of GOV gear[1]
1	Predominantly buried in sediment	0.066
2	On or near the seabed—anguilliform or fusiform	1.064
3	Predominantly on the seabed—flat	0.882
4	Predominantly close to the seabed, but not on it	0.767
5	Midwater species with some seabed association	0.527
6	Pelagic	0.375
7	Predominantly on the seabed—lumpiform	1.009

[1]The Grande Overture Vertical (GOV) gear is used for trawl surveys by the International Council for the Exploration of the Sea (ICES). For specification of the GOV trawl see ICES (2012).

3.1.2 Interviews with fishers and netmakers

A total of five fishers, two net makers, and two *Kaharoa* skippers were interviewed (Table 5).

Table 5: List of interviewees and specialist category. For species codes see Table 1.

Contact	Fishery	Species / category
Fishing skippers		
Arlun Wells	Tasman and Golden bays	SNA
Chris West	Tasman and Golden bays	SNA and inshore mixed
Tony Threadwell	East coast South Island	TAR, GUR, mixed inshore
Pay Nyhon	Otago/Southland	STA, ling (LIN), mixed inshore
Antonio Smith	South-east coast South Island	SPE
Net makers		
Andrew Hope	Motueka Nets, Nelson	R.V. *Kaharoa* & commercial gear
Glen Curtis	Motueka Nets, Nelson	R.V. *Kaharoa* & commercial gear
***Kaharoa* skippers**		
Lyndsey Copeland	N/A	R.V. *Kaharoa* South Island survey gear
Simon Wadsworth	N/A	R.V. *Kaharoa* South Island survey gear

General comments on R.V. *Kaharoa* and commercial gear

- *Kaharoa* research gear is 30 years old. It was a standard wing trawl of the day, that is relatively inefficient compared to the modern commercial gear set-up, which is regularly modified to target specific species (e.g., changing headline height or sweep length).
- *Kaharoa* 14–17° sweep angles (at 69.4–89.4 m doorspread) are optimal for this type of gear. Sweeps and bridles are not the best set-up compared to modern gear (modern plastic covered sweeps have better herding capability). Sweeps are potentially shorter than optimal for herding some species (i.e., these species will not tire out enough to be caught efficiently).
- *Kaharoa* gear has good headline height (4.6–5 m), greater than most commercial nets; and with the small veranda, there is probably not much escapement over the top. As such, *Kaharoa* is suited to catching more SPD (spiny dogfish), BAR, WAR, and SNA.
- *Kaharoa* gear is robust, fishes well in most depths and over most bottom types, except in Tasman and Golden bays where the groundrope is too heavy and the codend can fill up with debris. It fishes relatively hard down, but the 150 mm diameter cannon balls may allow some species to escape (e.g., FLA, STA, TAR). There is no false fishing wire that enables the groundrope to keep better shape and bottom-holding capability.
- The *Kaharoa* skippers keep power on and speed up when hauling; the survey standardised tow speed (3 knots) is not optimal for fast swimmers (e.g., WAR).
- The *Kaharoa* vessel noise is unlikely to scare fish in the survey depths of over 10 m.
- The survey constant trawl speed is not optimised for individual species; commercial fishers tow slower and faster to facilitate effective herding.

Note: SPD is spiny dogfish, FLA is flatfish, and all other species codes are defined in Table 1.

Fishing efficiency estimates

Details of the estimated *Kaharoa* efficiency by individual species, fishing zone, and interview are given in Appendix 2, along with a summary of key observations and comments on fish reactions to the gear. To better inform the vertical availability of each species, information on diet (Hanchet 1991, Stevens et al. 2012, and Bennett 2019) was also accessed to provide an indication of whether fish may be feeding in the benthic or pelagic zones; this information is also summarised in Appendix 2. Summaries of these estimates and associated comments are given in Tables 6 (a and b). These estimates, together with estimates of areal availability (u_a) form the basis of estimates of trawl survey catchability (q), (see section 3.3).

Table 7 gives the fishing efficiency estimates for all species, by catching zone. It is important to remember that the uncertainty of the fishing efficiency (Q) estimates was not attempted and that the scoring method for individual efficiency estimates by zone have an implied uncertainty of at least +/- 0.1.

Comparison of fishing efficiency estimates to estimates from literature

Gear efficiency estimates from the fisher interviews were compared with those from the studies of Walker et al. (2017) and Harley & Myers (2001) in Table 8. Results for thornyheads, *Sebastolobus spp.*, from Lauth et al. (2004) and anglerfish from Reid et al. (2007) are also given. The comparison studies all calculated gear efficiency in terms of wingspread whereas this study considers the swept area to be defined between the doors of the gear (doorspread). The gear efficiencies of this study were converted to between wing estimates in Table 8 by assuming a zone 2 score of 1 for fish initially between the wings added to the interview zone 2 score multiplied by 5 for the area between the wings and doors (the distance between the wings represents a sixth of the total distance between the doors).

Table 6a: Estimated proportions of fish vertically available (zone 1), herded (zone 2), and caught at the net mouth (zone 3), and overall fishing efficiency (*Q*) of Kaharoa trawl gear, for key species. H= High, MH=Medium high, M=medium, ML=medium low, L=low (see Table 2 for associated numeric values).

Species	Interview	Zone 1	Zone 2	Zone 3	Fishing efficiency (*Q*)	Comments summary
Snapper	1	MH	H	M	0.32	Short sweeps and tow duration, so fish do not tire; but can get high catch rates in short time (because of schooling behaviour?); target speed 3.2–3.3 knots.
	4	H	M	M	0.26	
Elephant fish	2	H	ML	H	0.34	Hard down, no difference day and night, good on dawn and dusk, not well herded e.g., by Danish seine.
	3	H	?	H	–	
Red gurnard	2	H	H	H	0.75	Hard down, big difference day and night, herd well, but not as well as schooling species; greater sweep length would tire fish more; low escapement; trawling speed good.
	3	H	H	H	0.75	
	4	H	MH	H	0.61	
Skates (RSK, SSK)	2	MH	ML	H	0.26	Hard down, may be buried (similar to stargazer); do not herd well (e.g., not caught by Danish seine).
	3	H	?	?	–	
Sea perch	3	H	M	H	0.47	Hard down, territorial (prefer rough bottom); herd effectively with 14–17° sweep angle; good bottom contact important.
	5	H	MH	H	0.61	
Stargazer	2	MH	ML	H	0.26	Hard down; buried and may pass below groundrope; or could be dug up by heavier *Kaharoa* gear? Do not herd well in Danish seine, some may escape under groundrope at net mouth.
	3	M	ML	MH	0.15	
Tarakihi	2	ML	H	MH	0.19	Better catches at night; herd well but may not tire with short tows and shorter sweeps; good at getting out of meshes.
	3	M	H	M	0.25	

Table 6b: Estimated proportions of fish vertically available (zone 1), herded (zone 2), and caught at the net mouth (zone 3), and overall fishing efficiency (*Q*) of Kaharoa trawl gear, for secondary species. H= High, MH=Medium high, M=medium, ML=medium low, L=low (see Table 2 for associated numeric values).

Species	Interview	Zone 1	Zone 2	Zone 3	Fishing efficiency (*Q*)	Comments summary
Barracouta	2	MH	MH	M	0.26	Off bottom at night feeding; headline height and speed reasonable for herding and capture but faster better; less stamina (cf. e.g., tarakihi, stargazer); easily damaged in net.
	3	MH	MH	H	0.47	
Blue warehou	2	ML	MH	ML	0.09	Off bottom at night feeding; strong swimmers so the more headline height the better; more speed and longer tows would be better.
	3	M	M	ML	0.09	
Dark ghost shark	2	H	H	H	0.75	Easily caught
Lookdown dory	3	H	?	H?	–	Hard down; can be caught with low headline height.
Red cod	2	MH	H	H	0.58	Off bottom at night feeding; up to 3 knots speed reasonable; herd well; easily caught.
	4	H	MH	MH	0.47	
School shark	2	MH	M	ML	0.12	Hard down; strong, fast swimmers so headline height and speed important and tow with tide; better at night, probably escape on hauling as not tired by length of tow and speed.
	3	H	M	ML	0.26	

Table 7: Summary of estimates of fishing efficiency (*Q*) for *Kaharoa*, by species (codes in Table 1) and capture zones (Figure 2 and Table 2).

	Estimates of fishing efficiency (*Q*)				
	0.75–0.60	0.60–0.45	0.45–0.30	0.30–0.15	0.15–0.00
All zones similar	GUR, GSH	RCO, BAR	BAR		
Low in zone 1				TAR	
Low in zones 1 & 2				STA	
Low in zone 2		SPE	ELE	SKA	
Low in zone 2 & 3			SNA	SCH	
Low in zone 3					
Low in zones 1 & 3					WAR
Colour key: No. of fishers	1, 2	3			

Table 8: Gear efficiency estimates from the fisher interviews compared with estimates for species groups from the studies of Walker et al. (2017) and Harley & Myers (2001). Results for thornyheads, *Sebastolobus* spp. from Lauth et al. (2004) and anglerfish from Reid et al. (2007) are also given.

Species	Fisher interview *Q* value (between doors)	Fisher interview *Q* value (between wings)	*Q* value after Walker et al. (2017)		*Q* value after Harley & Myers (2001)	*Q* value from other studies
Elephant fish	0.34	2.03	1.009	Species group 7		
Red gurnard	0.75	4.46	1.009	Species group 7		
	0.61	3.64				
Rough skate	0.26	1.58	0.882	Species group 3	0.83 (0.40, 2.22) flatfish	
Snapper	0.32	1.93	0.767	Species group 4		
	0.26	1.56				
Sea perch	0.61	3.64	0.767	Species group 4		0.56 (0.24-0.88)
	0.47	2.81				Lauth et al. (2004)
Giant stargazer	0.26	1.58	1.009	Species group 7		1 - 1.36.
	0.15	0.88				Reid et al. (2007)
Tarakihi	0.25	1.38	0.767	Species group 4		
	0.19	1.16				

3.1.3 Video observations of fish behaviour during bottom trawling

This part of the project was unable to be completed due to COVID-19 lockdown in April 2020, which resulted in postponement of the ECSI survey to 2021. However, a trial deployment of cameras was achieved on the NIWA snapper trawl survey in the Bay of Plenty in February 2020 and was particularly useful for determining appropriate camera angles and fields of view. A summary of the results achieved on the pilot deployment is provided in Appendix 3. Unfortunately, none of the observations made were on species relevant to the ECSI survey species of interest.

3.2 Estimation of areal availability

The areal availability values derived from predictions of species density over the stock area after using GAM fits of survey catch rates against environmental covariates are given in Table 9. Areal availabilities were calculated for each year where both survey data and covariate data were available. Figures showing the time series of areal availability values are given in Appendix 4. Areal availability values for hake and ling were calculated but are not shown here because they relate to the Chatham Rise survey only.

Table 9: Estimates of areal availability u_a derived from predictions of species density over the stock area after using GAM fits of survey catch rates against environmental covariates. 'GAM method' indicates the assumed distribution of the response data. The mean areal availability across all years with survey and covariate data available is given with the numbers in brackets giving the upper and lower confidence intervals (±1.96 sd(mean)).

Species	Survey	GAM method	Areal availability estimate u_a
Elephant fish	ECSI	Delta	0.732 (0.659, 0.804)
	ECSI	Tweedie	0.613 (0.552, 0.674)
Red gurnard	ECSI	Delta	0.531 (0.491, 0.571)
	ECSI	Tweedie	0.458 (0.418, 0.498)
Rough skate	ECSI	Delta	0.255 (0.255, 0.255)
	ECSI	Tweedie	0.302 (0.302, 0.302)
Snapper	WCSI	Delta	N.A.[1]
	WCSI	Tweedie	0.745 (0.692, 0.799)
Sea Perch	ECSI	Delta	0.324 (0.292, 0.356)
	ECSI	Tweedie	0.31 (0.25, 0.369)
Giant stargazer	ECSI	Delta	0.336 (0.329, 0.344)
	ECSI	Tweedie	0.341 (0.341, 0.341)
Tarakihi	ECSI	Delta	0.374 (0.36, 0.389)
	ECSI	Tweedie	0.53 (0.497, 0.562)

[1]Species density prediction over the stock assessment area failed to give a sensible result.

3.3 Estimation of survey catchability

Values of survey catchability using the gear efficiency estimates from the fisher interviews multiplied with the areal availability estimates using the GAM fits to survey data are given in Table 10. To give a sense of the variability in catchability estimate, each Q value obtained from the interviews was multiplied by the lower confidence interval value, mean and upper confidence interval value from the u_a estimates. The minimum and maximum q values obtained are highlighted in bold.

Where available, catchability estimates for the same survey output from integrated assessments are also shown. For elephant fish, confidence intervals were not available but mean values resulting from two alternative assumptions for survey selectivity are given. In both cases the integrated assessment q values are considerably lower than those from this study. For red gurnard, the lowest and highest values for q from this study match the confidence interval of values from the integrated assessment very closely. For snapper, q values are higher than those from the integrated assessment. For giant stargazer, the q values from this study fall within the upper half of the confidence interval of results from the integrated assessment. For tarakihi, the *q* values from this study are lower than those from the integrated assessment; the upper value from this study is effectively equal to the lower confidence bound from the integrated assessment.

Table 10: Estimates of survey catchability using gear efficiency estimate (*Q*) from fisher interviews multiplied by areal availability estimate (u_a) from GAM fits. 'GAM method' indicates the assumed distribution of the response data. The maximum and minimum *q* estimates for a species are highlighted bold. Estimates of catchability from integrated assessments (all using Stock Synthesis) are also shown where available.

Species	*Q* from fisher interview	GAM method	$q = Qu_a$	*q* from integrated assessment
Elephant fish	0.34	Delta	0.224, 0.249, **0.273**	0.035 (double normal selectivity) 50+ cm fish
		Tweedie	**0.188**, 0.208, 0.229	0.055 (logistic selectivity) 50+ cm fish
Red gurnard	0.61	Delta	0.3, 0.324, 0.348	0.307 (0.231,0.450)
		Tweedie	**0.255**, 0.279, 0.304	20+ cm fish
	0.75	Delta	0.368, 0.398, **0.428**	
		Tweedie	0.314, 0.344, 0.374	
Rough skate	0.26	Delta	**0.066**[a]	
		Tweedie	**0.079** [a]	
Snapper	0.26	Tweedie	**0.18**, 0.194, 0.208	0.109 (0.05 ,0.168)
	0.32	Tweedie	0.221, 0.238, **0.256**	
Sea perch	0.47	Delta	0.137, 0.152, 0.167	
		Tweedie	**0.118**, 0.146, 0.173	
	0.61	Delta	0.178, 0.198, 0.217	
		Tweedie	0.153, 0.189, **0.225**	
Giant stargazer	0.15	Delta	**0.049**, 0.05, 0.052	0.052 (0.007,0.097)
		Tweedie	0.051 [a]	30-45 cm fish
	0.26	Delta	0.086, 0.087, **0.089**	
		Tweedie	0.089 [a]	
Tarakihi	0.19	Delta	**0.068**, 0.071, 0.074	0.174 (0.142,0.214)
		Tweedie	0.094, 0.101, 0.107	2-4 yr age classes
	0.25	Delta	0.09, 0.094, 0.097	
		Tweedie	0.124, 0.133, **0.141**	

[a] Covariates chosen in the GAM fitting meant no change in areal availability estimate between years.

4. DISCUSSION

There is little agreement between the gear efficiency estimates from this study and the estimates found in the literature. With the exception of giant stargazer compared to species group 7, 'predominantly on the seabed—lumpiform' (Walker et al. 2017) and anglerfish (Reid et al. 2007), all estimates from this study, when converted to between wing estimates are considerably higher than the estimates from the other studies. It is possible that trying to compare similar species (or species with similar functional forms) between what appear to be similar gear types is a futile exercise.

The *q* values from the integrated assessment and this study are very different for elephant fish but the integrated assessment in question is not considered to be fully resolved and its estimates of both abundance and survey *q* are considered questionable (A. Langley, pers. comm.). The data available to the integrated assessment for giant stargazer were not considered to be informative for obtaining an abundance estimate and the estimate of survey catchability has wide confidence intervals. The *q* values from the integrated assessments for red gurnard, snapper, and tarakihi are considered credible (and the latter two are accepted assessments for management advice, Langley 2020, Langley 2018, Langley 2019). The *q* values for red gurnard from this study all lie within the confidence interval of the integrated assessment values. The *q* values for tarakihi are lower than those from the integrated assessment. The ECSI survey predominantly catches young tarakihi (up to 4 years old) and the integrated assessment assumes that tarakihi move north out of the survey area as they become older, explicitly including a northward migration of fish as they become older (Langley 2018). The integrated assessment model altered the proportions at age (length) between the survey area and the remainder of the stock area, in effect restricting the geographic range of fish of sizes seen by the survey. This in turn would see an increase in survey *q* value while survey vulnerable biomass is kept realistic through a decline in the estimated survey selectivity for older ages. The GAM predictions are unable to incorporate the idea of age-specific migration. For snapper, higher values of *q* obtained from this study compared with the integrated assessment could in part be because the GAM prediction of species density was restricted to FMA 7 (SNA 7). The results suggest relatively high fish densities pass into the FMA 8 area at suitable depths. Areal availability may, therefore, be overestimated. In contrast the integrated assessment included commercial fishing from any trip "that conducted fishing within the statistical areas that comprise SNA 7 (Statistical Areas 017 and 033–039) and targeted the range of inshore species that are caught in association with snapper (i.e., snapper, flatfish species, red cod (*Pseudophycis bachus*), red gurnard, and John dory (*Zeus faber*))". Statistical Areas 037 and 039 straddle the FMA 7/FMA 8 boundary.

The approach of fisher interviews in part conforms to the principles of the 'Delphi method', a formalised approach for 'judgmental forecasting' used in instances where data to make statistical forecasts are unavailable (Hyndman & Athanasopoulos 2018). The key requirements and steps of the Delphi method are:

- A facilitator and expert panel are identified.
- The forecasting task(s) are set and distributed to the experts.
- Experts return initial forecasts and justifications. These are compiled and summarised to provide feedback, but the experts' responses are kept anonymous.
- Feedback is provided to the experts, who review their forecasts in light of the feedback. The Delphi method stipulates at least one round of feedback, but the step may be iterated until a satisfactory level of consensus is reached.
- Final forecasts are constructed by aggregating the experts' forecasts.

In the current study suitable experts and a suitable facilitator were identified and forecasting tasks (for named species, opinions on the vertical availability and vulnerability in the path of the *Kaharoa* trawl gear, as split into three defined zones) were clearly defined. Justifications for the opinions expressed were also sought and summarised. There is little consensus in the literature on the minimum number of experts required but the lowest estimate was for five experts. The estimates of gear efficiency from this study are based on only one or two interviews per species. Anonymity of experts' responses is considered important to prevent experts being influenced by political and/or social pressures (Hyndman & Athanasopoulos 2018). To conform to the Delphi method requirements, a greater number of fishers would need to be assembled. The full number of experts would need to be gathered ahead of the first round of responses because all experts need to contribute to all rounds of forecasting. At least one feedback and review round would also need to be conducted but Hyndman & Athanasopoulos (2018) suggest that two or three rounds are usually sufficient (and warn that too many rounds should be avoided to prevent expert 'drop out'). Given the way it was possible in this study to re-cast the fishers' responses into numeric values, a greater number of responses per species and some iteration towards a consensus might allow mean and confidence intervals to be derived for the final gear efficiency values. It is not known, however, whether a large enough number of fishers and other experts could be assembled.

It is unfortunate deployment of opportunistic cameras on an ECSI survey was not possible. It was hoped that sufficient footage of a given species might allow the quantification of fish behaviour using the approach recommended by Reid et al. (2007). The Delphi approach described above allows expert opinion to be used to provide 'judgmental adjustments' to statistical data (Hyndman & Athanasopoulos

2018). It must be borne in mind, however, that the trial deployment of cameras on the snapper Bay of Plenty survey suggest the muddy nature of the substrate in large parts of the inshore survey area could make useable footage difficult to obtain.

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APPENDIX 1: R.V. *Kaharoa* trawl catchability background information provided to interviewees

Background: Objectives of the low information stock project and fisher questionnaire
The Fisheries New Zealand project LSP201902 aims to estimate stock status of "low information" inshore finfish species by making more use of trawl survey data and commercial catch spatial data (which includes areas beyond survey boundaries). This project is initially focussed on the South Island *Kaharoa* trawl surveys.

We would like to get a better understanding of how well the *Kaharoa* trawl survey catches a variety of species, relative to each other, and are seeking your expert knowledge of commercial inshore trawling to help us with this. For key species, we would like to better understand areal availability, vertical availability and vulnerability of species in the path of the *Kaharoa* trawl gear, as well the effect of important environmental factors.

We have developed a set of questions for key ECSI species of interest listed below:

Survey target species	Secondary species
Elephant fish	Barracouta
Red gurnard	Blue warehou
Sea perch	Dark ghost shark
Stargazer	Lookdown dory
Tarakihi	Red cod
Skates (rough & smooth)	School shark

The initial focus will be on the survey target species – the secondary species will be included where time permits, potentially in a more generic way – e.g., by considering what species they are likely to similar to in their behaviour or catchability.

***Kaharoa* description**
Kaharoa is a 28 m stern trawler with a beam of 8.2 m, displacement of 302 t, engine power of 522 kW, and capable of trawling to depths of 500 m. The two-panel trawl net used during the survey was designed and constructed in 1991 specifically for South Island inshore trawl surveys and has been maintained to the same specifications for the last 30 years. The net is fitted with a 60 mm knotless codend. The net plan and photos of the gear are shown in Appendix 1.

Research tows are 3 nautical miles long, at 3 knots (variable propeller, 700 rpm, revs and pitch held constant on hauling). Gear parameters that vary and are measured each tow are summarised below for the most recent South Island surveys, which cover depths of 10–400 m:

	WCSI & TBGB		ECSI	
	mean	range	mean	range
Headline height (m)	4.5	(4.1–4.9)	4.8	(4.3–5.1)
Doorspread (m)	82	(67–99)	77	(66–96)
Warp:depth ratio	4.3:1	(2.3-11.8)	4.0:1	(2.4–13.3:1)

Proposed interview questions on *Kaharoa* catchability will cover three main capture zones (Figure A1.1).

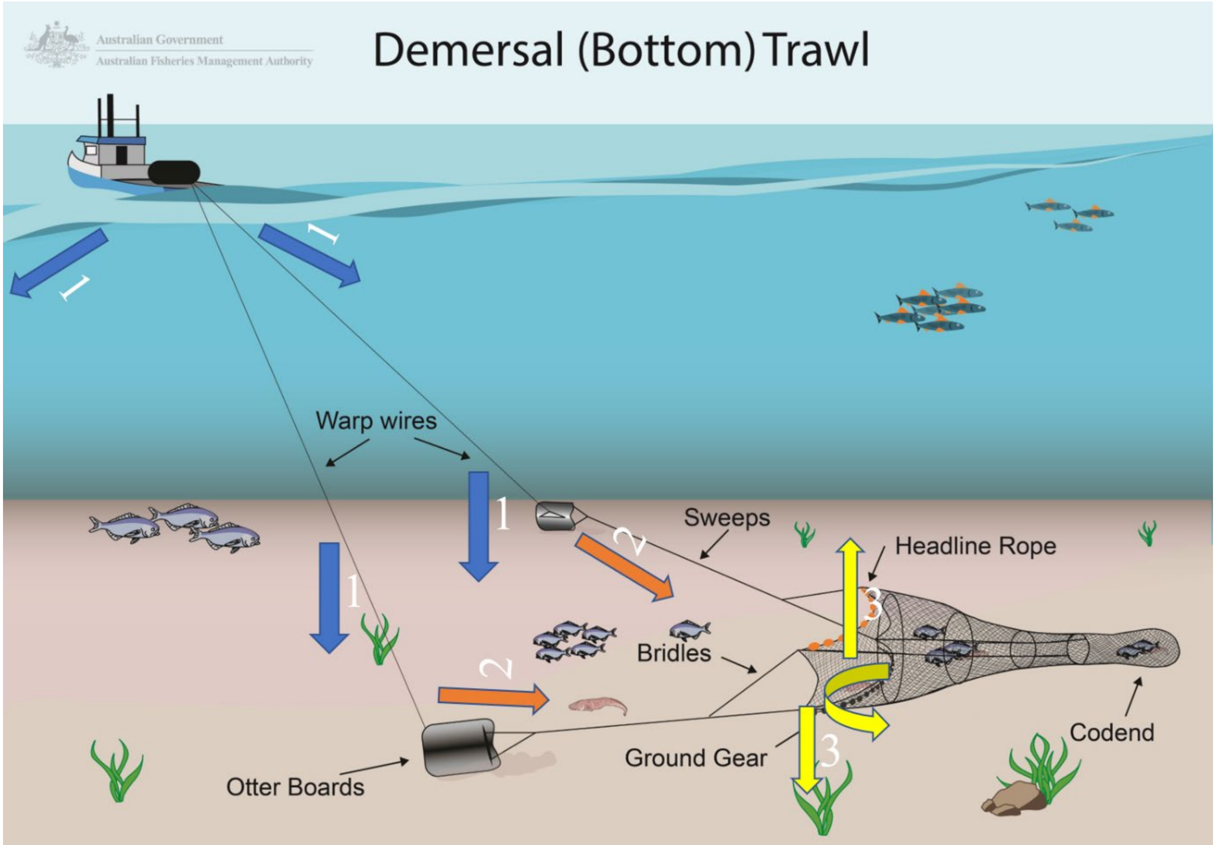


Figure A1.1: Capture zones. Copyright permission for background image was granted by the Australian Fisheries Management Authority.

1. Ahead of the doors (vertical availability): e.g., are fish scared by vessel, herded down by warps into path of trawl?
2. Vulnerability to capture between the doors and the net: e.g., are fish herded by doors, sweeps and bridles, sand clouds, pressure waves?
3. Vulnerability at net mouth: e.g., can fish escape over the headline, sideways, or under the groundrope?

We are also interested in what environmental factors can significantly affect catchability, e.g., moon phase, habitat type (does the species occur over rough ground?), recent rainfall/water clarity, time of day, earthquakes, climate variability.

Trawl warp			16 mm, 6 x 19 PPC	
Approximate doorspread			60 – 90 m	
Optimum wingspread			12.35 m	Using (Prado & Dremiere 1990)
Angle of attack of sweeps and bridles			14° @ 69.4 m	
			16° @ 77.4 m	
			19° @ 89.4 m	
Trawl doors – rectangular vees			3.2 m^2	630 kg
Backstrop length			7.5 m	
Sweep length			55 m	51 kg
			16 mm, 6 x 19 PPC	
			Polyprop core (9/9/1)	
			Weight 0.92 kg/m	
Bridle length	Top		55 m	29 kg
			12 mm, 6 x 19	
			Polyprop core (9/9/1)	
			Weight 0.52 kg/m	
	Bottom		55 m	51 kg
			16 mm, 6 x 19	
			Polyprop core (9/9/1)	
			Weight 0.92 kg/m	
Layback			150 mm	
Flotation				Buoyancy
	headline	2	360 mm diameter floats	27 kg
		20	300 mm diameter floats	199.5 kg
	net sonde	2	fender floats	negligible
	CTD logger	3	fender floats	negligible
	total buoyancy			~ 227 kg
Ground rope specifications				Weight
	wire rope		35 m 18 mm (6 x 19)	
	rubber rollers	48	110 x 170 mm	
	rubber spacers	464	40 x 80 mm	
	steel balls	12	150 mm diameter, 12 kg	144 kg
	toggled hangers	50		
Net attachments	BCS		7.1 kg	
	Net sonde		15 kg	
	CTD logger		15 kg	
	total weight			~ 280 kg
Fishing line specifications	Rope covered wire		2 x 14.7 m, 1 x 2.8 m	
V-line specifications	'Hi-man' Superline		24 mm, 6.4 m	
Headline specifications	Rope covered wire		25.05 m	

Figure A1.2: R.V. *Kaharoa* bottom trawl specifications 2014.

Mesh and twine size	No. meshes deep	Selvage ropes nylon 26 mm	Joining Ratios
150 mm 4 mm (Olivene)	20	V-lines 24 mm Hi-man superline 6.4 m	
150 mm 4 mm (Olivene)	50.5	6.3 m	
150 mm 4 mm (Olivene)	25	3.3 m	
150 mm 4 mm (Olivene)	25	3.3 m	
120 mm 400/60 (pe)	99.5	10.8 m	4:5
120 mm 3.5 mm (Olivene)	39.5	4.0 m	1:1
100 mm 5 mm (Olivene)	50.5	4.2 m	5:6
60 mm knotless (type)	50	-	4:5

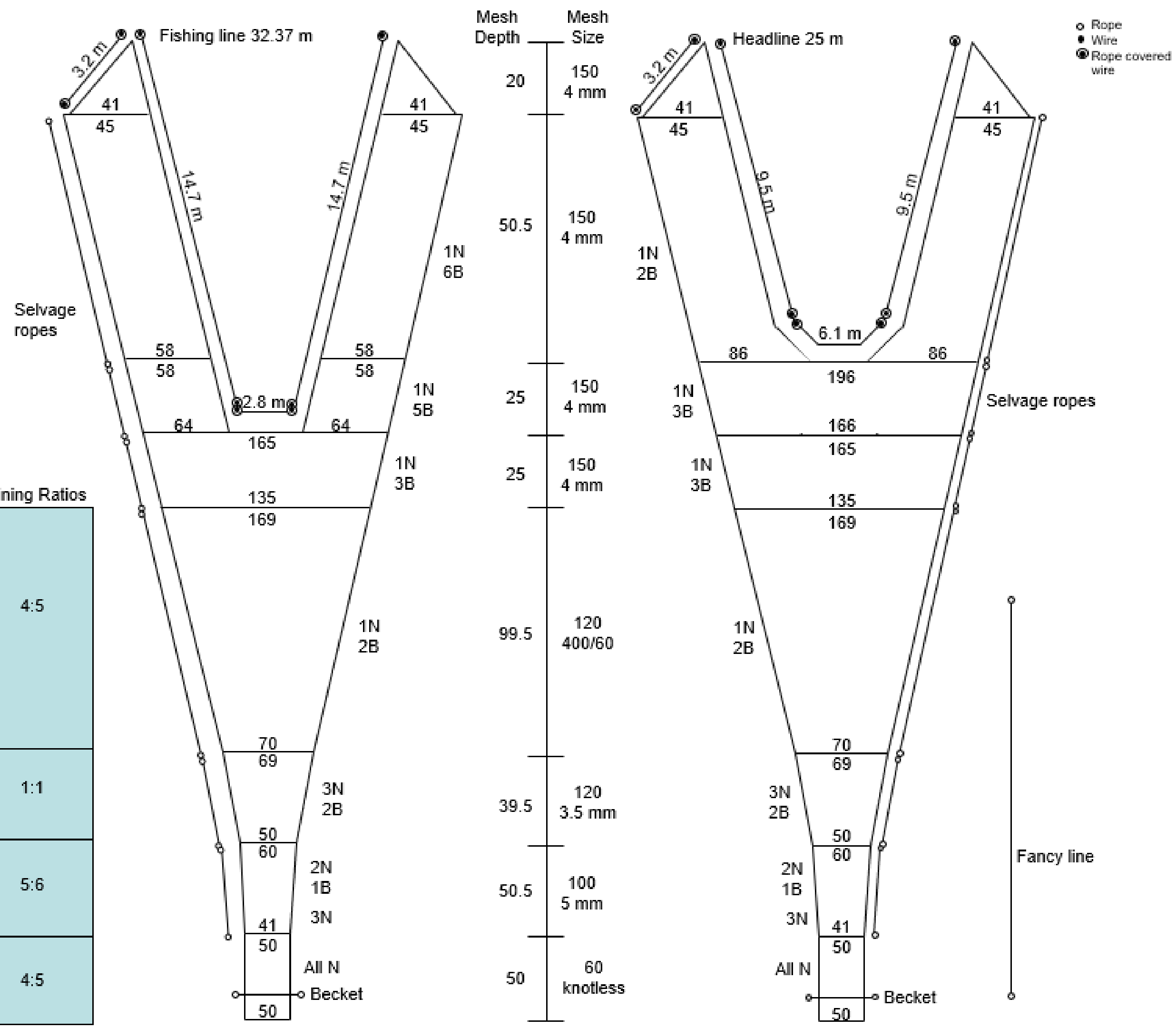


Figure A1.3: Net plan for R.V. *Kaharoa* bottom trawl.

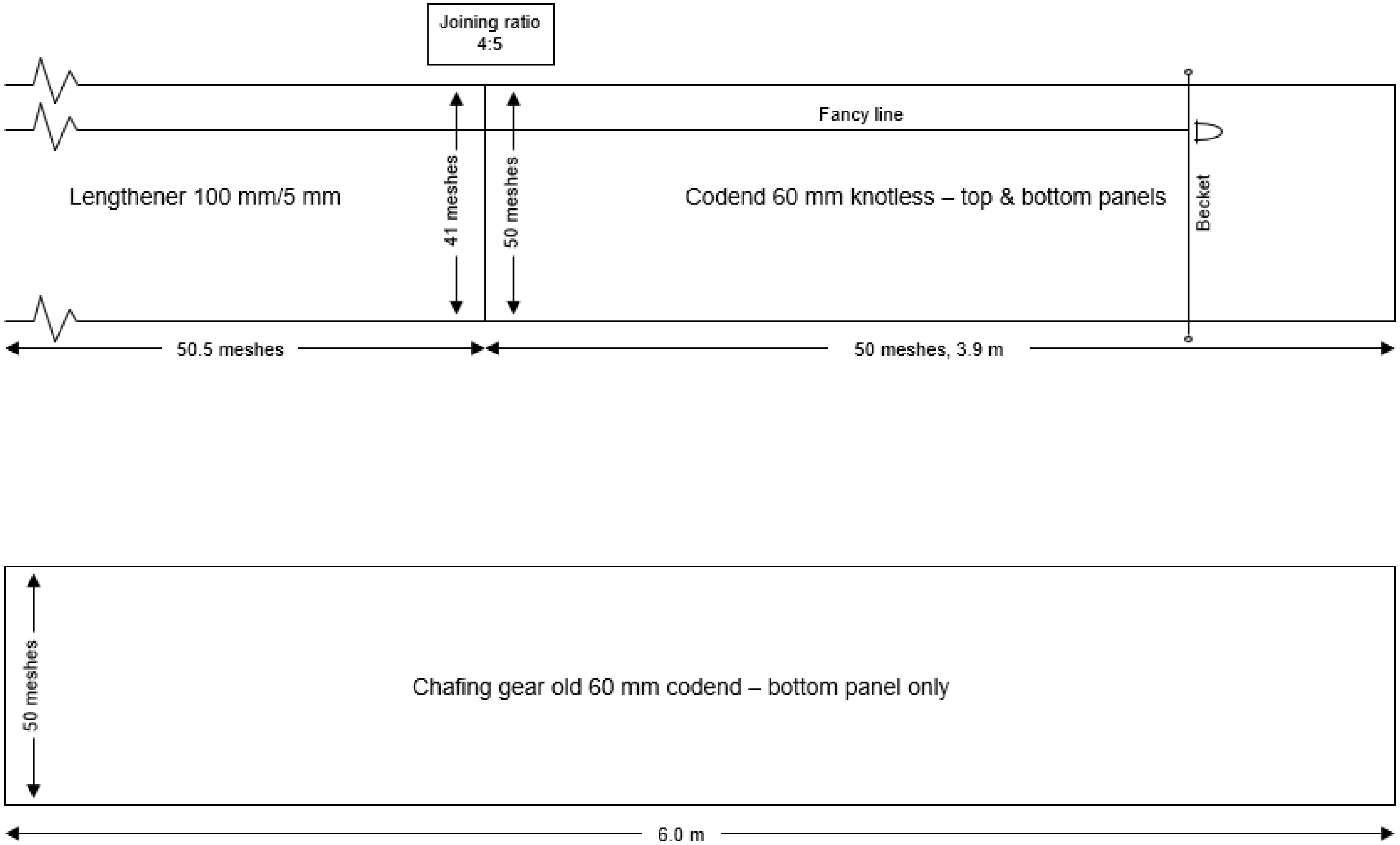
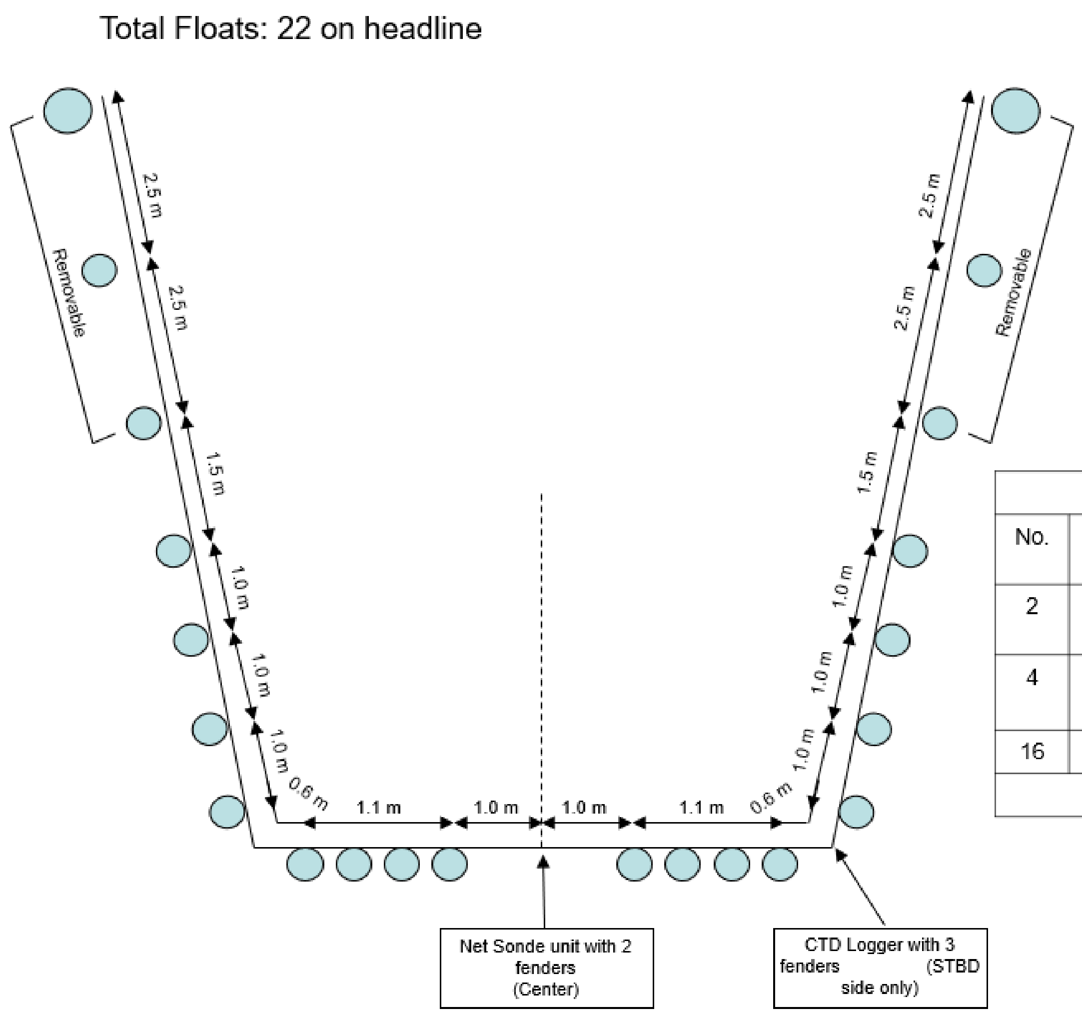


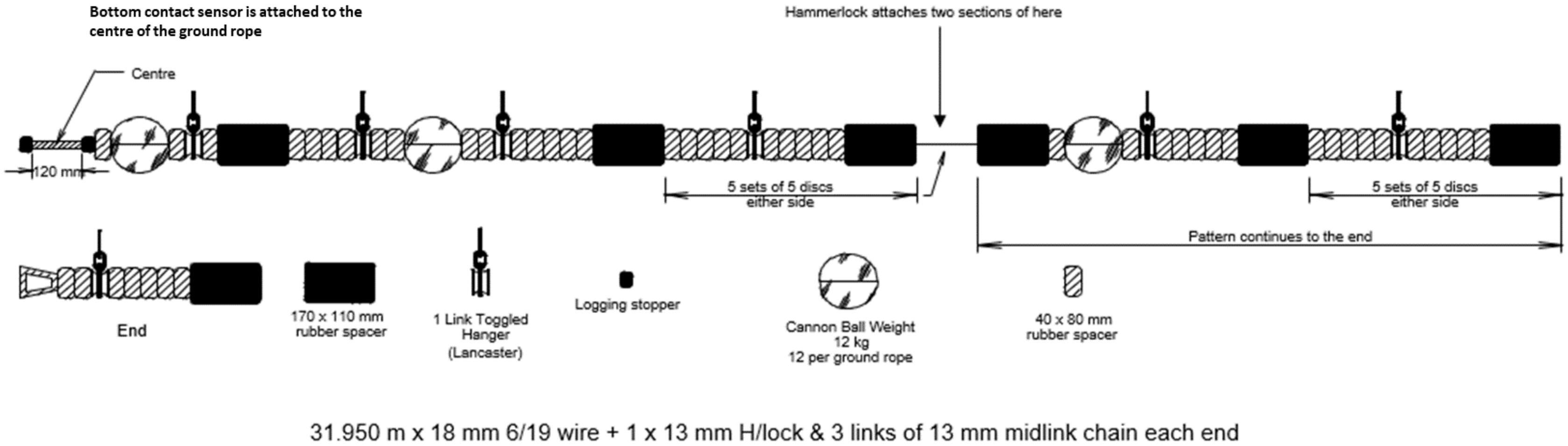
Figure A1.4: Codend for ECSI Inshore (30 – 400m and 10 – 30m) trawl survey.

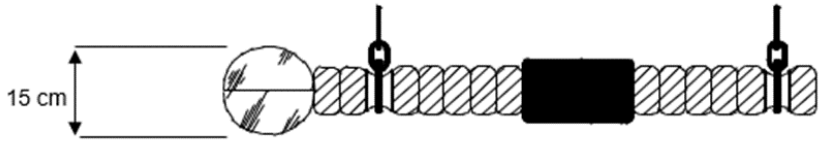


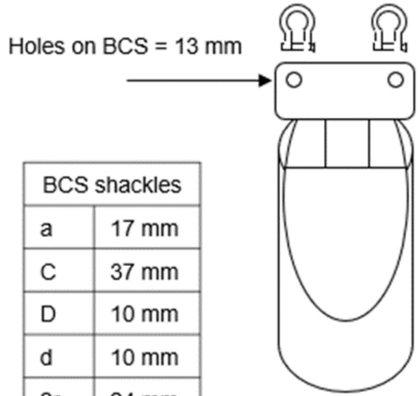
Floats			
No.	Diameter (mm)	Buoyancy (kg)	Rated depth (m)
2	360	13.3	Removable rated to 1500 m
4	300	9.7	Removable, rated to 800 m
16	300	9.7	Rated to 800 m
Total Buoyancy = 221 kg			

Figure A1.5: Float plan: R.V. *Kaharoa* bottom trawl net.

Figure A1.6: Headline deployed (left), showing CTD and contact sensor (middle) and bottom contact sensor attachment on groundrope (right).







BCS shackles	
a	17 mm
C	37 mm
D	10 mm
d	10 mm
2r	24 mm

Figure A1.7: Group rope assembly: R.V. *Kaharoa* bottom trawl.

Figure A1.8: Groundline and fishing line setup.

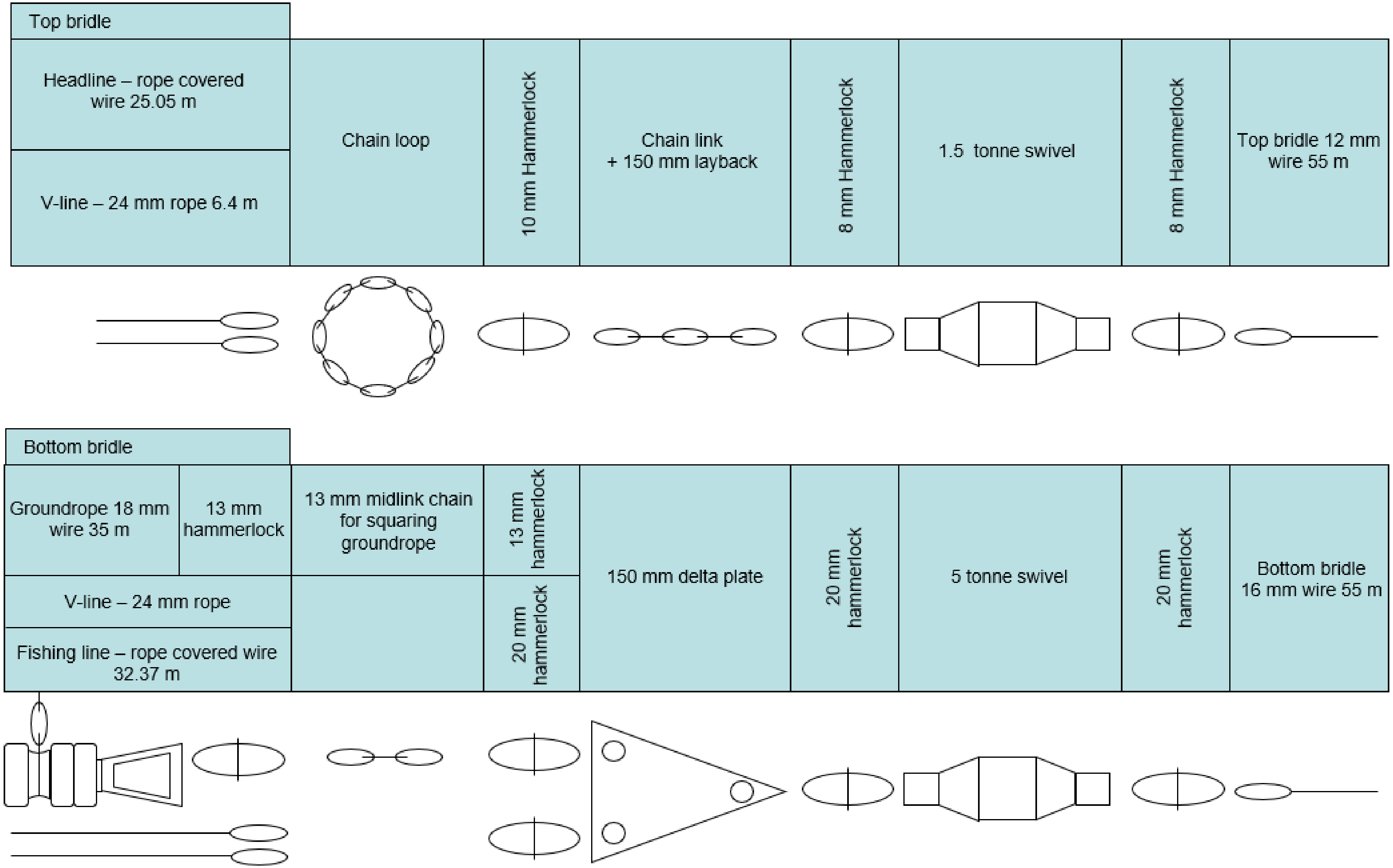


Figure A1.9: Net to bridle assembly: R.V. *Kaharoa* bottom trawl with 150mm layback.

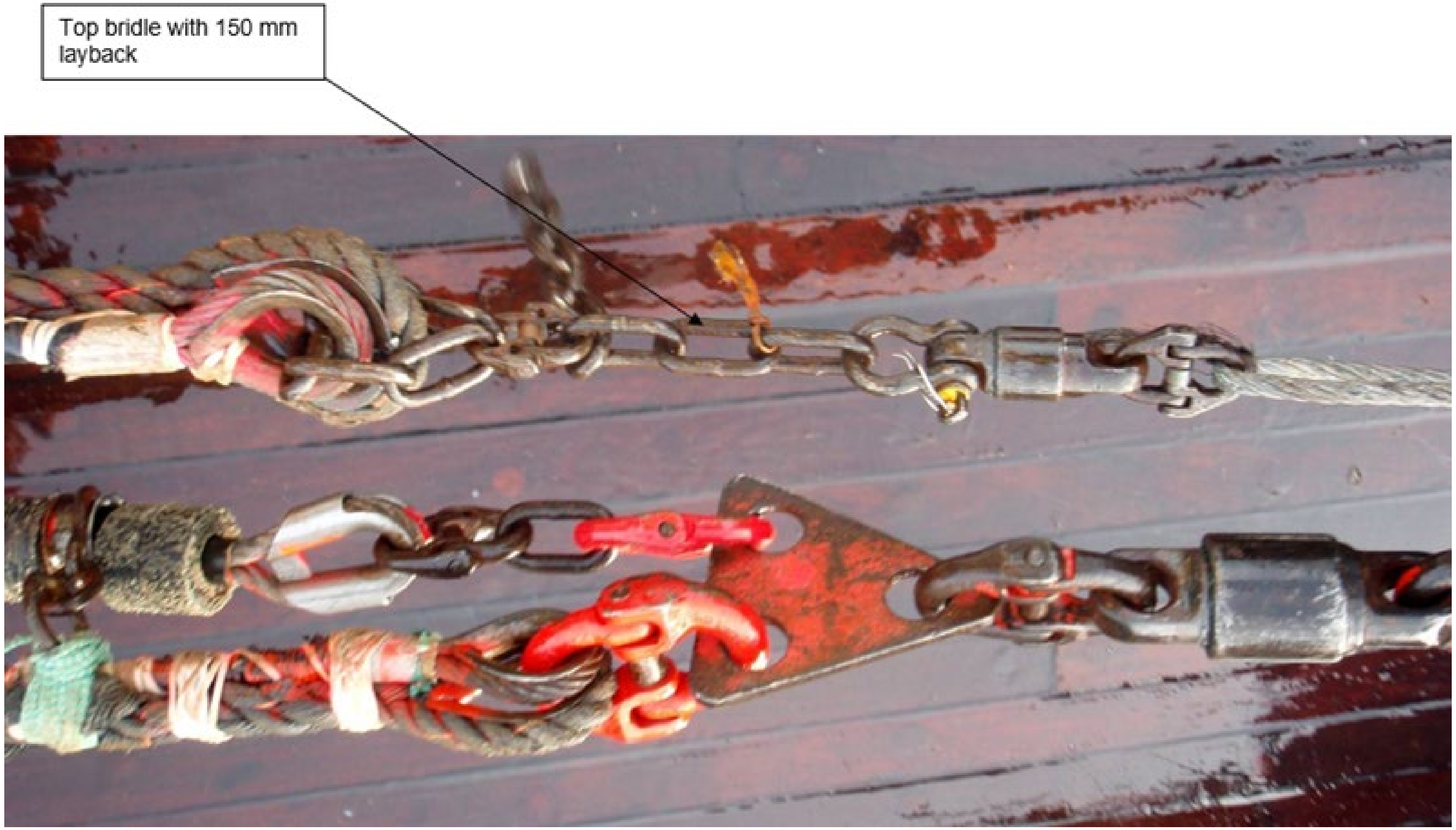
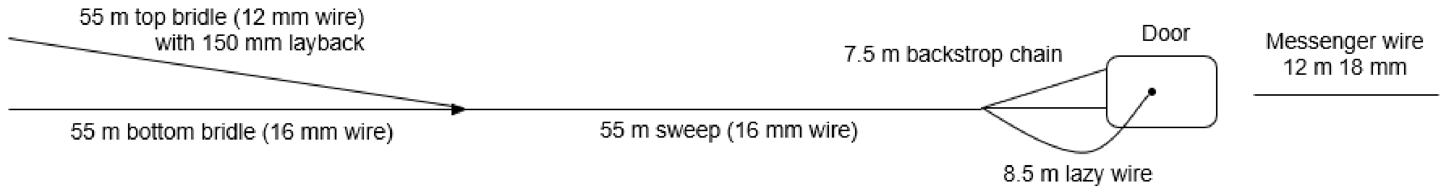
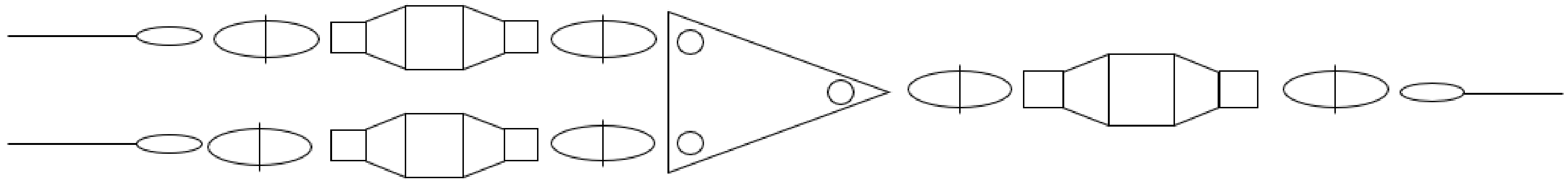


Figure A1.10: Top and bottom bridle-net attachments.



Bridle to sweep connection								
Top bridal 55 m 12 mm wire	13 mm hammerlock	3 tonne swivel	16 mm hammerlock	150 mm delta plate	16 mm hammerlock	5 tonne swivel	16 mm hammerlock	Sweep wire 55 m 16 mm
Bottom bridal 55 m 16 mm wire	16 mm hammerlock	3 tonne swivel	16 mm hammerlock					



Trawl door setting																	
Sweep wire 55 m 16 mm	Hook	Chain	14 mm H/L	10 mm H/L	Chain	10 mm H/L	10 mm H/L	Shackle	Door Rectangular V 2.4 m x 1.5 m	16 mm H/L	Chain	14 mm H/L	Chain	14 mm H/L	Dry swivel	14 mm H/L	Trawl warp wire 16 mm
				10 mm H/L	Chain		10 mm H/L	Shackle	$3.2\ m^2$ 630 kg	16 mm H/L	Chain						

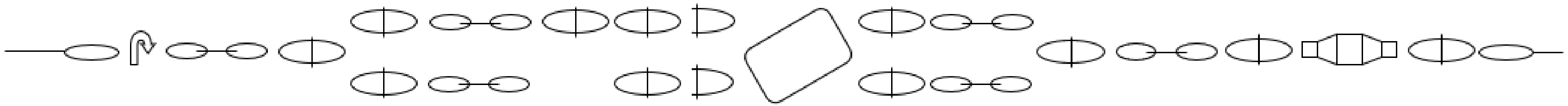


Figure A1.11: Sweeping gear: R.V. *Kaharoa* bottom trawl.

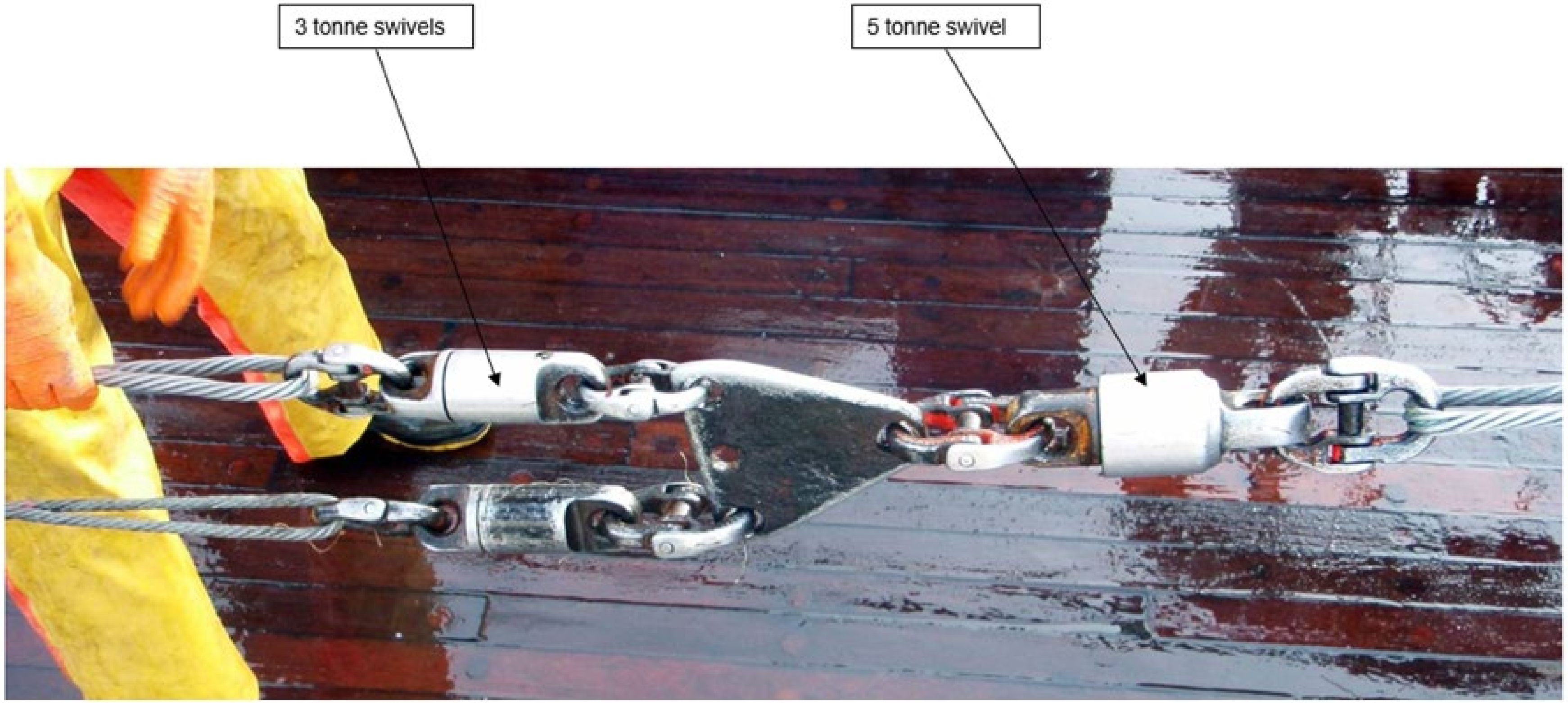


Figure A1.12: Sweep to bridle attachment

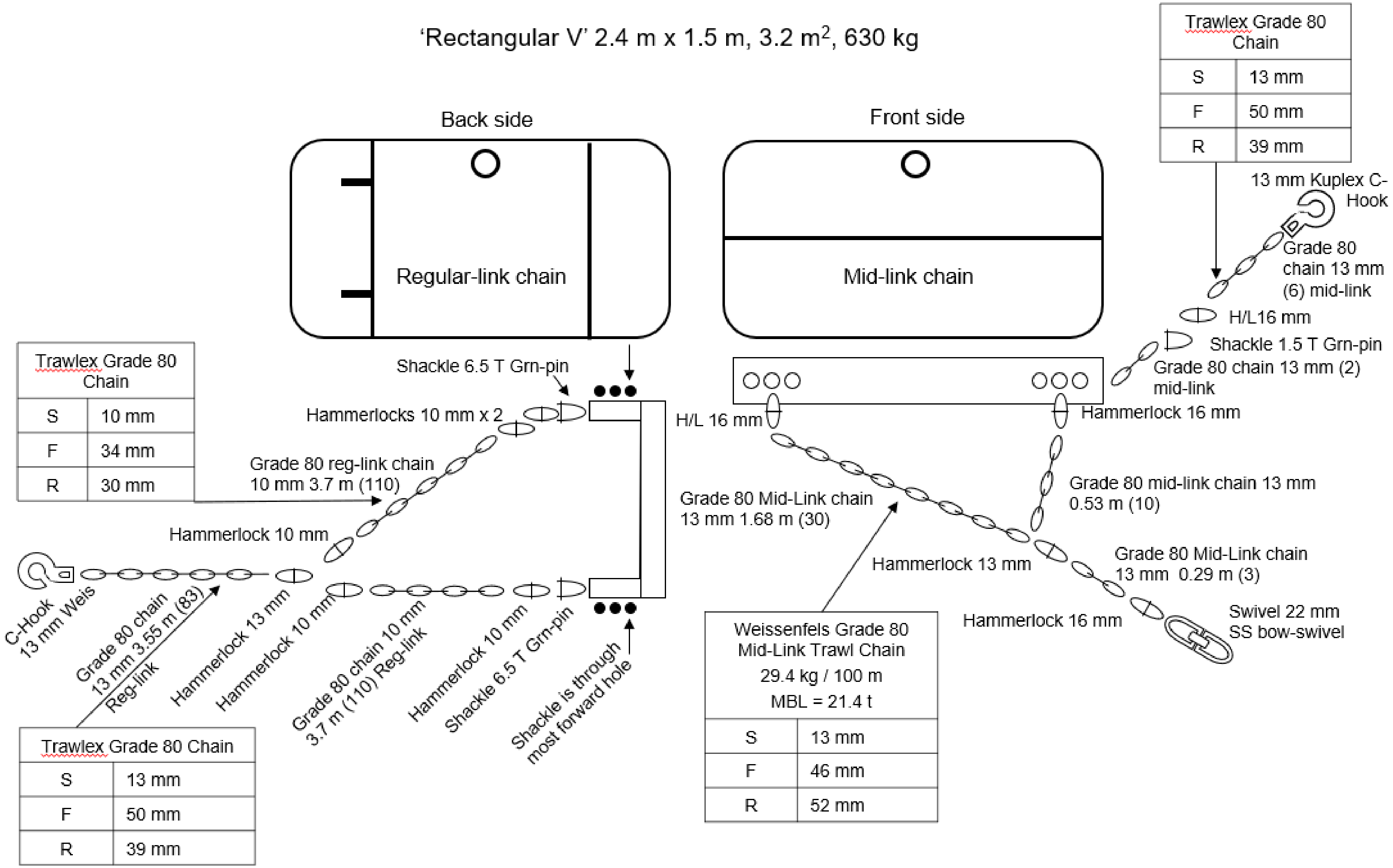


Figure A1.13: Door rigging for R.V. *Kaharoa* bottom trawl

APPENDIX 2: Estimated *Kaharoa* fishing efficiency (*Q*) by individual species, fishing zone, and interview

The following tables provide a more detailed summary of fishers' observations and comments on key and secondary survey species from Tasman Bay and Golden Bay (TBGB), the east coast South Island (ECSI), and Southland (STH), than that given in Table 6. The interview number is the fisher identifier, the capture zones are shown in Figure 2, and the scores are described in Table 2. Note the environmental observations and feeding information are relevant to fish availability in capture zone 1.

Snapper (TBGB)

Capture zone	Interview	Score	Observations/comments
1	1	MH	Marks off bottom in summer
	4	H	Surface schools only spawning season; headline height good (pair trawl 8 m)
		Diet*	Polychaetes, echinoderms, crustaceans, molluscs, tunicates. BENTHIC invertebrates
2	1	H	Herded by doors and sweeps, pressure wave down sweeps important (15° angle of attack)
	4	M?	Well herded (schooling species) speed good (uses 3.2–3.3 kn.), *Kaharoa* sweeps short
3	1	M	*Kaharoa* good headline height and floatation, but speed not fast enough (uses 3.6 kn.) and length of tow won't tire fish. Veranda important.
	4	M	Headline height good, ground gear OK, shorter sweeps may not tire fish
Environment			Temperature critical – recent increase extended season from 5 to 8–9 months Westerly winds better in Golden Bay, E/SE catches decline Timing: Arrive Sept/Oct, move offshore in mid-March (survey start date important). Easier to catch during stronger tides (within 1 week of full moon); Moon phase (affects all species). Earthquakes – fishing goes off for 3–4 days. Better fishing morning than evening (especially in winter), can be caught at night-time on bottom.

* Stevens et al. (2012). Summary of published and unpublished dietary information.

Elephant fish (ECSI)

Capture zone	Interview	Score	Observations/comments
1	2	H	Hard down, no difference day and night
	3	MH	Good on dawn and dusk
		Diet*	Shellfish, crustaceans, cod (Australia: polychaetes, molluscs, crustaceans). BENTHIC
2	2	ML?	May dive when encounter sweep; not caught well by Danish seine, suggests not well herded?
	3	?	Schooling, slow swimmers
3	2	H	Headline height and veranda good – low escapement for most species
	3	H	Better catches with higher headline height (so, OK)
Environment			No difference in catch rates day and night Best around full moon, good on dawn and dusk

* Stevens et al. (2012). Summary of published and unpublished dietary information.

Red gurnard (TBGB, ECSI)

Capture zone	Interview	Score	Observations/comments
1	2	H	Hard down
	3	H	–
	4	H	Hard down, not schooling. Low headline height ok
		Diet*	Crustaceans 57%, mainly *Munida* (20%), *Ovalipes* (18%), and unid crabs; teleosts 43% (incl. red cod 6%, sprat). Similar by size.Mostly BENTHIC
2	2	H	Effectively herded well by Danish seine
	3	H	Herded, faster the better
	4	MH?	Shorter sweeps = potential issue – does not tire fish. Herd well, but not as well as schooling species
3	2	H	Headline height and veranda good – low escapement for most species
	3	H	Better with higher headline height (so good)
	4	H	Ground gear good
Environment			Off bottom/not herded = uncatchable at night (opposite to TAR in FMA 3); stickers in top of net. Large increase in abundance in recent years – displaced red cod?

*Stevens et al. (2012). 986 fish sampled from ECSI (sampled fish 20–55 cm length). 30% of stomachs contained food.

Rough and smooth skates (ECSI)

Capture zone	Interview	Score	Observations/comments
1	2	MH	Hard down, buried, probably *Kaharoa* gear digs them up? Similar to STA.
		Diet*	Red swimming crab (*Nectocarcinus antarcticus*). BENTHIC
2	2	ML	Buried or not herded? Not caught by Danish seine
3	2	H	Low escapement most species
Environment			

*Stevens et al. (2012). Summary of published and unpublished dietary information.

Sea perch (ECSI, STH)

Capture zone	Interview	Score	Observations/comments
1	3	H	Hard down. Territorial, non-schooling
	5	H	Hard down (<2.5 m)
		Diet*	Crustacea 62%, *Munida* 41%, Teleosts 18% (most unidentified); squid 4%; similar by size. BENTHIC but some pelagic?
2	3	M?	Not fast swimmers
	5	MH	Herds effectively (e.g., comparable catch rates with different groundrope length), 14–17° sweep angle, 2.7 knots, maybe not so well at >17°?
3	3	H	Headline height and veranda good – low escapement for most species
	5	H	Lower headline height not less efficient, keeping bottom contact important
Environment			Like rough & spongy bottom, localised (tow ~45 minutes) so areal availability might be low. Territorial, prone to localised depletion. Hard down, close to areas of foul ground (e.g., Separation Pt.)

*Stevens et al. (2012). 266 fish sampled from ECSI (sampled fish 15–40 cm length). 40% of stomachs contained food.

Giant stargazer (ECSI, STH)

Capture zone	Interview	Score	Observations/comments
1	2	MH	Hard down or buried but *Kaharoa* gear probably digs them up?
	3	M	Some buried and go below groundrope
		Diet*	Teleosts 71% (60% unid), opalfish, RCO, BAR, macrourid, TAR, squid 15%; *Munida* (5%). BENTHIC and some pelagic? (some feeding in trawl?)
2	2	ML	Don't herd well in Danish seine (but maybe because buried and trawl has better bottom contact)
	3	ML	Tows 2.3–2.4 kn. (so too fast) – theory flick over sweeps if tow faster
3	2	H	Headline height and veranda good – low escapement for most species
	3	MH	Some loss under groundrope, otherwise OK
Environment			No difference in catches day and night. Territorial. Do better on a bright moon, lower catch rates (~half) at night

*Stevens et al. (2012). 1 475 fish sampled from ECSI (sampled fish 10–80 cm length). 73% of stomachs contained food.

Tarakihi (ECSI, STH)

Capture zone	Interview	Score	Observations/comments
1	2	ML	Catch about 70% at night – suggests dispersion in MW during daytime?
	3	M	Better with higher headline height (i.e., >2.5 m, so *Kaharoa* ok)
		Diet*	Mostly polychaetes, crustaceans, echinoderms (plus, fish, molluscs, etc.). BENTHIC
2	2	H	Herd well?
	3	H	Herd well
3	2	MH	Headline height and veranda good
	3	M	Lots of stamina so may not be tired
Environment			Catch ~70% at night, more in week prior to full moon (as for many other species); larger fish as move north and deeper, gnarly bottom is better, especially off Banks Peninsula; good at getting out of meshes. Different catchability around the country (e.g., time of day; better on full moon and at night

*Stevens et al. (2012). Summary of published and unpublished dietary information.

Barracouta (TBGB, ECSI, STH)

Capture zone	Interview	Score	Observations/comments
1	2	MH	Daytime catch only – off bottom feeding at night. Feed layer moves off bottom 10–12 m – sprats and *Munida*. More in water column than other species
	3	MH	Higher headline height (> 2.5 m) catch more (so, *Kaharoa* good)
	4	MH	
		Diet*	Crustacean 79% (euphausiid 70%, *Munida* 9%); squid 15%; Teleosts 9% (most unid). Slightly less crustacean and more squid with size. PELAGIC
2	2	MH	Speed important
	3	MH	Sweeps short?
	4	MH	
3	2	M	May need more power/speed
	3	H	Fish have less stamina
	4	MH	Shorter sweeps may not tire the fish enough
Environment			Daytime catch only – off bottom feeding at night Less at night

*Stevens et al. (2012). 3 594 fish sampled from ECSI (sampled fish 20-100 cm length). 58% of stomachs contained food.

Blue warehou (ECSI, STH)

Capture zone	Interview	Score	Observations/comments
1	2	ML	Daytime catch only – off bottom feeding at night.
	3	M	
		Diet*	Salps 97%; Crustacean 8% (euphausiid 7%); Similar by size. PELAGIC invertebrates
2	2	MH	Speed important, strong swimmers
	3	M	Speed important
3	2	ML	Speed > important than headline height
	3	M	Higher headline height better
Environment			Daytime catch only – off bottom feeding at night +/- 2 days of full moon best

*Stevens et al. (2012). 974 fish sampled from Southern NZ (sampled fish 25–65 cm length). 77% of stomachs contained food.

Dark ghost shark (ECSI)

Capture zone	Interview	Score	Observations/comments
1	2	H	
		Diet*	Crustacean 57% (*Munida* 21%, crabs 19%); teleosts 9% (most unidentified, incl. red cod, stargazer), molluscs 9% (shell and scallops); echinoderms 8%; polychaetes 8%; tunicates 7%. BENTHIC
2	2	H	Easily caught
3	2	H	Low escapement most species
Environment			Higher catches on full moon

*Stevens et al. (2012). 225 fish sampled from Chatham Rise & Southern NZ (sampled fish 30-75 cm length). 40% of stomachs contained food.

Lookdown dory (ECSI)

Capture zone	Interview	Score	Observations/comments
1	3	H	Hard down, catch with low headline height
		Diet*	82% crustaceans (mostly natant decapods), 20% teleosts. BENTHIC
2	3	?	
3	3	H	Hard down, catch with low headline height
Environment			

*Stevens et al. (2012). 549 fish sampled from north island, west coast south island, Chatham Rise & Southern NZ (sampled fish 15–55 cm length). 38% of stomachs contained food.

Red cod (ECSI, TBGB)

Capture zone	Interview	Score	Observations/comments
1	2	MH?	Daytime catch only – off bottom feeding at night, sprats & *Munida*.
	4	H	
		Diet*	Crustacean 80% (*Munida* 64%); squid 2%; Teleosts 25% (most unid); mollusc 3% (incl. benthic). Slightly less crustacean and more squid with size. BENTHO-PELAGIC
2	2	H	Can tow too fast (up to 3 kn. is OK)
	4	MH	Herded well (but short sweeps)
3	2	H	Low escapement most species
	4	MH	Easily caught, not tired out?
Environment			Daytime catch only – off bottom feeding at night. Recent abundance low, also *Munida*

*Stevens et al. (2012). 3 420 fish sampled from ECSI (sampled fish 10–75 cm length). 50% of stomachs contained food.

School shark (ECSI, STH)

Capture zone	Interview	Score	Observations/comments
1	2	MH	Hard down
	3	H	Better with higher headline height (so ok)
		Diet*	Fish (incl. sardines, cod, flatfish), crustaceans, squid. BENTHO-PELAGIC
2	2	ML	Relatively fast swimmers.
	3	M H	Quick, so need faster speed. Also tow with the tide to max. chance of catching
3	2	HL	Maybe escape on hauling as not tired out?
	3	M	Keep speed on when hauling
Environment			Better catches at night

*Stevens et al. (2012). Summary of published and unpublished dietary information.

APPENDIX 3: Pilot attachment of trawl cameras

The aim of the pilot deployment of video cameras on the February 2020 survey was to determine the best methods of attachment, camera angles, and resulting fields of view, as well as to assess the quality of any images of fish obtained for the potential to quantify fish behaviour in response to the trawl gear.

The GoProHero-4 cameras (Set to 1080P-30) resolution housed in a NIWA built protective cage, were deployed in waters less than 75 m depth (after Larsen et al. 2018). Deployments were possible on 29 occasions, of which 17 were opportunistic and 12 were dedicated deployments after the survey was completed. This allowed for the cameras to be trialled in more than the two positions originally envisaged (next to the headline transducer and on the wing next to the CTD). The additional positions included the centre of the groundrope, looking forward (Figure A3.1).

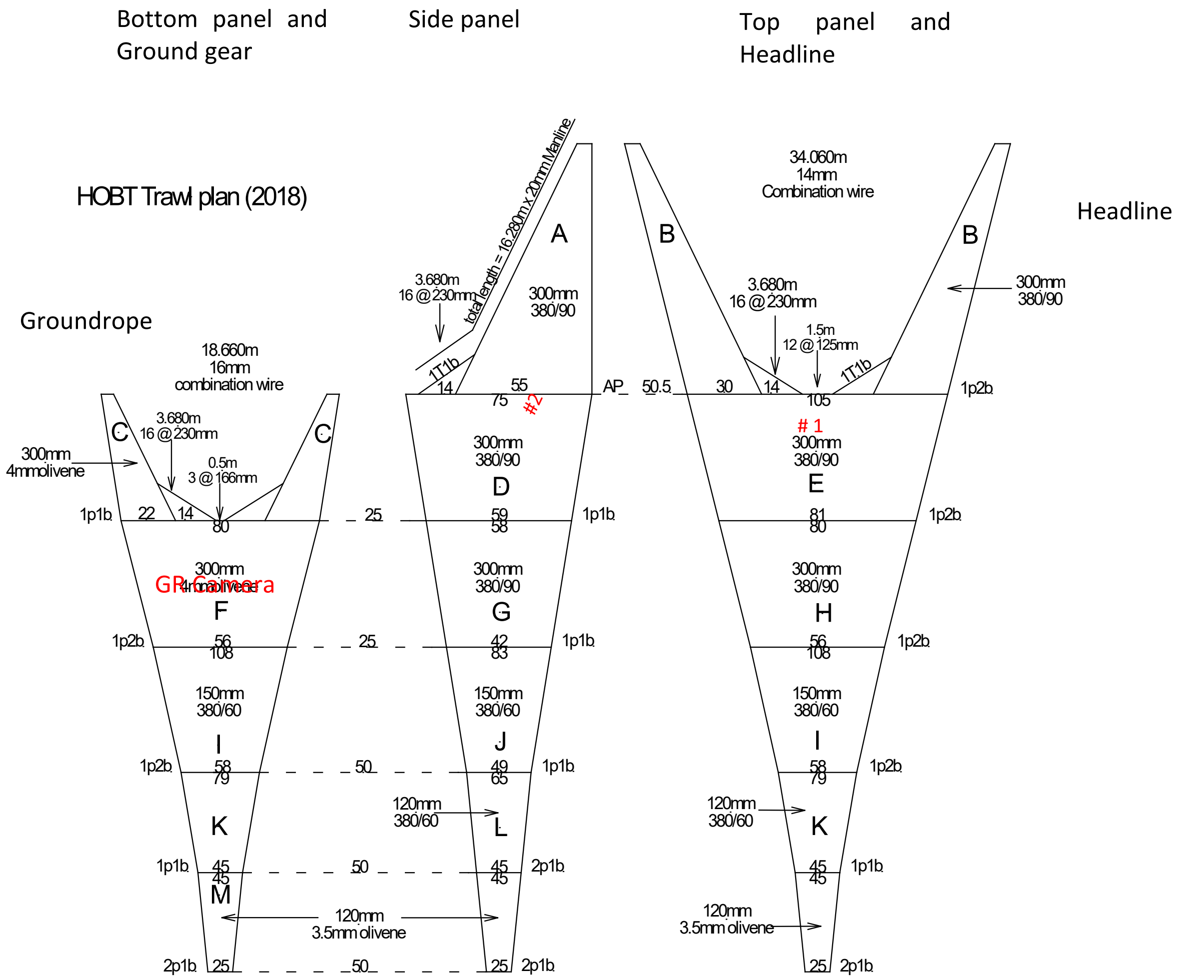


Figure A3.1: Placement of cameras on the *Kaharoa* trawl gear. GR, groundrope.

Limited footage was collected that could be used to quantify fish behaviour or gear avoidance; however, several of the videos showed small pelagic species escaping capture during early stages of hauling. The key factor that affected video quality was visibility, which depended on the bottom substrate. Areas of coarse sand and broken shell had good clear water; other bottom types produced a plume of fine sediment that severely reduced visibility. The other key challenge was that the large meshes of the top panels of the trawl made it difficult to accurately orientate the camera housings and get reliable camera angles.

None of the video data collected were analysed in detail. Some examples of recorded fish behaviour are shown in Figure A3.2. Note that the snapper survey trawl gear is not the same design as that used for South Island surveys.

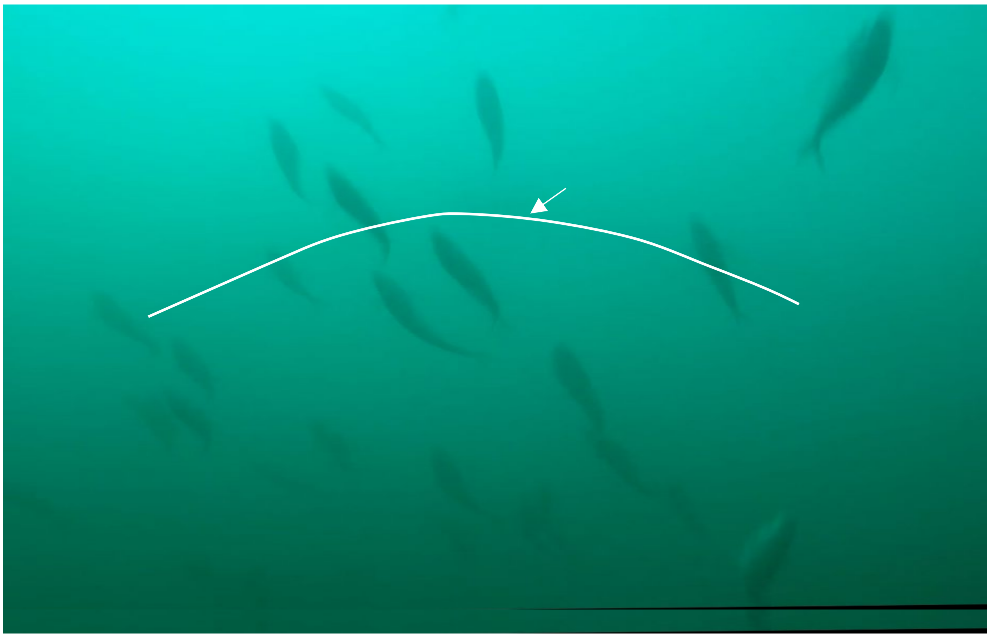


Figure A3.2a. Overlay of the aft end catenary of the headline – viewed from the groundrope looking up.

Figure A3.2b. Trevally swimming forward and escaping during hauling.

APPENDIX 4: Annual areal availability (u_a) results using predictions from GAM modelling

Areal availability of the stocks covered by the project was determined by relating survey catch rate data to environmental covariates using a generalised additive model (GAM) and then using the environmental covariate data to predict maps of species density over the full stock assessment area. Integrating the densities over the stock assessment area and over the area of the survey gave an estimate of the proportion of the stock within the survey area, i.e., the areal availability. The method produces a result for each year in which there are both survey data and covariate data. The following figures show these annual results. Included in the figures are text giving the mean result across all years and the 95% confidence interval of the mean. Results are shown from two approaches to the GAM fitting, a delta method approach (also known as a 'hurdle' model approach) and one that assumed the data conformed to a Tweedie distribution.

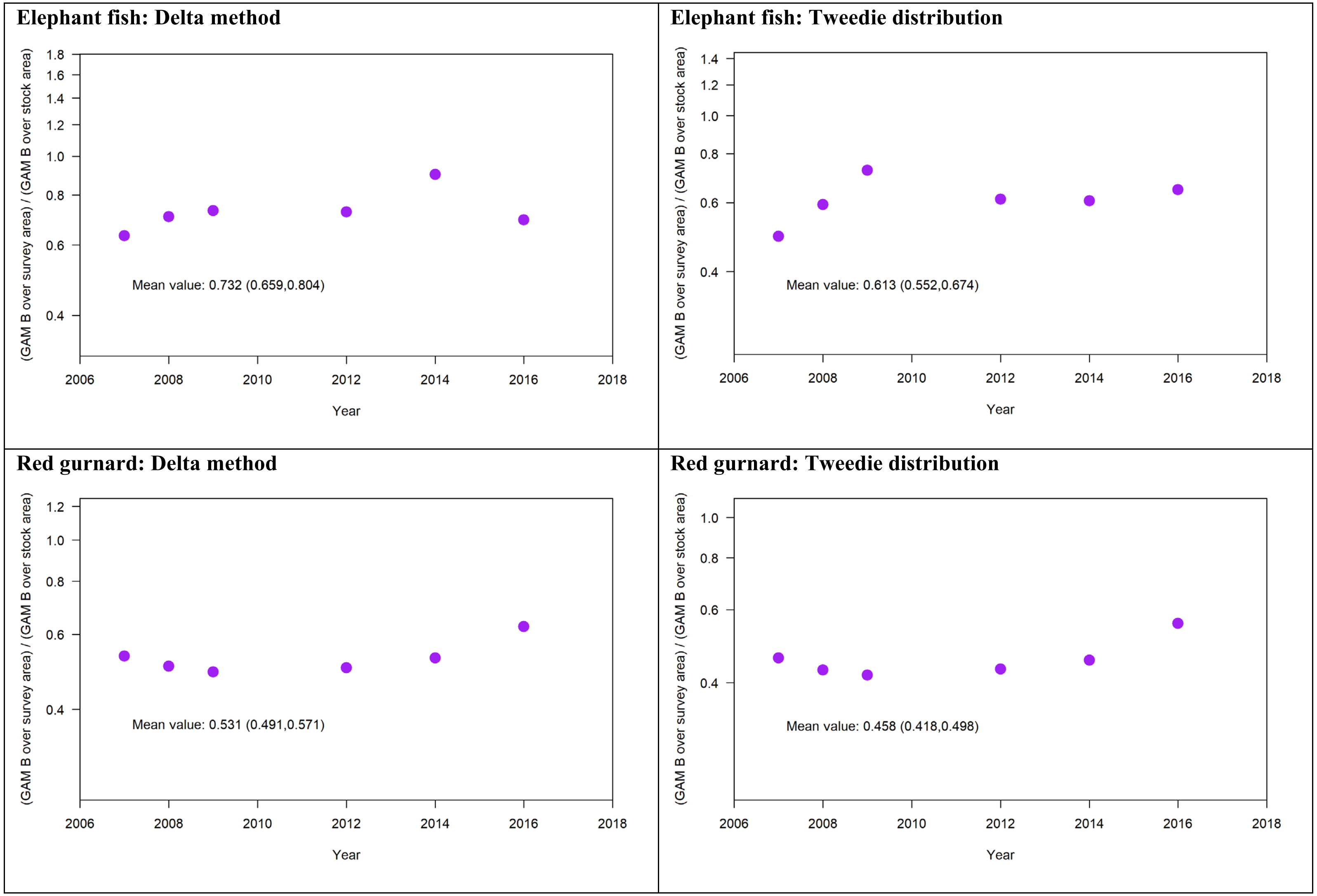


Figure A4.1: Areal availability estimates after GAM fitting to *Kaharoa* survey data and prediction of species surfaces using the chosen covariates. Left, GAMs using the delta method; right, GAMs assuming catch rate data are from a Tweedie distribution.

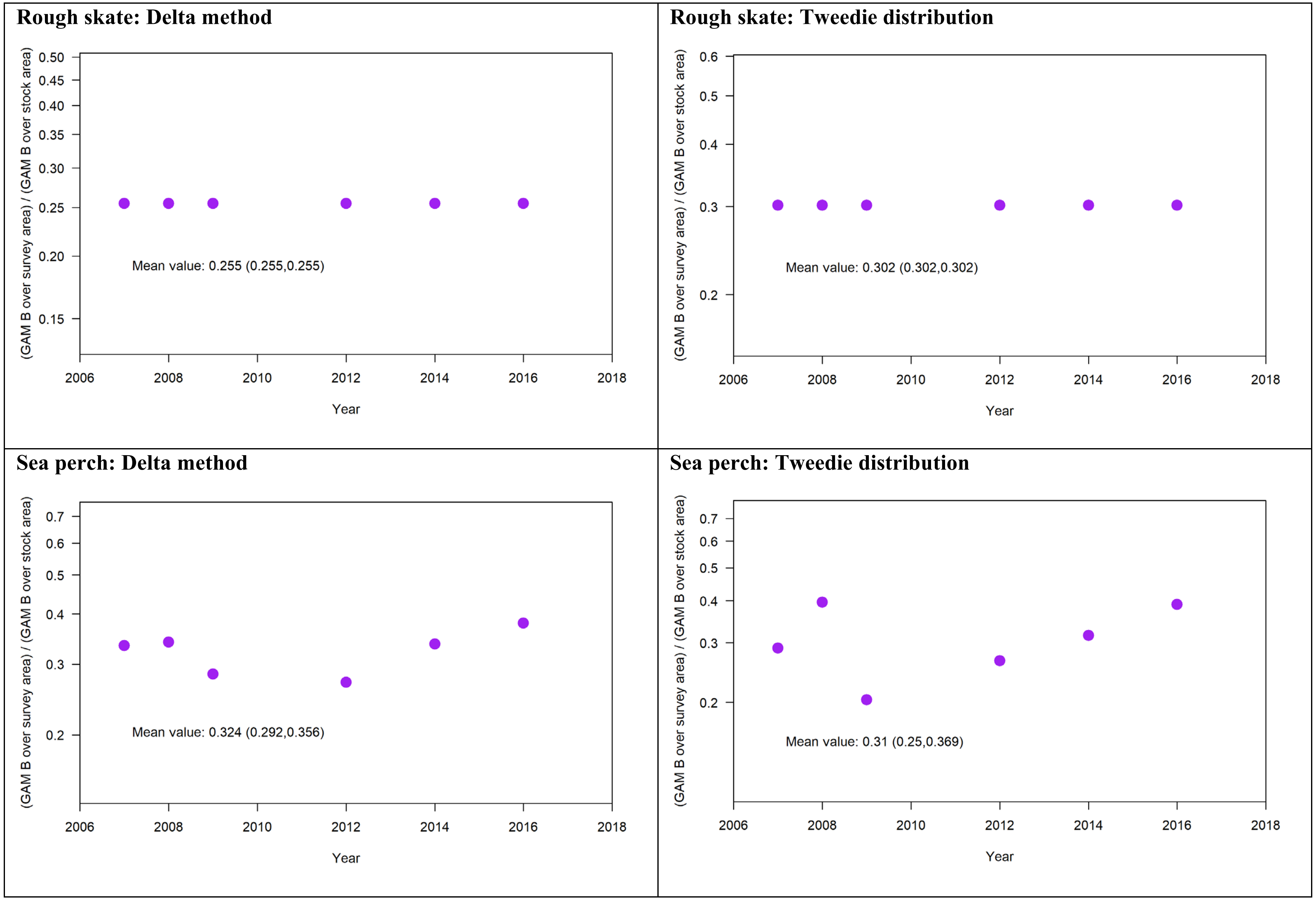


Figure A4.1 (cont.): Areal availability estimates after GAM fitting to *Kaharoa* survey data and prediction of species surfaces using the chosen covariates. Left, GAMs using the delta method; right, GAMs assuming catch rate data are from a Tweedie distribution.

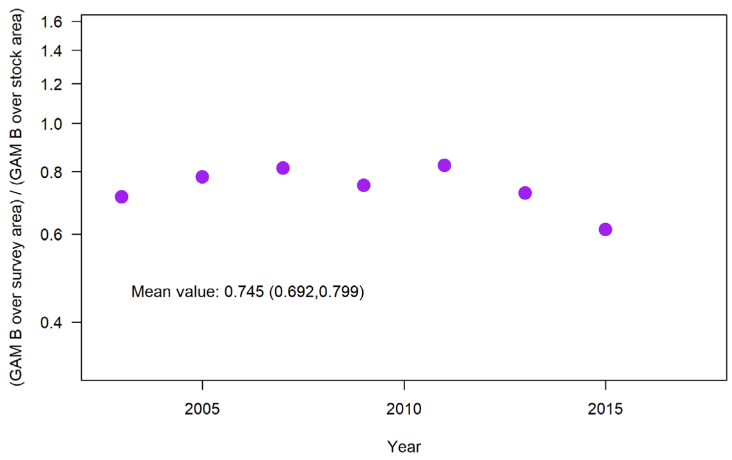
Snapper: Delta method	Snapper: Tweedie distribution
Comparison failed because prediction over full stock area gave unrealistic results (high densities at depths where snapper not encountered).	

Figure A4.1 (cont.): Areal availability estimates after GAM fitting to *Kaharoa* survey data and prediction of species surfaces using the chosen covariates. Left, GAMs using the delta method; right, GAMs assuming catch rate data are from a Tweedie distribution.

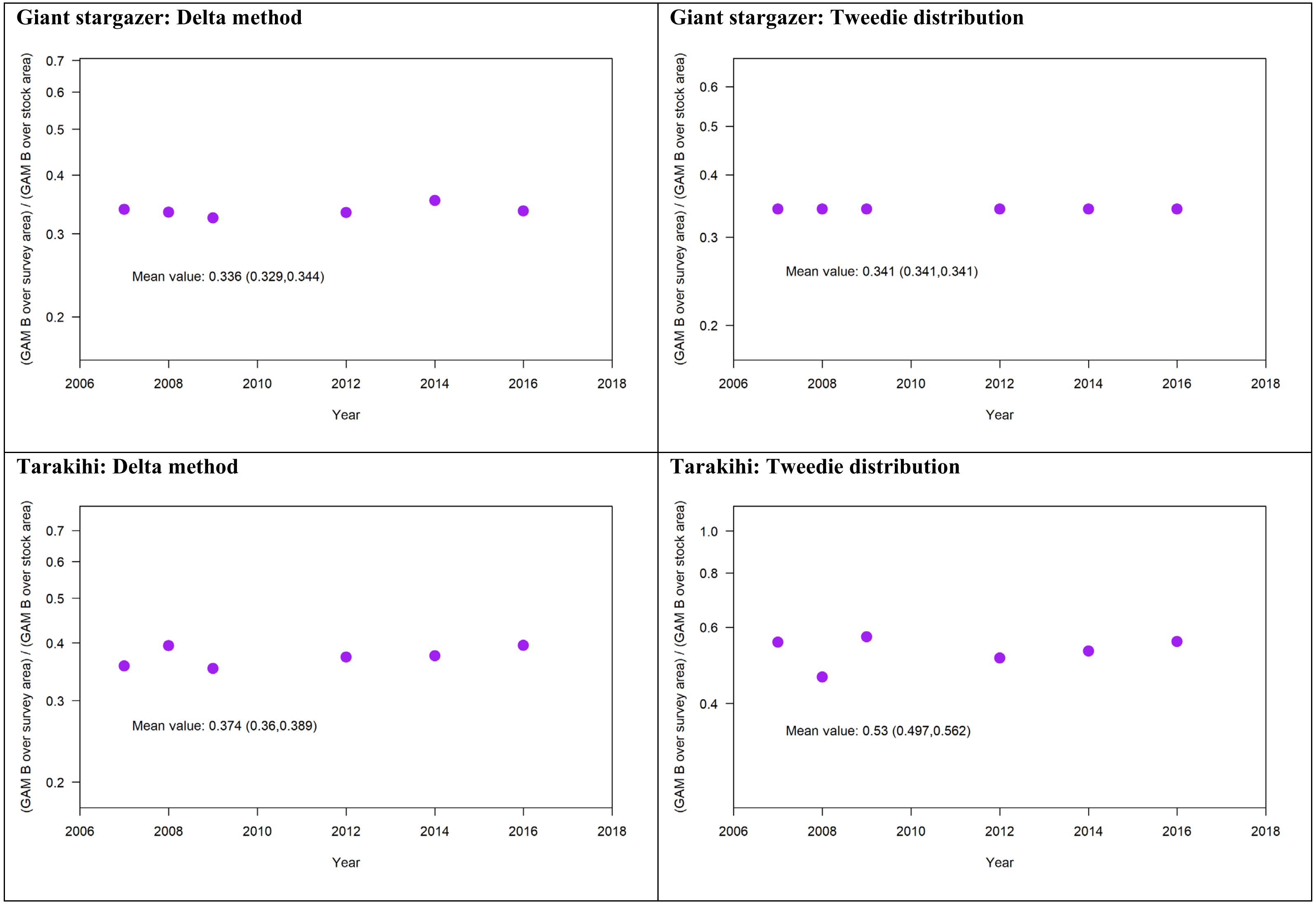


Figure A4.1 (cont.): Areal availability estimates after GAM fitting to *Kaharoa* survey data and prediction of species surfaces using the chosen covariates. Left, GAMs using the delta method; right, GAMs assuming catch rate data are from a Tweedie distribution.