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SC8-DW03

Estimating Biomass of *Jasus caveorum* on Kopernik Seamount in the South Pacific Ocean from the Cook Islands Trap Fishery

Cook Islands

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Estimating biomass of *Jasus caveorum* on Kopernik Seamount in the South Pacific Ocean from the Cook Island exploratory trap fishery

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Executive Summary

Under the auspices of CMM14b-2020 and its predecessors the Cook Islands has undertaken a three-year program of exploratory trap fishing targeting lobsters and crabs on seamounts along the Foundation Seamount Chain. This analysis used a series of experimental trap lines to estimate the effective fishing area of a trap, then selected a fishing lines from a commercial exploratory operation on Kopernik Seamount that were set on “virgin ground” to estimate biomass from transects lines within a number of depth class over the course of the fishery.

The experimental lines resulted in an estimated effective fishing area of a trap to have a 30m radius. However, the high variability in the results suggests that a range of estimates be used for biomass estimation. The plausible range total biomass was estimated to be 3,161t - 790t. The shallow areas of Kopernik Seamount (150-260m depth) have the highest biomass and below 260m biomass declined rapidly. Estimated biomass declines relatively rapidly from initial through Trips 1 to 3. Assessing the biomass weekly through the course of the fishery shows considerable variability in weekly mean biomass estimates but also a steep decline.

Management considerations for any future fishery ideally should be carried out across a number of seamounts each with a specific small TAC, along with other measures such as mesh size limits to protect the female population and closed seasons to avoid disrupting spawning and impacting females carrying eggs.

1 Introduction

South Pacific Regional Fisheries Management Organisation (SPRFMO) CMM14b-2018, which has subsequently been superseded by CMM14b-2020, allows for exploratory fishing to take place within the SPRFMO Convention Area. Under the auspices of CMM14b the Cook Islands has undertaken a three-year program of exploratory trap fishing targeting lobsters and crabs on seamounts along the Foundation Seamount Chain.

This programme which began in 2019 has provided new biological information on *Jasus caveorum* and *Chaceon* sp. as well as fishery data (Brouwer et al., 2019) and (Brouwer et al., 2020b). The key findings are that the fishery caught primarily lobster, *J. caveorum*, most of which were male ($\sim$ 60%), and that most females were not carrying eggs (in berry). These data are being used to evaluate the effectiveness of existing measures, to ensure that the bottom trap fishery is developed through a precautionary and gradual process in accordance with the best available scientific information. Additional information on Vulnerable Marine Ecosystems and the Benthic Footprint of this fishery are being documented within Brouwer et al. (2020a).

Thirteen seamounts were identified for initial exploratory fishing, where the greatest catch is coming from the Kopernik Seamount. The volume of catch and the small fishable area of Kopernik seamount has worried some Members at the SPRFMO Scientific Committee meeting who requested that exploration be undertaken cautiously and that the exploratory fishery diversify their targeting to catch more crabs and a smaller deep water lobster *Projasus* sp. (SPRFMO, 2019). In addition, the Cook Islands have been asked to undertake analyses in support of the management of this stock including undertaking an estimation of the stock biomass.

Biomass estimation is complicated and often undertaken within a complex stock assessment with the benefit of a long history of fishery data (Johnston and Butterworth, 2017), or highly controlled experimental design (Briones-Fourzán and Lozano-Álvarez, 2001). Alternatively surveys can be undertaken using cameras or baited traps (Cruz and Borda, 2013). As this is a new fishery in a remote area with no available historic fishing catch and effort information and no fishery independent surveys have been undertaken, alternative biomass estimation methods will need to be tested.

When using traps to estimate the abundance of benthic resources, it is important to estimate the relationship between captures and population density. Due to the depth of the habitat and the cryptic behaviour of lobsters, other survey methods such as video transects would be cost prohibitive. This work used data from commercial traps set on longlines as transect lines to estimate lobster biomass on Kopernik Seamount.

Firstly, we used experimental lines to estimate the effective fishing area of a trap, then selected a series of lines that were set on “virgin ground” to estimate initial biomass. The seamount was then divided into depth contours and catch per trap from selected lines (lines that did not overlap with others from that trip) were used as transects to estimate biomass within each depth class over time.

2 Methods

This analysis used a two phased approach to estimating biomass. The first phase was to estimate the effective fishing area of a trap. This was done to determine the the effective fishing area of a trap. Once a range of plausible effective fishing areas was determined, this was used to estimate biomass from the observed catch per trap of selected trap lines. These estimates were derived only for Kopernik Seamount as fishing effort, and thereby the level of information available, was too low to repeat the analysis on additional seamounts, at this stage.

2.1 Estimating the Effective Fishing Area

When undertaking a line transect type survey one needs to estimate the effective fishing area. When a trap lies on the seabed the bait will send out a plume that predators can detect and will move towards it, this is the area under the influence of that trap. For some individuals the trap will be too far away and while they may move towards the trap they will not get to it before the trap is pulled back to the surface, or the bait inside the trap is consumed and the plume subsides. The area around the trap that is close enough for individuals to find and the bait plume to reach, is likely to catch the target species and is called the effective fishing area. The probability of capture relative to the trap is assumed to have an exponential decay with increasing distance from the trap, with lobsters immediately adjacent to the trap having a probability of 1. For this exercise however, the actual catchability will be assumed to be knife edged within the effective fishing area.

To estimate the effective fishing area an experiment was designed and run from a commercial vessel the *Altar 6* at the Kopernik seamount prior to the normal fishing operations beginning on the third and fourth trips to the seamount (Trip 3 and Trip 4). Traps were set on a longline by the vessel with the instructions to set three lines a day, parallel to one another and at least 300m apart. The lines were allowed a soak time of 24h before being hauled back on-board the vessel. All traps were sampled by observers on retrieval. The catch in mass and number was recorded for each trap and all lobsters were measured for length and sexed.

Each experimental fishing line was set with 30 traps, and the traps were divided into six groups, each group set at varying distances apart (Figure 1). The smallest inter-trap distance was set at 20m as lobster telemetry studies on *Jasus lalandii* have shown that the normal foraging range (in the absence of a baited trap) of these lobsters is 10-45 m per day (Atkinson et al., 2005). Studies on other crustaceans indicate that a 20m trap separation (equivalent to a 10m radius) is likely to be within easy reach of an adult lobster. For each consecutive group, trap spacing was increased. Between each group a space equivalent to the next biggest group spacing was inserted, for example the distance between the last trap of Group 1 (20m) and the first trap of group 2 (40m) was 40m. It is hoped that this will reduce traps from the lower groups competing for lobsters from the higher group. The final layout was as follows (Figure 1):

- Group 1 - inter-trap distance 20m, followed by a 40m space.
- Group 2 - inter-trap distance 40m, followed by a 60m space.

- Group 3 - inter-trap distance 60m, followed by a 90m space.
- Group 4 - inter-trap distance 90m, followed by a 140m space.
- Group 5 - inter-trap distance 140m, followed by a 190m space.
- Group 6 - inter-trap distance 200m.

The aim was to undertake five experimental fishing events (i.e. three lines set on each of five days on each trip) with target soak time of 20-30 h. This would result in 30 replicates of each trap group. Each line was set at 300m or more from the previous line, and lines were set parallel to one another. This may seem like a relatively high level of replication but the variable nature of the CPUE data from Kopernik suggests that the CPUE is likely to be fairly variable within each group and increased sampling was likely to produce usable data. In addition, the increasing inter-trap distance and the large difference between group 1 and 6 was expected provide enough contrast in the data for meaningful analysis, the theory being that as trap distance increases the lobsters will not compete for traps and the CPUE of the latter groups will be higher (Figure 2). The vessel allowed for fewer sets on the first day to familiarise the crew and observers with the experiment and sampling protocols.

Sets were deployed in order from Group 1-6 as the first group with closely spaced traps was likely to sink fastest, hereby keeping the line taught on the set. The observers had the flexibility to change the setting and hauling order e.g. setting from group 1-6 but then hauling from group 6-1 thereby allowing them to stack traps from groups 1 and 2 to allow time for sampling, if required.

The data were housed in an access database and retained for analysis post trip.

Comparisons among groups was done using an ANOVA in R (R Core Team, 2018) using the function *aov*. A Levene's test for homogeneity of variance was performed. From the outputs there was evidence to suggest that the variance across groups is statistically significantly different. Indicating that variances in the different treatment groups is not homogeneous. Therefore, a Welch one-way test, that does not require homogeneity, was performed followed by pairwise t-tests with no assumption of equal variances.

2.2 Biomass estimation

In an attempt to estimate lobster biomass at Kopernik Seamount, this analysis used a range of estimates of effective fishing areas and stratified the estimates by depth. These fishing areas were then extrapolated through estimation of catch per unit area and expansion to total depth area of the seamount. As lobster densities vary with depth, density from the surface of the seamount (130m depth) to 300m depth was likely higher, but the lobster density declines from 300m - 500m, below which density was assumed to be zero (see Figure 7 in Brouwer et al., 2019).

The analysis required accurate depth information across the seamount. The depth data were obtained from the fishing operation over all trips (Figure 3) and then depth and slope surfaces were calculated. This database consisted of 559 data points. A raster interpolation tool set was applied in ArcGIS to attempt to predict the continuous surface representation of the seabed using a rasta dataset format. Using the surface tool inverse distance weighting (IWD) provided a deterministic interpolation method where assign values to locations were based on the surrounding measured values to determine the smoothness of the resulting surface (Johnston, 2004). Raster values were then reclassified to provide slope intervals and depth strata with five class rages, this included 0-5m, 5-10m, 10-15m, 15-35m, 35-65m. The reclassified raster was then converted to a polygon feature to allow the generation of contour lines and calculation of geometry attributes. Further reclassification of the polygons allowed for slope including, 0-5, 5-10, 10-18, 18-35, 35-67 degrees classes. The resulting points were converted in into a grid in R (R Core Team, 2018) with mean slope and depth being assigned to each cell (Figure 4).

Kopernik seamount was relatively well covered by trap lines through the course of the first fishing trip. During the trip the fishery showed a relatively strong fishing response (Brouwer et al., 2019). As a result, it was necessary to select a number of lines that were set in unfished areas at the start of the trip. The sets from Trip 1 were subset to find "pristine seamount" transect lines. These were a subset of lines set where another fishing line had not previously been placed, and for which the set time was 20-30 hours (see Figure 14 in Brouwer et al., 2019). These lines were used as a series of transect lines to sample the "virgin population" by depth stratum. The lines were selected purely on placement relative to other lines with no prior knowledge of the catch per line (Figure 5).

As the results from the experimental lines were variable, a range of effective fishing areas were used with effective fishing area radii ranging from 11 to 60m (Table 3), for estimating biomass. Note that the commercial lines had the traps spaced 25m apart, therefore if the true effective fishing area was above 25m radius traps could compete for lobsters reducing the CPUE and resulting in an underestimate of true biomass.

The area was divided into 0.005^o grid squares with the mean depth and slope calculated for each square, traps were allocated to each to calculate the catch and effort for each grid square (Figure 6). The area under investigation at Kopernik Seamount (the seamount areas shallower than 700m) totalled 64.056km^2. This area was divided into shallow, middle, deep and very deep strata (Table 1). Each of the grid squared was allocated to one of theses depth strata. Initially 16 transect lines covering 3.82% of the area were selected. However, after assessing the overall trap line layout, four lines that were later in the trip were dropped as they appear to have been impacted through fishing close by, catch was then allocate to the grid. The remaining 12 lines covering 3.17% of the area and having 1,796 traps were used as the core set of transect lines. Lobsters were assumed to be evenly distributed within each stratum.

Catch and effort data from the transect lines were allocated to each grid square, even with the removal of the three lines from later in the trip, reasonable effort and catch coverage of the area was achieved (Figure 6; Figure 7).

Each trap was converted to an effective fishing area to estimate the area fished and catch was converted to kilograms per m^2, within each grid square. These values were then scaled up to the total area of each stratum, the strata were summed to estimate the total biomass.

Initial biomass was estimated using the data from the selected transect lines. This was assumed to approximate initial biomass as there has be little fishing prior to the commencement of this fishing operation. Some exploratory fishing was attempted in the early 1990s, but there is thought to have been no fishing for lobsters in the area since that time. Biomass was then estimated using the data from the entire catch effort dataset per trip, and weekly biomass across all trips.

3 Results

3.1 Estimating the Effective Fishing Area

For this experiment to work ideally traps would need careful placement to ensure accurate spacing. Given that the shallowest depth here was 129m careful accurate trap placement was not possible, but was assumed.

The vessel *Altar 6* had considerable difficulty in deploying the research lines the first time this was attempted. The line set-up itself was challenging with varying densities of traps altering the sink rates and it also provided challenges at hauling. The observers found the first groups challenging to sample due to the proximity of the traps. A number of traps were missed at the time of deployment. In these instances, the traps on either side of the missing trap were dropped from the analysis. Bad weather prevented a number of lines from being hauled within the specified time and as their soak time was >30h these lines were dropped from the analysis. Brouwer et al. (2019) noted long soak time allow lobsters to escape, lowering the CPUE. These issues required the data set from Trip 3 to be extensively groomed prior to analysis. The experiment was successfully undertaken on Trip 4, as a result the data from Trip 3 were excluded and only Trip 4 data were used.

Figure 8 shows the change in CPUE with increasing trap spacing. The CPUE was highly variable, nevertheless, Table 2 shows that there is a weakly significant difference between the CPUE from trap group 1 (20m spacing) to group 2 (40m spacing) to the remainder of the traps. In addition collating the traps by groups shows a reasonably large step from group 1 and 2 after that the CPUE is relatively flat, with some high observations for the traps with spacing >100m Figure 9. The residual compared to the fitted values by group and the Q-Q plots are shown in Figure 10, these data show weak fits at the extremes but some difference between the groups.

The CPUE flattens off at Group 3 i.e. a spacing of 60m (30m radius) this was therefore chosen as the most appropriate estimate of the effective fishing area. However, the high variability in the CPUE suggests that a range of estimates should be used for the remaining analyses, until a more reliable estimate can be derived.

3.2 Biomass estimation

The transect line CPUE is shown in Figure 11. The CPUE from this data set is variable and the data after haul 25 are likely impacted by the fishery. For the initial biomass only lines from the first 25 hauls were used. For the transect group of liners effort was relatively evenly spread although the deeper strata have low effort Figure 6, most of the catch came from the shallowest stratum with the lowest slope Figure 12.

Biomass estimates increased with decreasing effective fishing area, and total biomass estimated ranged from 10,449t to 350t Table 3 although the plausible range is more likely to be 3,161t - 790t. The shallow areas of Kopernik Seamount (150-260m depth) have the highest biomass and below 260m biomass declined rapidly, this was due to decrease in CPUE with depth and the smaller areas of the deeper strata. Using the experimental traps to estimate effective fishing areas having a 30m radius the initial biomass was estimated at 1,405t.

Estimated biomass declines relatively rapidly from initial through Trips 1 to 3 Figure 13. Assessing the biomass weekly through the course of the fishery shows considerable variability in biomass but also a rapid decline in the estimated biomass Figure 14.

4 Discussion

4.1 Estimating the Effective Fishing Area

The CPUE was extremely variable, both within groups and between them. This is a result of very uneven distribution of lobsters across the area (see Figure 5). Other factors such as daily bottom current will also influence the bait plume and thereby influence catchability. Despite this some detectable trends were evident, and it is most likely that competition between traps for lobsters declines when traps are spaced more than 40m apart. As there was a stepped change between groups two and three and not much difference between groups three to six, it was assumed that the effective fishing area has a radius of between 20 and 30m.

Studies on *Jasus lalandii* have shown that the normal foraging range, in the absence of a baited trap, is 10-45m per day (Atkinson et al., 2005). This suggest that a 30m walk to an abundant food supply like bait is not an unrealistic distance for *Jasus caveorum*. Despite this given the variability in these results and the complexity in setting the experimental traps in deep water, this experiment would need to be repeated a number of times before they should be considered reliable. Nevertheless, in the absence of any other information, the effective fishing area assumed to be an even circle with a 30m radius. Noting the lack of certainty around this estimate, for the biomass estimation work, a range from 20-40m was used. Few other studies on deepwater *Jasus* exist for comparison and more work investigating this would be valuable.

4.2 Biomass estimation

Some of the most important commercially exploited spiny lobster fisheries found in the Southern Hemisphere are *J. lalandii* , *J. edwardsii* and *Sagmariasus verreauxi* and are associated with rocky reefs in coastal waters of Southern Africa, Australia and New Zealand (Jeffs et al., 2013). J. caveorum, *J. frontalis* and *J. tristani* [*J . paulensis*], exist on small isolated oceanic islands and seamounts. All species of *Jasus* and *Sagmariasus* are commercially exploited, with the exception of *J. caveorum*, and all fisheries are considered fully exploited (Jeffs et al., 2013). Jeffs et al. (2013) noted that initially these fisheries are characterised by high catch rates, followed by a rapid decline in population size, and then relatively consistent landings provided management controls are implemented, mostly in the form of a Total Allowable Catch (TAC) being implemented along with a minimum legal size, and protection of ovigerous females. As these trends have been noted for other larger lobster populations tracking biomass of *J. caveorum* on the Foundation Seamounts and in particular Kopernik Seamount is essential for the effective management of this resource.

The first step in estimating the biomass was to stratify the seamount into depth classes as the CPUE data suggests strong depth related trends. Following this an estimate of initial biomass was made. This initial biomass was thought to be close to B_0 as no fishing has been recorded in the area since 1995, and the seamounts have been left unfinished for 23 years. Prior to this there were three known fishing events in 1988, 1992 and 1995 removing approximately 94 tonnes of *J. caveorum* from the Foundation Seamount chain, it is not known how much of this came from Kopernik Seamount, but it is assumed that it was the bulk of that early catch. The initial biomass was relatively high at 1,405t (range 790-3,161t) and this declined on average a little through Trip 1. The biomass average declined relatively rapidly over Trip 2 and again during Trip 3.

Reviewing the weekly changes in biomass estimated over all fishing events, indicated that the estimates are variable. This is due to the variability in CPUE, that is dependant on trap placement and the prevailing conditions on any one day. Due to this high variability the trip level biomass estimates are probably a closer reflection of reality than the weekly estimates. However, noting the amount of catch that has been removed from Kopernik ($\sim$140t), it seems that either the biomass estimates are high or the change in CPUE is overestimating the decline.

Converting the biomass to estimates of density we get a mean lobster across Kopernik Seamount of 2.19kg/100m^2. Density estimates (kg per unit area) for *Jasus* on islands or seamounts are difficult to find. Pollock (1991) inferred lobster densities from variability in CPUE between Islands at the Tristan da Cunha Island group but only provided relative comparisons. Briones-Fourzán (2014) found 15 - 100 lobsters per hectare for *Panulirus inflatus* but that is also not directly comparable to this analysis, given the very different habitats involves in these two studies. However, in principal 2.9 kg per 100 m2 appears to be low but the overall productivity of a deep seamount is likely to be poor and food for lobsters is probably limited there.

Seamount lobster fisheries are likely to suffer from issues relating to larval connectivity. It is very unlikely that a clear stock recruitment relationship exists for *Jasus* lobsters in a particular area (Jeffs et al., 2013) as the very long larval life-cycle of means that larvae are dispersed over a wide area and recruits arrive many months after a spawning event. This issue will be exacerbated on a small seamount. When examining larval connectivity of *Jasus tristani* between Tristan da Cunha, St Paul and Amsterdam Islands and two seamounts Cockcroft et al. (in prep) found that the seamounts are dependent on pulses of recruitment from these island groups. This sporadic recruitment onto seamounts indicates that they would have limited means to re-populate and are therefore likely to be susceptible to rapid depletion.

Intensive commercial harvest of *Jasus tristani* from an intensive 2-year long fishery on Vema Seamount (about 20% of the size of Kopernik) in the 1960s reduced the population within that time to levels that were no longer commercially viable. There has been no sign of recovery since then indicating that recruitment to the seamount is very small or has been interrupted by the removal of the adult population (Jeffs et al., 2013). In addition, as lobsters on rocky reefs are keystone predators depleting their populations to extremely low levels can permanently alter that ecosystem in a way that can prevent lobster re-population (Barkai and McQuaid, 1988). This suggests that seamount lobster populations need to be managed with care.

As the biomass is estimated to have declined by roughly 50% over the course of this fishery, future exploitation will need to be cautious. Like other lobster fisheries in the world specific TACs, size limits and protection of the female stock will be paramount to the management protocols of this resource if it is to be sustainably harvested. Due to the remote location of the Foundation Seamount Chain and the high costs associated with getting there, a successful commercial operation would need access to enough catch to make the venture worth while. As any future catch limit on Kopernik would likely need to be relatively small, finding lobsters on additional seamounts in the area or alternative species to harvest in addition to lobsters will be key to developing a functional commercial enterprise in that area. Ideally the fishery would consist of a number of seamounts each with a specific (and small) TAC.

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Tables

Table 1: Depth strata used for the biomass estimation analysis showing the stratum, mean, minimum and maximum depth and the area size in Km^2.

Depth group	Mean depth	Minimum depth	Maximum depth	Area
Shallow	203	149	259	22.28
Middle	310	262	349	13.17
Deep	417	358	480	17.98
Very deep	537	480	651	10.63

Table 2: Pairwise comparisons between research line trap groups using t-tests with with no assumption of equal variances, p-values have been adjusted by the Benjamini-Hochberg method. n = no significant difference, * = $p<0.05$ G1 - G6 refer to Trap Groups 1 - 6 as per Figure 1.

	G1	G2	G3	G4	G5
G2	n	-	-	-	-
G3	*	*	-	-	-
G4	*	*	n	-	-
G5	*	*	n	n	-
G6	*	*	n	n	n

Table 3: Biomass estimates (t) using subset of transect lines sampled from Kopernik seamount using different effective fishing areas per trap.

Effective fishing radius	Shallow	Middle	Deep	Exreme deep	Total biomass
11	7992	1948	508	0	10449
20	2418	589	154	0	3161
30	1075	262	68	0	1405
40	604	147	38	0	790
60	269	65	17	0	351

Figures

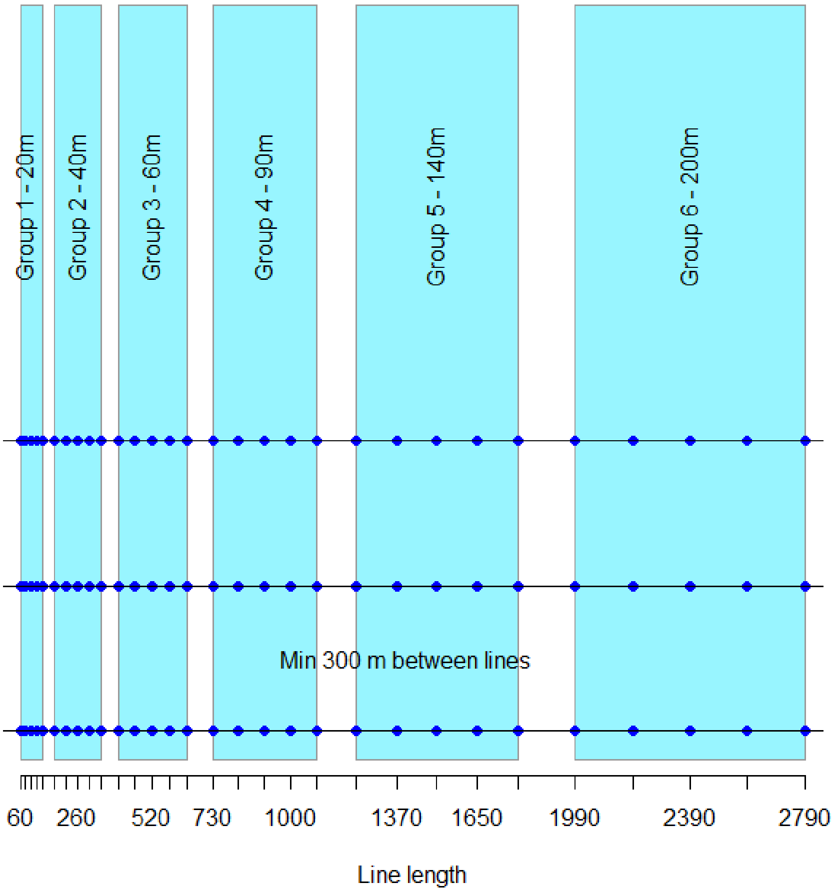


Figure 1: The experimental trap layout showing the increasing distance between traps and trap spacing between group.

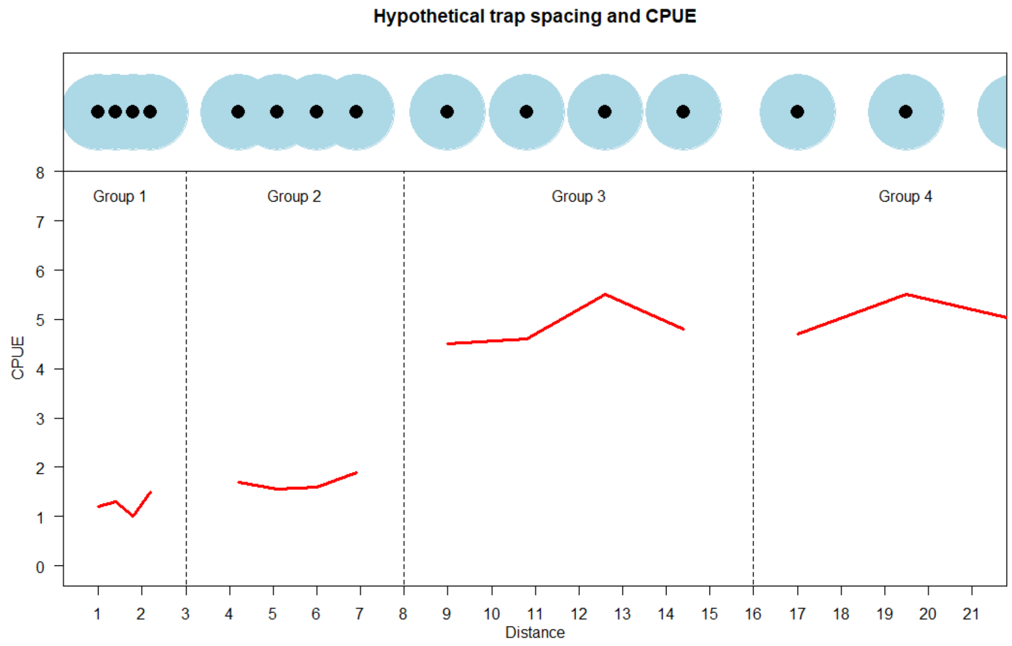


Figure 2: Experimental trap distance between traps (black dots) showing the hypothetical effective fishing area (blue circles) and the expected CPUE (red lines).

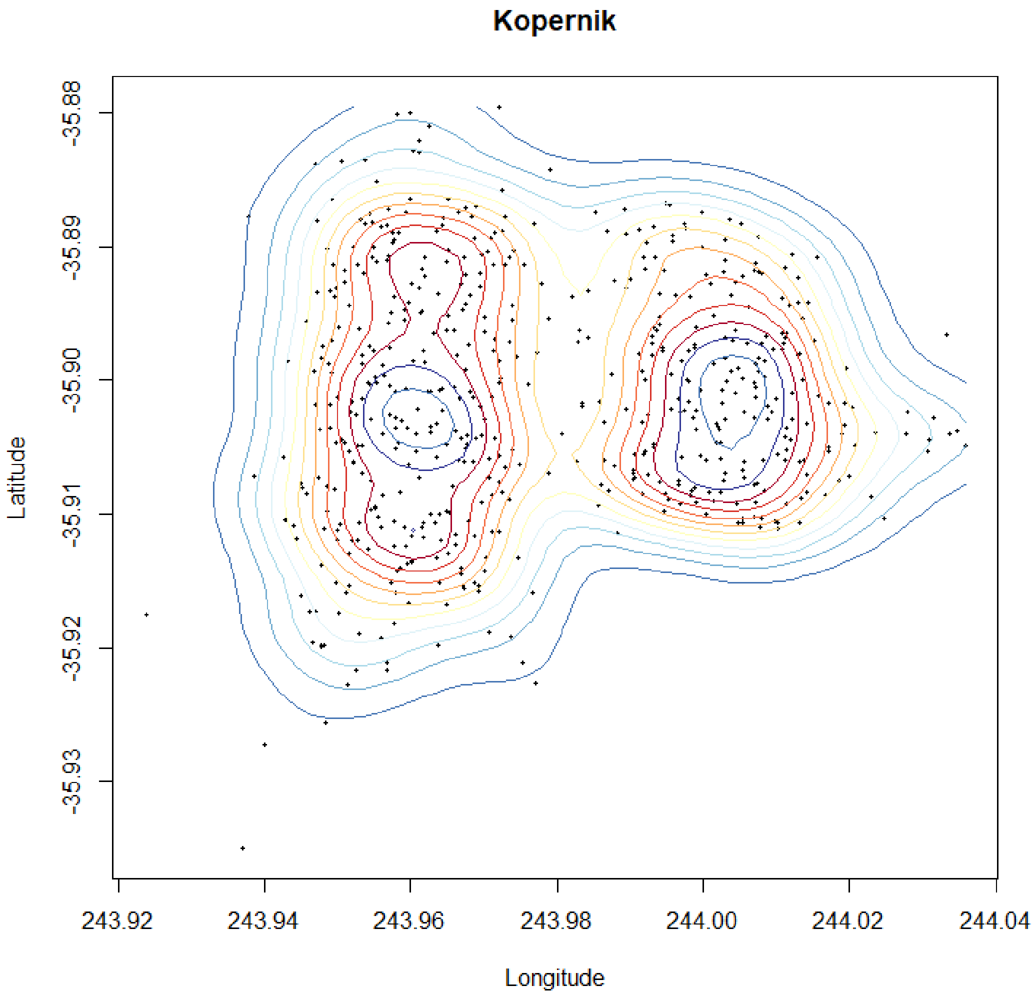


Figure 3: Observed depth information for the fishing vessel *Altar 6* and the calculated depth contours.

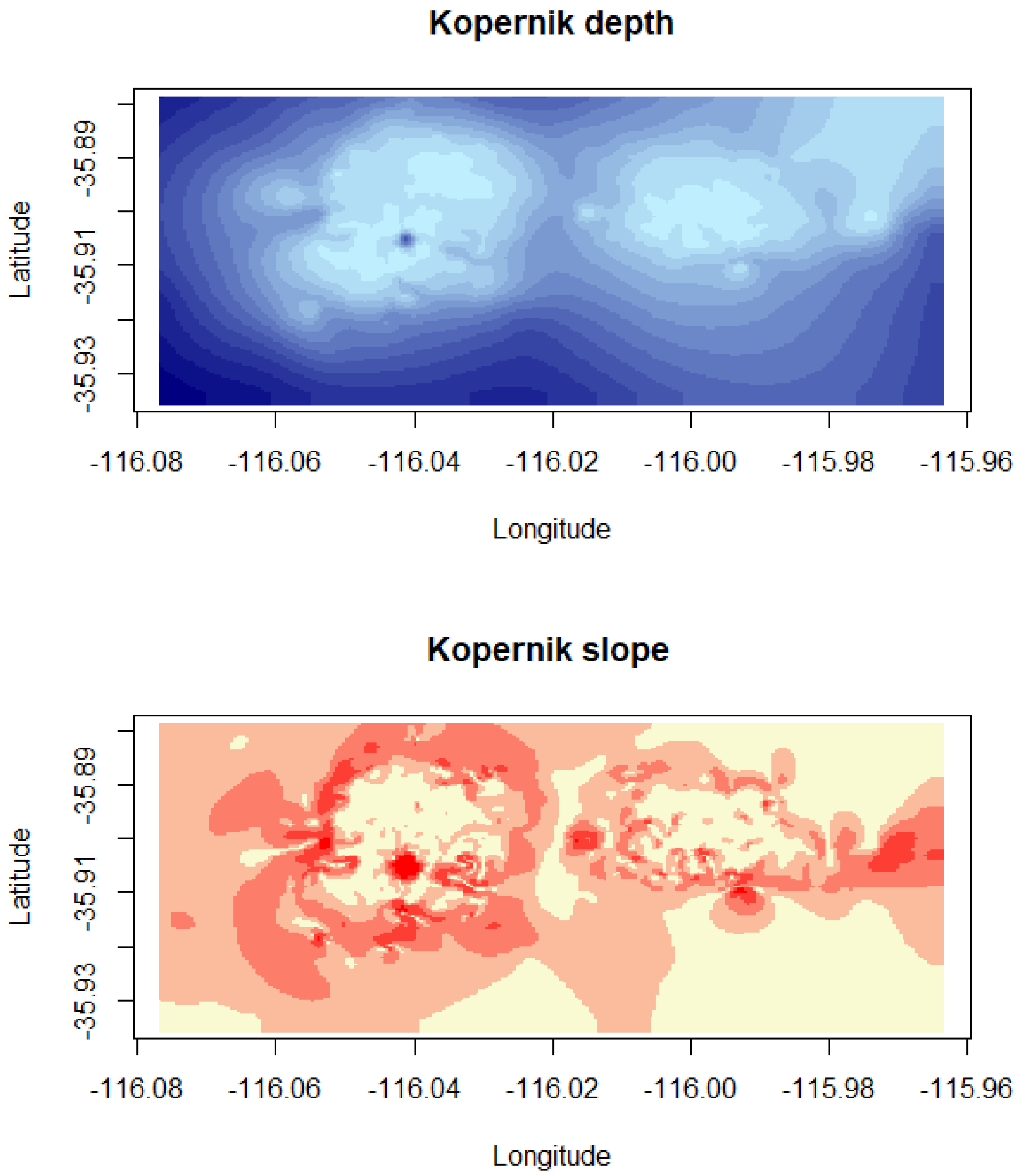


Figure 4: ArcGIS predicted surface of Kopernik Seamount estimated through inverse distance weighting showing the depth (top) and slope (bottom) estimates. darker blue represents deeper depth, and deeper red indicates a steeper slope.

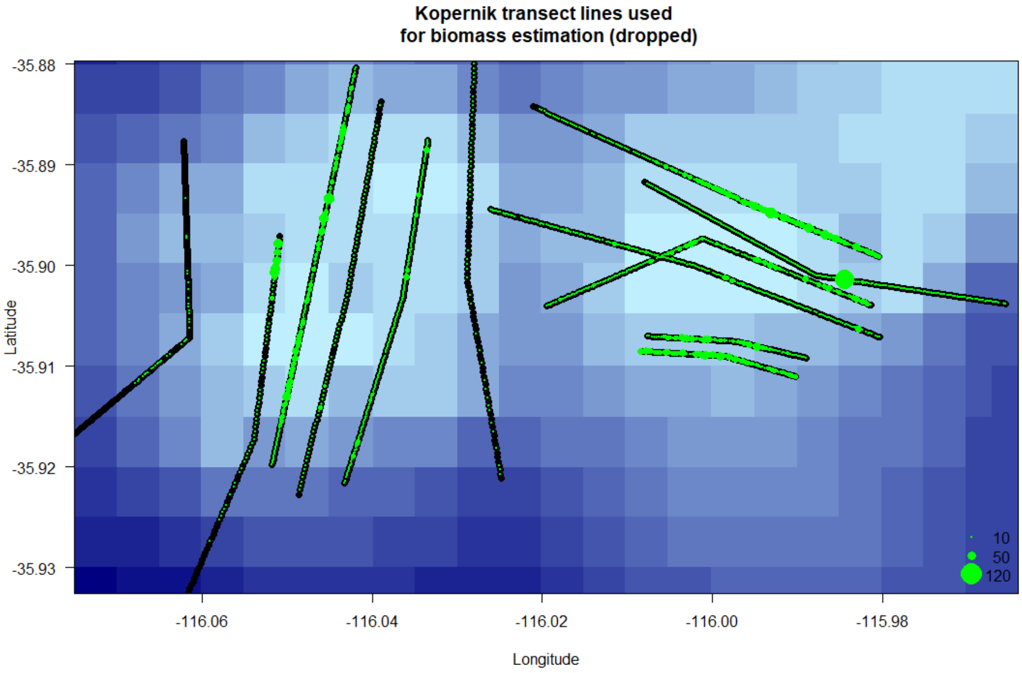


Figure 5: Transect line effort across Kopernik Seamount for selected lines in Trip 1 that represent areas where no fishing has occurred previously. black points represent individual traps and green points represent the catch in kg.

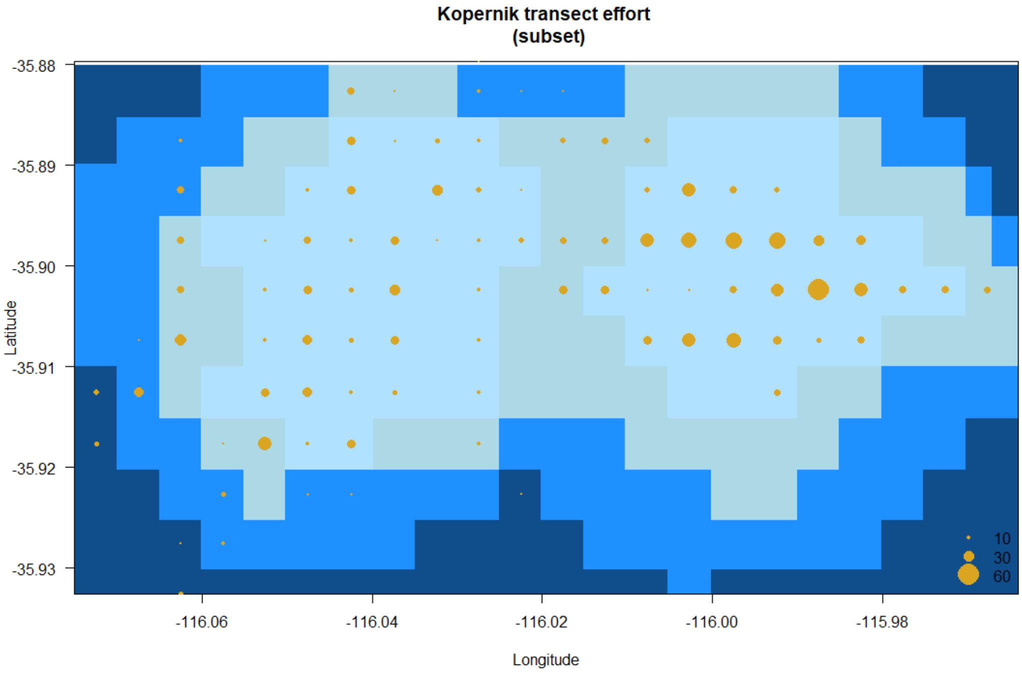


Figure 6: Transect line effort by depth group for the final set of pristine lines, and showing the four depth groups used for the biomass assessment.

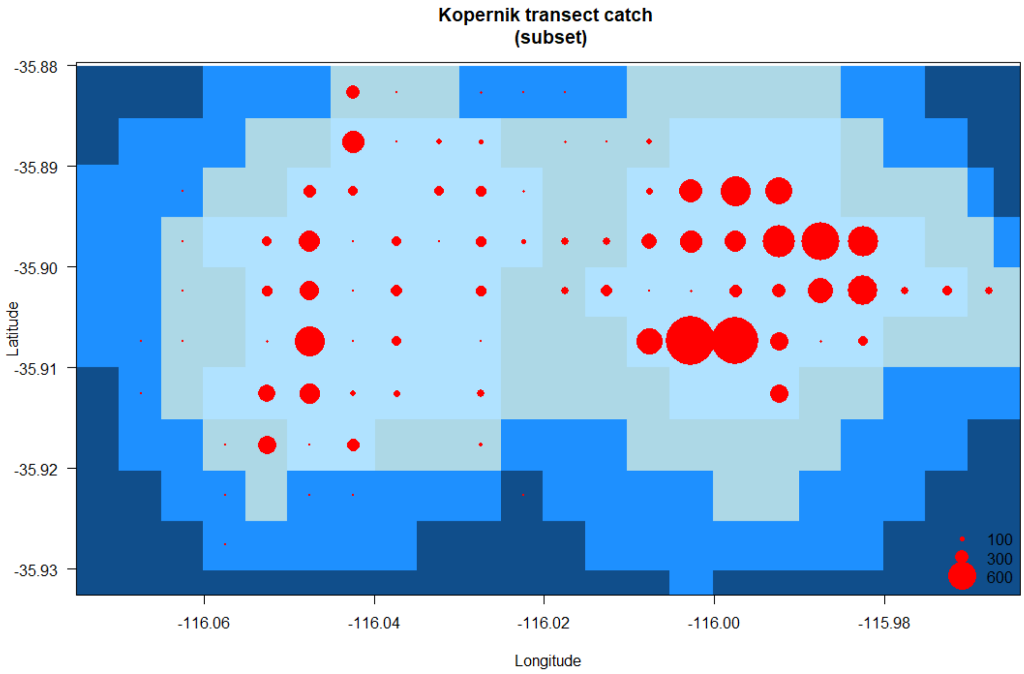


Figure 7: Transect line catch by depth group for the final set of pristine lines, and showing the four depth groups used for the biomass assessment.

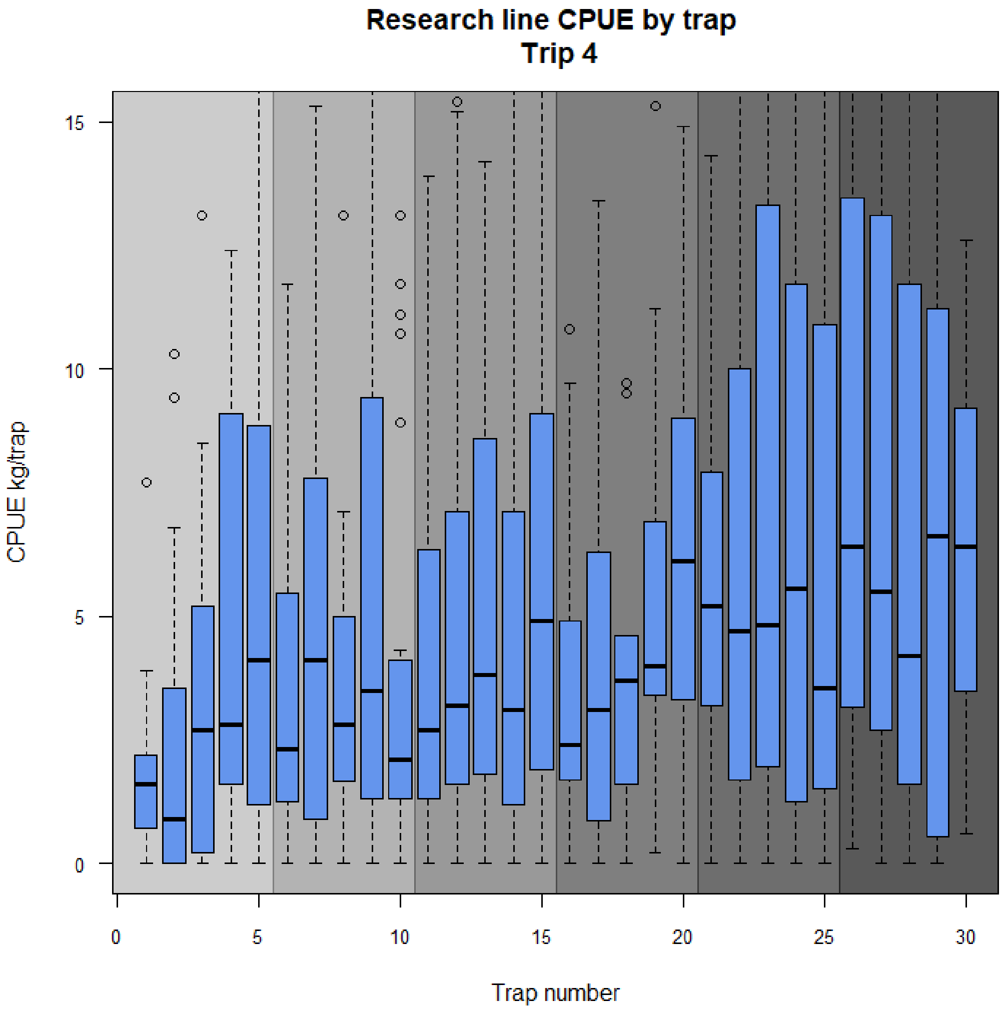


Figure 8: CPUE (kg/trap) for the experimental lines, shading is to designate trap groups, with traps 1-5 (Group 1); 6-10 (Group 2); etc.

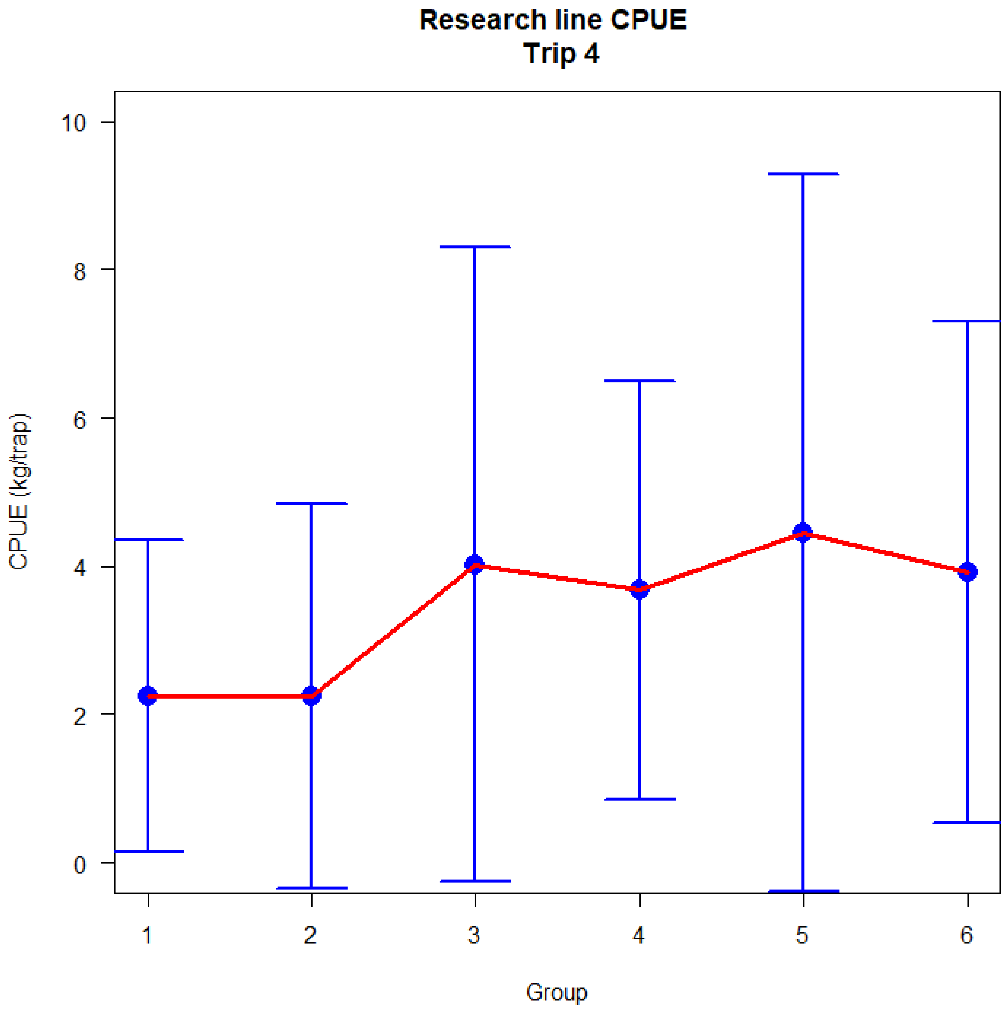
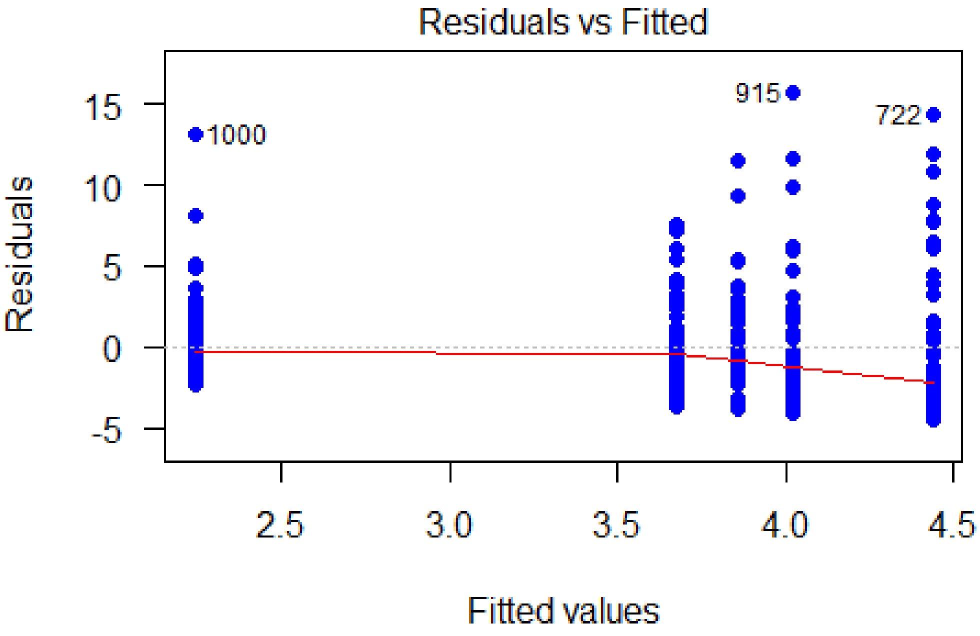


Figure 9: CPUE (kg/trap) for the experimental lines by group showing the mean CPUE (points) and the standard deviation (error bars).



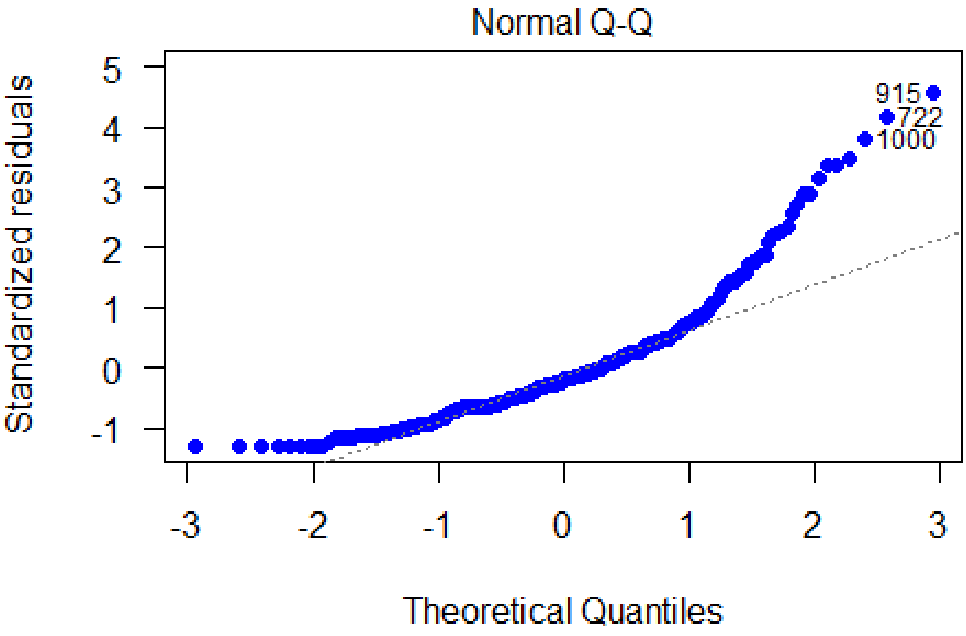


Figure 10: Residuals v.s. Fitted and Normal Q-Q plots for the experimental line CPUE.

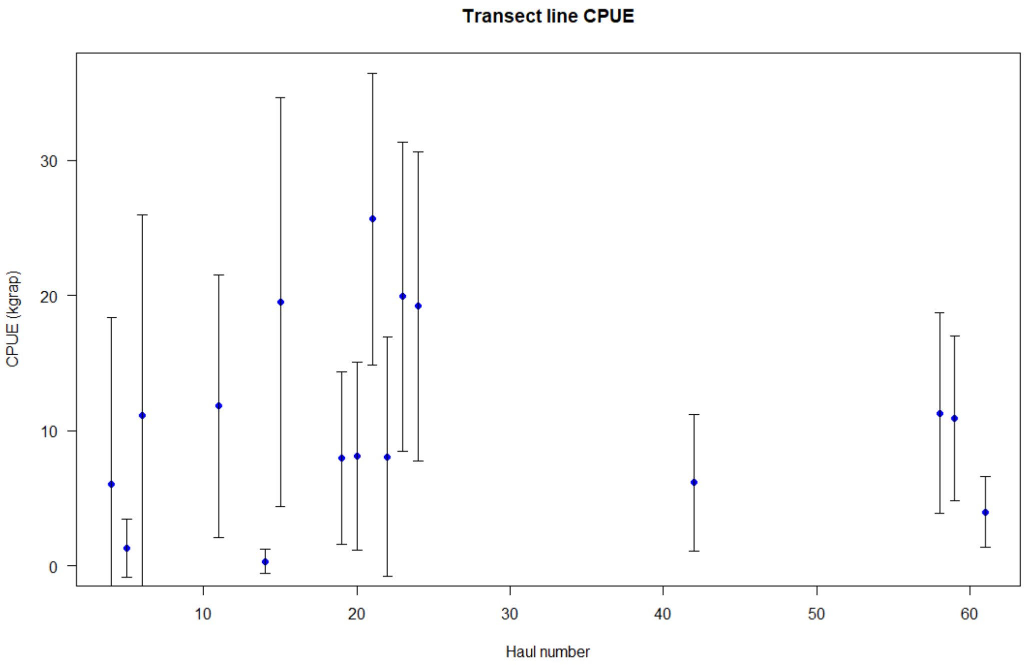


Figure 11: Transect line CPUE (kg/trap) for selected lines in Trip 1 that represent areas where no fishing has occurred previously.

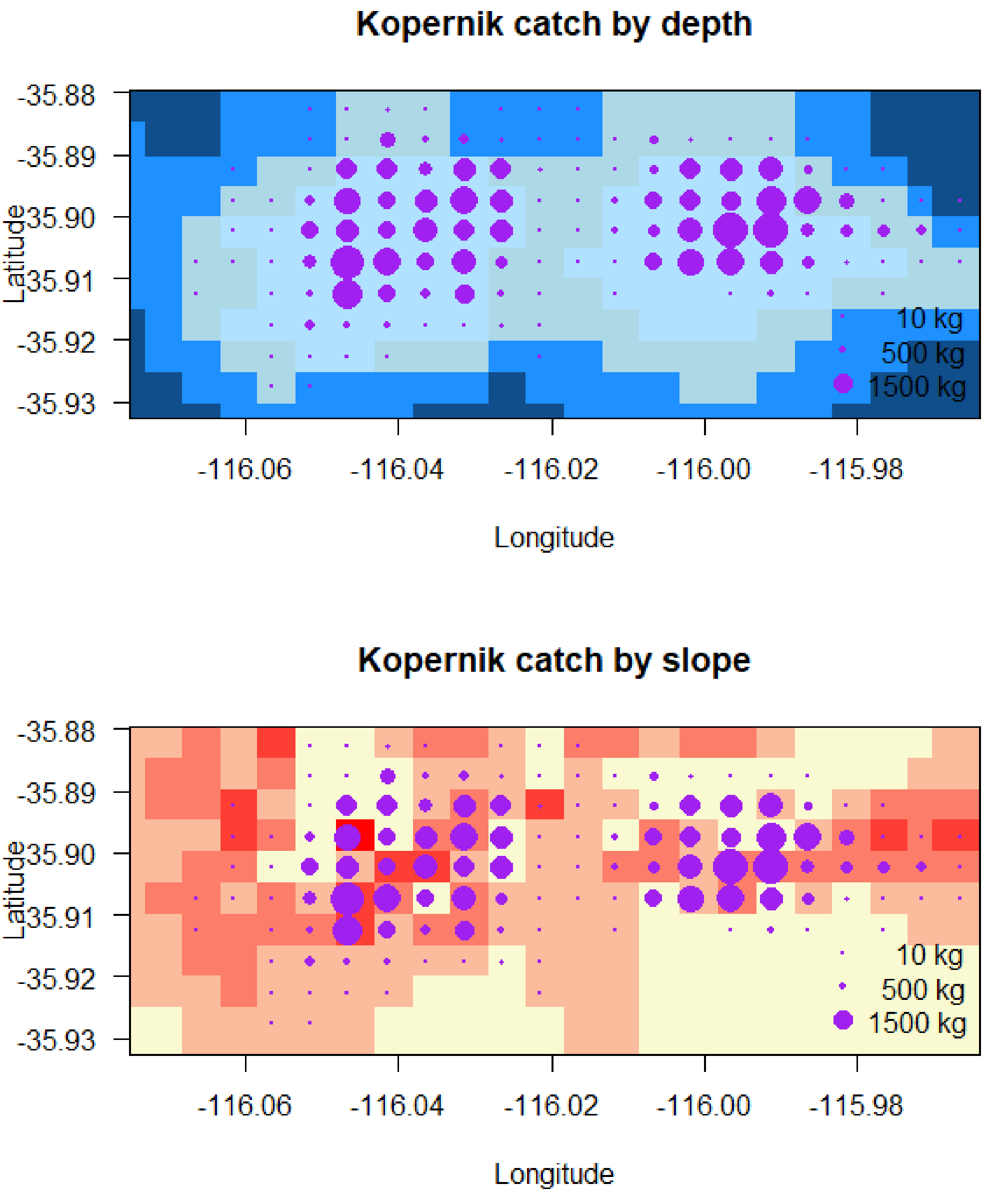


Figure 12: Total catch of lobsters by depth group (top) and slope (bottom) on the Kopernik Seamount.

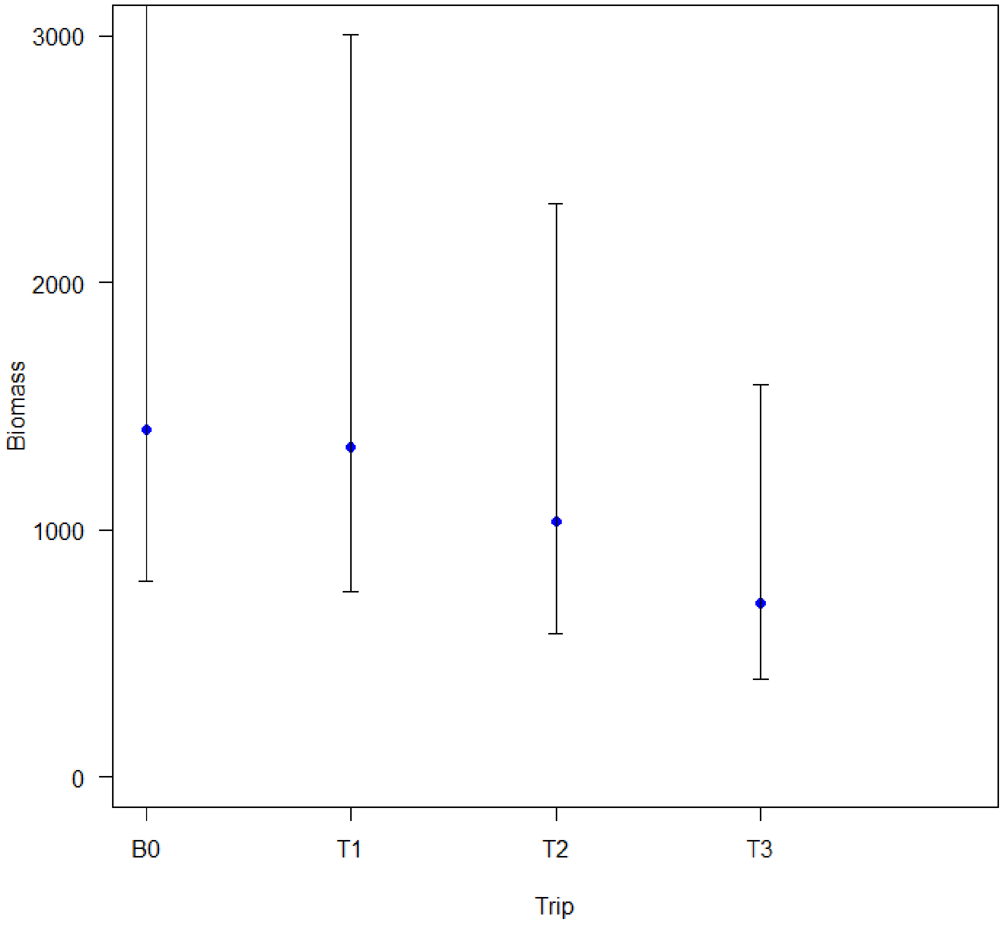


Figure 13: Biomass estimates by trip, B0 refers to the initial estimates of pristine biomass form the transect lines. T1-T3 are the biomass estimated derived by applying mean CPUE from each trip.

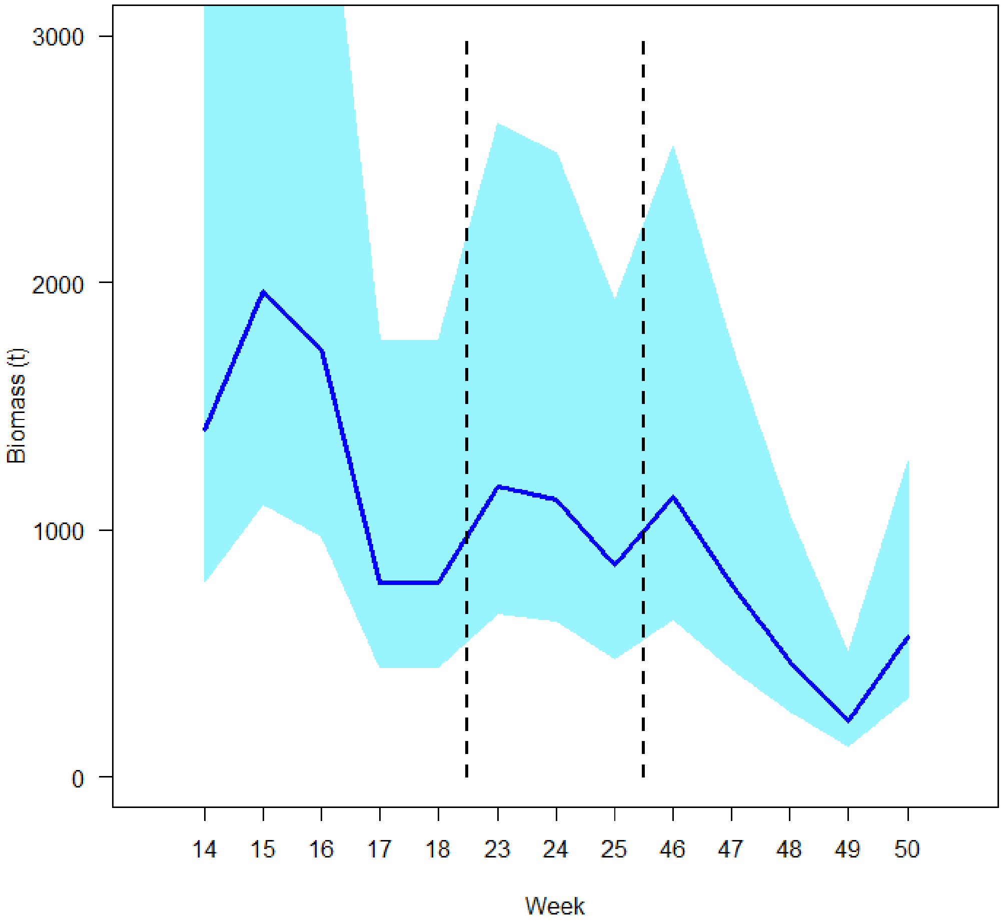


Figure 14: Biomass estimates by week for trips 1-3. Note the weeks in the x-axis are week of the year when the vessel fished on Kopernik seamount. Vertical lines represent breaks between trips.