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Using GPS logger data to monitor change in the PAU 7 pāua (*Haliotis iris*) fishery

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The pāua (*Haliotis iris*) stock in New Zealand quota management area PAU 7 was at or near the soft limit of 20% of virgin biomass (B_0) at the time of the most recent stock assessment (2011). Biomass was projected to increase under the current Total Allowable Commercial Catch (TACC; 187 t) with a probability of increase only slightly above 50%. A shelving scenario suggested that both the probability of increase and the projected biomass would increase substantially with a shelving of 20% of the current TACC. This shelving level was agreed upon by the pāua fishing industry for the 2013–14 fishing year. Anecdotal reports early in the fishing season, however, suggested a decline in catch rates. Lower catch per unit effort (CPUE), in turn, may reflect a decrease in available biomass that could not only offset the expected benefits from shelving, but also drive the stock further towards extremely low biomass levels.

The pāua data logger initiative is an industry-led and Ministry of Primary Industries (MPI) supported programme to achieve fine scale spatial and temporal monitoring of the fishery. Within this programme, data loggers recording dive positions, depth, and duration are worn by individual pāua divers. Catch information is also recorded on separate boat units. A previous assessment of the dive logger data suggested that the catch and effort metrics have the potential to provide fine-scale information on CPUE. Parameters of the pāua dive operation, including dive times and depths, were found to be strong predictors of catch.

Here, data logger data were used to assess changes in standardised catches between the 2012–13 and 2013–14 fishing years. We applied both qualitative comparisons of temporal and spatial trends in catches as well as modeling of catch and effort data to obtain indications of potential changes between these fishing years.

Temporal patterns in catch histories were broadly similar, however lower catches were reported for most months in the 2013–14 fishing year. The logger data suggested that divers searched smaller areas on average during the 2013–14 season to obtain equivalent catches (i.e., higher catch per unit area).

Models of catch and effort data showed a slight increase in effort-standardised catches for the current (2013–14) fishing year. However, this effect was only significant in a fixed-effects model that estimated an overall year change. When estimating interannual change for individual divers and statistical areas within PAU 7, the pattern was more variable: 50% of divers (7 out of 14 with data for both fishing years) had a higher CPUE in the 2013–14 season, while 6 out of 14 divers had a lower CPUE. Similarly, the year trend in statistical areas was highly variable, but did not show a consistent decline from 2012–13 to 2013–14. We conclude that the combined evidence does not support a decline in CPUE and overall performance of the fishery.

1. INTRODUCTION

Pāua (*Haliotis iris*) are harvested throughout New Zealand by fishers free-diving for the resource, which is managed under the Quota Management System (QMS). Within designated Quota Management Areas (QMAs), minimal legal size (MLS) and a Total Allowable Commercial Catch (TACC) are two of a number of management tools used to manage the fishery (e.g., Ministry for Primary Industries 2012).

In most QMAs, stock assessments are undertaken to inform the management process. In PAU 7, the most recent stock assessment in 2011, indicated that biomass was close to 20% of virgin biomass (B_0; Fu (2012)). At the current levels of commercial catch (187 t), the stock assessment model estimated a 3% increase in biomass over the following 3 years. The assessment also projected more substantial increases in biomass under a 20% reduction in commercial catch. The commercial fishery agreed to a 20 % catch reduction (shelving) for the 2012–13, 2013–14 and 2014–15 fishing years. However, there has been recent concern that biomass is not rebuilding to the target of 33% of B_0.

In pāua stock assessments, the primary indicator of stock abundance has been fishery-dependent CPUE data (Fu 2012, Fu et al. 2012, Breen & Smith 2008). Analysis of CPUE data currently relies on information from Pāua Catch Effort Landing Return (PCELR) forms, on which daily fishing time and catch per diver are recorded. Every three years, CPUE data are analysed and standardised in preparation for stock assessments. To provide catch and effort information on smaller spatial and shorter temporal scales, dive loggers were introduced in the fishery in 2010 (Neubauer et al. 2014, Abraham 2012). These loggers are worn by individual divers and record GPS positions as well as dive depth and duration. Catch information is recorded on separate boat units, and both data sources are uploaded and combined in a logger database.

Using fishing data logged at fine spatial and temporal scales can substantially improve effort calculations and the resulting CPUE indices (McCluskey & Lewison 2008, Hanchet et al. 2005). A fish-down experiment first validated the use of fine scale logger data to estimate catch rates, which were found to accurately reflect local depletion (Abraham 2012) in a previously unfished area. Due to high initial biomass levels at the fish-down site, however, these findings may not easily transfer to fished areas. A comprehensive analysis confirmed that the logger data can indeed be used to obtain descriptive indicators of dive activity and spatial resource use at small spatial and temporal scales (Neubauer et al. 2014). Modeling of the logger catch and effort data further demonstrated that the logger data made it possible to estimate fine-scale (i.e., by statistical area) and QMA scale indices of standardised catch-rates that can incorporate the cumulative effect of different effort metrics (spatial, temporal, dive versus total fishing time).

Given the continued concern about low biomass in the PAU 7 fishery, this project attempted to identify temporal trends in PAU 7 catch rates from logger data. Neubauer et al. (2014), used linear mixed models relating catch to effort variables (e.g., time spent under water (bottom time), dive depth and total fishing time). They found evidence for a declining trend in catch rates in PAU 7, and a noticeable drop in catch rates in the 2013–14 fishing year relative to previous years. These inferences, however, were made with relatively few divers reporting logger-catch and effort for the 2013–14 fishing year (up to March 2013). Here, we employed descriptive statistics of spatial resource use as well as models for diver catch and effort first described in Neubauer et al. (2014) to compare the performance of the fishery between fishing years in order to investigate whether catch rates may have declined in the 2013–14 fishing year relative to the preceding year.

2. METHODS

2.1 Data loggers

The dive loggers (also called "turtle loggers") are compact units carried by divers that record diver position at the surface (in 10 s intervals), using a Global Positioning System (GPS). A depth switch on the turtle loggers switches the unit into dive mode, which records depth (at 1 s intervals) during dive events. A GPS unit is also kept on the boat (called "boat unit"), and is used to record the location and time of catch bags landed on the boat. This unit may therefore be regarded as the "catch unit", whereas the "turtle logger" records the effort.

The two units together are referred to as pāua data loggers, and records from both are needed to calculate CPUE (for additional information on the loggers and data obtained from the units, see Neubauer et al. 2014). Divers enter a personalised Seafood Industry Training Organisation identification number ("SITO ID") in the boat unit along the with number of their turtle unit (the "turtle ID"). The turtle ID then links the turtle logger data to the boat data, and the SITO ID attributes with data types to the diver. Failure to enter the correct turtle ID thus leads to problems linking the two data types, whereas entering the wrong SITO ID makes it difficult to attribute catch and effort data to a particular diver.

2.2 Data preparation

The turtle logger will occasionally switch into dive mode if the diver carrying the logger is immersed, even if they are not diving (i.e., if they are upright in the water rather than lying flat). To filter out dive data that may reflect switching into dive mode by the turtle logger, we defined a surface depth which is intended to represent the average immersion depth of the turtle logger. The surface depth was calculated using a moving window of 10 min medians of depth records while the unit was in surface mode. Data recorded in dive mode were retained as actual dives if the dive depth was 20 cm below the corresponding 10 minute median surface depth. A dive event is thus marked by a diver exceeding the depth threshold, and the bottom time is the period of time spent below this depth threshold (e.g., for a single dive, or summed within a spatial or temporal unit, such as over a day or within a hectare of the fishery). Failures to correctly switch from surface into dive mode occur occasionally, and we removed all records that indicated depths over 1 m but where the dive sensor indicated that the diver was at the surface.

Data of pāua fishing activity in the 2012–13 and 2013–14 fishing years were extracted from the pāua logger database as three distinct tables with dive, bag and daily summaries as explained below. These summaries link at the diver-day level (i.e., one daily record per day and diver):

- Dive table (from the turtle logger): Records for all dives linked to a given diver-day, including median and maximum dive depth, dive duration, as well as start and end time and locations for each dive.
- Bag table (from the boat unit): Location, landing time and assumed weight for all catch bags linked to a diver-day. Bag weight was assigned by dividing the days catch among all catch bags.
- Day table: Table linking boat unit and turtle logger data for diver-days, with fields for total catch weight, dive conditions, boat assistant use, boat unit, turtle and diver (SITO) identification (ID).

To obtain CPUE measures, diver and unit IDs from boat and turtle logger units need to match in order to associate landed bags (catch—recorded on the boat unit) with dive activity (effort—recorded on the turtle unit). On 430 days this matching failed, and we manually corrected entries where divers had entered wrong turtle ID or SITO ID numbers, which corrected 38 fishing day records (Table 1). The remaining unmatched daily records corresponded to fishing days where only one of the units was uploaded to the database, precluding any analyses based on CPUE for these days. In addition, daily data were excluded when dive conditions were not recorded or when visibility and swell were recorded as above 20 m and 5 m. Divers indicated that swell greater than 5 m would be data recording mistakes as such conditions would not be suited for pāua diving. Similarly, visibility entries of over 20 m were generally considered by divers to be data entry errors that do not reflect real dive conditions. These records were thus considered data entry errors.

Table 1: Summary of data from the dive-logger database, including data used as input for models in the present study. HDD are diver days within individual hectare hexagons, which were used as model input.

Data set	Diver days	Bags	Hexagons	HDD
Raw data	1 042	10 456	350 470	25 005
Matched units	612	7 361	269 176	19 669
Manual fix	650	7 826	294 742	21 159
Model subset				8 709

2.3 Catch and effort comparison

We used dive parameters (i.e., bottom time, median dive depth) described in Neubauer et al. (2014) to compare harvesting between fishing years. Previous models showed that bottom time, defined as the

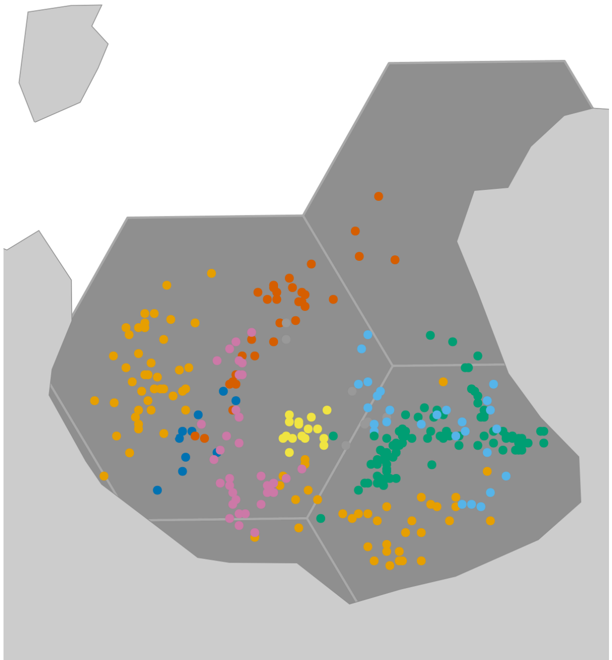

Figure 1: A schematic of dives by a single diver on a single day illustrating attribution of dives to catch bags and hexagons. The land is shown in light grey, and the 1 ha hexagons are indicated in darker grey. The positions of each dive are shown by dots, with dives associated with individual given the same colour. For each bag, the catch was allocated to hexagons according to the proportion of dives within the hexagon.

time recorded as dives by the dive loggers over any given interval (e.g., for a filled catch-bag, or within a day), and median depth, defined as the median of all recorded depths for a dive, were strong measures of dive effort (Neubauer et al. 2014). We compared these dive parameters for individual divers between fishing years, over the whole QMA and on individual reefs (i.e., within individual hectare hexagons that were fished in both fishing years).

As the fishery is likely to be driven by small-scale biological differences in habitat, population abundance and productivity (Prince & Hilborn 1998), we allocated data to hexagons to investigate catch and CPUE at small spatial scales. This allocation was achieved by i) dividing the day's catch evenly over the number of reported catch bags. ii) The bag-weight of each catch bag was then allocated to hexagons, in proportion to the number of dives corresponding to each catch bag within each hexagon (see Figure 1 for an illustration). Based on this allocation, we calculated diver behaviour (depth, bottom time) for each hexagon. Only hexagons with more than 4 recorded dives and only divers with more than 100 recorded dives were retained as model input. The turtle logger may remain activated when dives return to the boat, causing individual data points to appear over large spatial scales (e.g., when divers are traveling back to their launch point after a day's fishing). The condition of at least four dives within a hexagon therefore removed a large number of hexagons from the analysis as many hexagons had only one or two of such potentially erroneous data-points. Table 1 summarises the different data (dives, landed bags, dive days and catch/effort allocated to hexagons (as model input)).

Catches for both years were compared using cumulative catch curves on temporal and spatial axes (i.e., counting hexagons as many times as they were dived). For the latter, catch was summed over the total number of hexagons dived and number of unique hexagons fished (counting each hexagon that was dived only once, regardless of the number of visits to that hexagon within the season). While the first catch/area curve gives an indication of the total area visited by divers for a given catch, the second catch/area curve shows the spatial extent of the fishery at a given cumulative catch.

2.4 Standardised catch models

We formulated linear mixed models relating the log of daily catch within hexagons to total harvest activity (measured as total activity time: the total time that loggers recorded either surface or dive data within the hexagon). Dive parameters (bottom time and median dive depth) as well as other potential predictors of catch, such as effects for fishing-year and dive conditions (swell, visibility), were included in the model as regression co-variates. All variables were centred and divided by twice their standard deviation to compare effect sizes relative to effect standard deviation. Each model also included a random intercept for each diver and individual statistical areas. To investigate changes from the 2012–13 to 2013–14 fishing years, we included random year effects, either for individual divers (model A) or individual statistical areas (model B). Both models were compared to a base case model with a fixed year effect. In both cases, a population year effect represents the overall change between years. The full model was specified as:

$$log(Y_{i,h,y,s}) = \alpha_i Y_{2013-14} + SA_{s,y} + \beta X_{i,h} + ID_i + \epsilon_h \quad (1)$$

$$\epsilon_h \sim N(0, \sigma_h^2) \quad (2)$$

$$SA_{s,t} \sim N(0, \sigma_{SA}^2) \quad (3)$$

$$ID_i \sim N(0, \sigma_{ID}^2) \quad (4)$$

$$\alpha_i \sim N(\mu_\alpha, \sigma_\alpha^2), \quad (5)$$

where $Y_{i,h,y,s}$ is the catch of diver i in hexagon h within statistical area s in year y, ID_i is a diver-specific random effect and α_i is the difference between years for each diver (model A) or statistical area (model B), with the population level (mean) effect drawn from a population level distribution. The effect $Y_{2013-14}$ represents the overall change in the catch, $Y_{i,h,y,s}$, in 2013–14, relative to 2012–13 (this effect is zero for fishing during 2012–13). For the fixed year effect base case model, $\alpha_i = \alpha$, i.e., the subscript for the random effect and hierarchical expression for α_i are omitted. Regression coefficients were estimated as regression parameters $\beta = \beta_1...\beta_p$ for the p remaining covariates (dive effort and external variables) in the matrix X. The statistical area effect $SA_{s,y}$ for statistical area s within year y was modeled as a random effect with mean zero and estimated variance σ_{SA}^2.

Priors for β and μ_α were normal with mean 0 and variance of 1×10^6; the (hyper-)prior for the sampling variance σ_h^2 was a vague inverse-gamma prior with shape s and rate r set to $s = r = 10^{-4}$. For random effects (statistical area and diver effects), the hyper-prior for the population variances was formulated as a half-Cauchy according to Gelman (2006), with a scale parameter of 0.01.

The model converged to a stationary posterior distribution (using three independent chains started at random starting values to verify convergence), and was run for one million iterations with a thinning interval of 250 applied to each Markov Chain, resulting in 4000 samples from each chain (12 000 total samples) for further analysis. Auto-correlation within chains was negligible (using Gelman-Rubin and Raftery-Lewis diagnostics in the R package *coda* to confirm). We further used posterior predictive checks (Gelman et al. 2004) to confirm that the models provided a reasonable fit to the data (Figure 2).

3. RESULTS

3.1 Comparison of spatial resource use

Total recorded catch from boat units for the 2013–14 fishing year (to May 2014) was 49 (39 matched) t of pāua over 350 (267) fishing days, compared with 71 (58 matched) t logged over 490 (383 matched) fishing days in 2012–13 (Table 2). The catch in 2012–13 represented 47% of PCELR landings. The corresponding area recorded as hectare hexagons was about 60% larger in 2012–13 than in 2013–14. Nearly 92% of hexagons fished in 2013–14 were also fished in the previous fishing year. In both fishing years, the largest proportion of the catch was logged in statistical areas in the southern portion of Cook Strait (Figure 3).

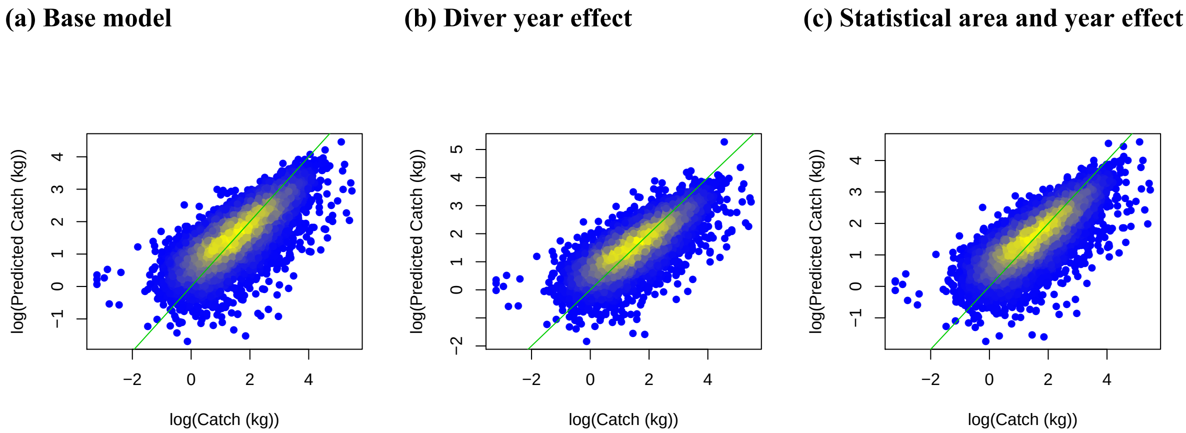

Figure 2: Posterior predictive check of models at the hexagon scale. Points are posterior means of posterior predictive distributions at each data-point. Colours indicate density of points from low (blue) to high (yellow) density. The green line indicates the 1:1 line corresponding to perfect predictions.

Table 2: Summary of catches for fishing years 2012–13 and 2013–14 (to May 2014). The spatial overlap was calculated as the proportion of fishing areas (hectare hexagons) overlapping between years (for each year). PCELR landings were calculated from the Pāua Catch Effort Landings Return (PCELR) database.

	Fishing year	
	2012–13	2013–14
PCELR landings (t)	150	69
Logger catch (t)	71	49
Days	490	350
Matched catch (t)	58	39
Matched days	380	270
Hexagons (ha)	5 200	3 300
Spatial overlap	0.85	0.92

Most of the catch was recorded early in the season in both years, with a total of 40 t logged by February in 2012–13 fishing year. The corresponding catch in February of the 2013–14 fishing year was 30 t (Figure 4). By the 1st of May 2014, the over-all logged catch for the 2013–14 season was about 30% lower than the catch logged to April during the 2012–13 season. There was no indication that this pattern was caused by the different subsets of divers fishing between fishing years (Figure A-1).

The spatial extent of the fishery increased approximately linearly in both fishing years as the season progressed, with a faster increase in the 2013–14 fishing year (Figure 4). For an equivalent catch, fewer hexagons were visited in the 2013–14 season to date (i.e., May 2014). This was probably due to a higher spatial overlap (i.e., divers fishing the same areas). Thus, for an equivalent catch and a larger number of total hexagons fished in the 2012–13 fishing year, the number of unique hexagons in both years was approximately equal early on in the season (Figure 4 c, d). On average, divers seemed to utilise smaller areas in the 2013–14 fishing season, and fishing days with large areas (i.e., many hexagons) dived within a given day were more common in 2012–13 (Figure 5).

3.2 Dive activity

Dive activity was similar in both years, and data for bottom times and median depths from individual dives indicated slightly shorter and shallower dives in 2013–14 (Figure 6). There was no indication that this trend was caused by the difference in periods analysed (i.e., the full fishing year for 2012–13

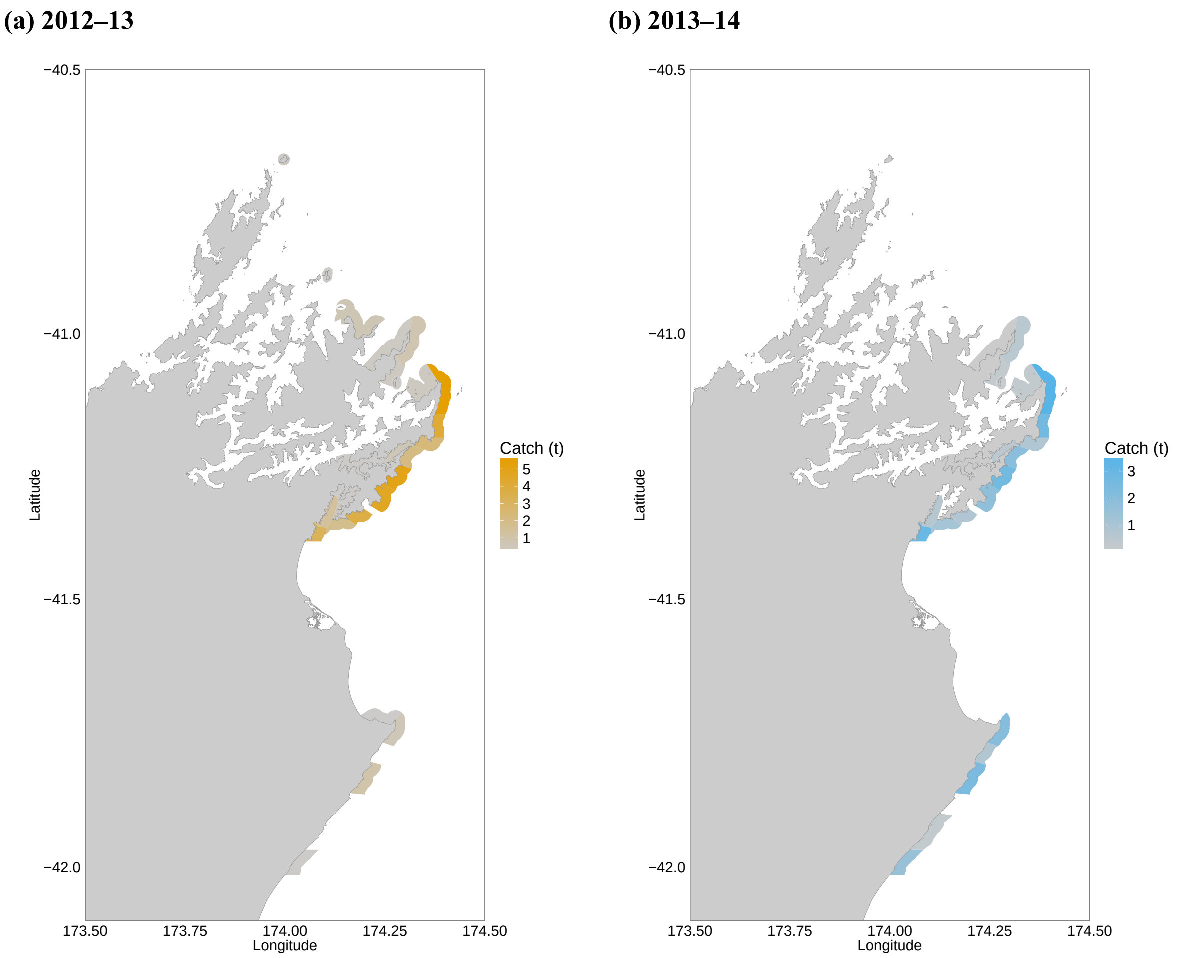

Figure 3: Catch (t) recorded in the logger database from statistical areas in PAU 7 for a) the 2012–13 and b) the 2013–14 fishing year (to May 2014). Only statistical areas with divers corresponding to at least three Annual Catch Entitlement (ACE) holders are shown in each year. A small amount of fishing on the northern West Coast is not shown.

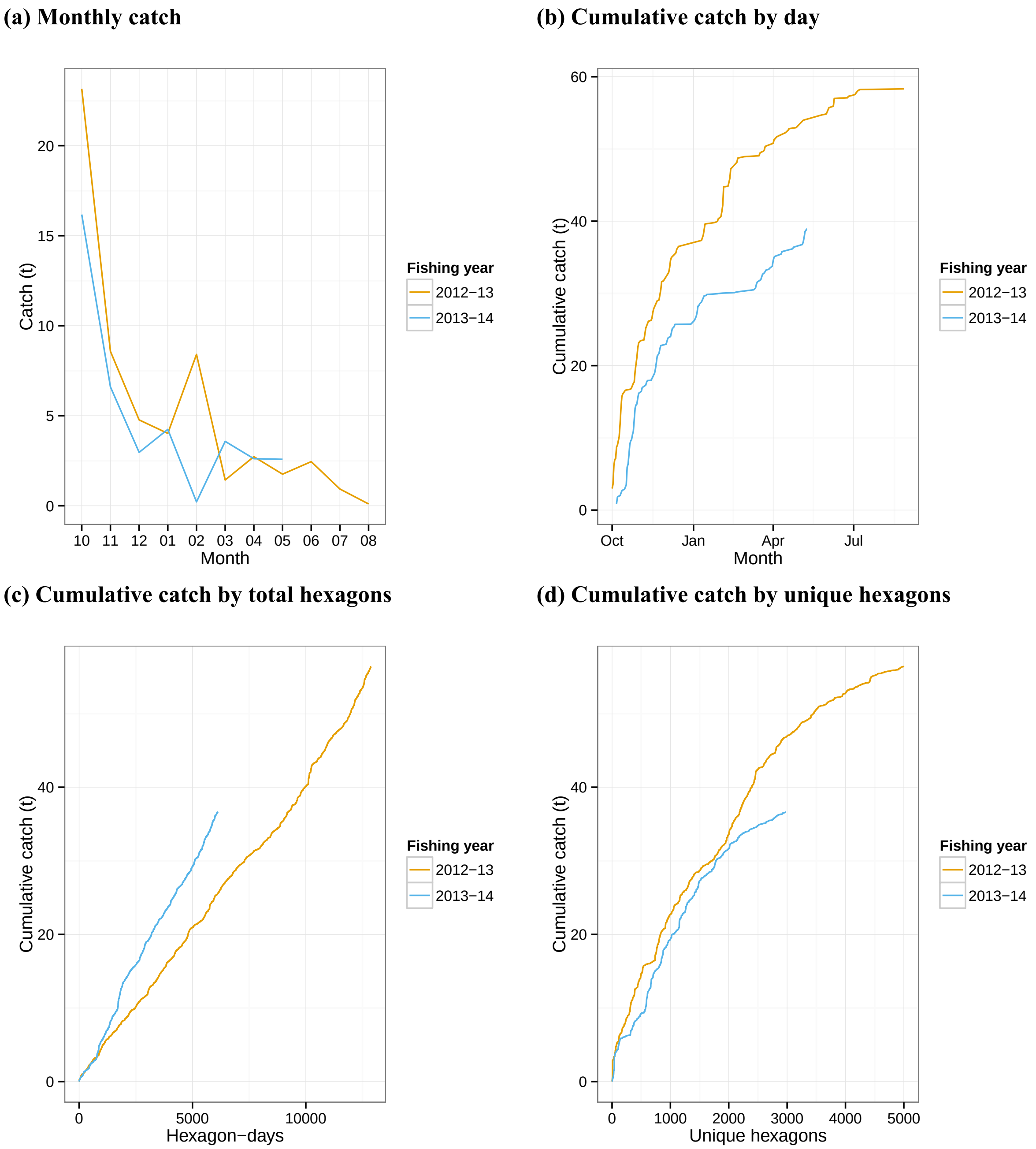

Figure 4: Monthly catch (a) and cumulative catch (b–d) for fishing years 2012–13 and 2013–14 (to May 2014) as b) function of day into season, c) number of unique hectare hexagons fished and d) number of total hexagons fished (i.e., counting hexagons as many times as they were fished by different divers or on different days). In c) and d) hexagons are ordered by the first day in which they were visited.

(a) Hexagons per diver-day **(b) Revisits per hexagon**

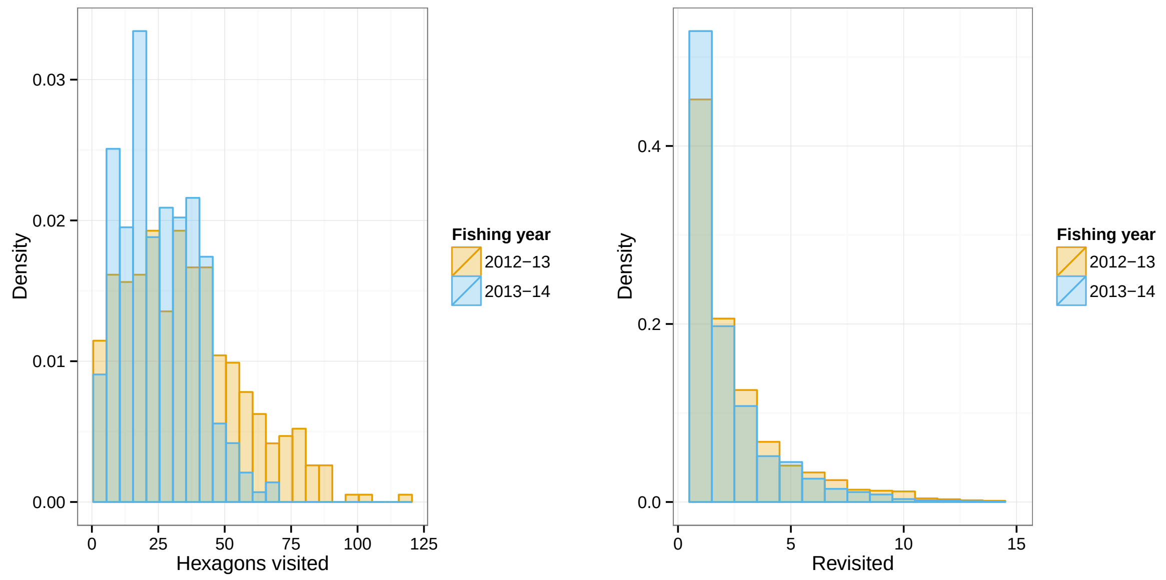

Figure 5: Hexagon visit statistics for fishing years 2012–13 and 2013–14 (to May 2014) for a) divers (number of hexagons visited per day) and b) hexagons (number of visits to hexagons).

(a) Bottom time **(b) Median depth**

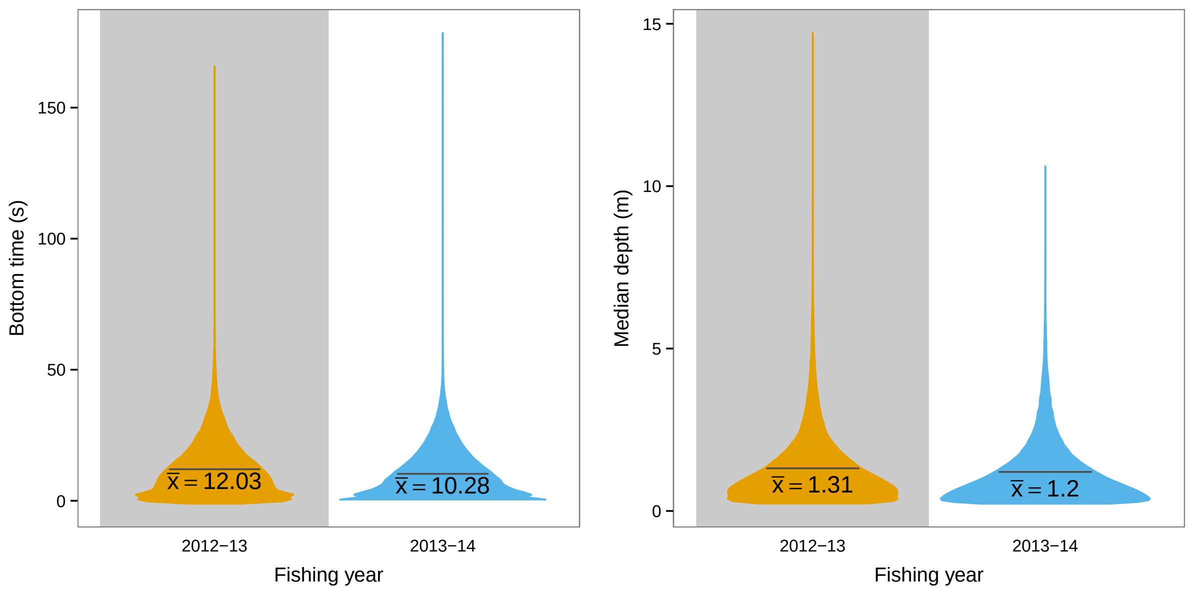

Figure 6: Dive parameters for 2012–13 and 2013–14 fishing years (to May 2014). The panels show a) bottom time and b) median dive depth distributions from individual dives within years, including their mean values.

compared with 2013–14 fishing year data analysed to May 2014), as monthly plots indicated that monthly medians for both dive parameters were generally lower for the 2013–14 fishing year than for the 2012–13 fishing year (Figure A-2).

Comparing bottom times and median dive depth within hexagons that were dived in both fishing seasons showed that shorter and shallower dives were not consistently observed within overlapping fishing areas between years (Figure 7). When standardised by total fishing time within hexagons, bottom times were

(a) △ Bottom time/fishing time **(b) △ Summed median depths**

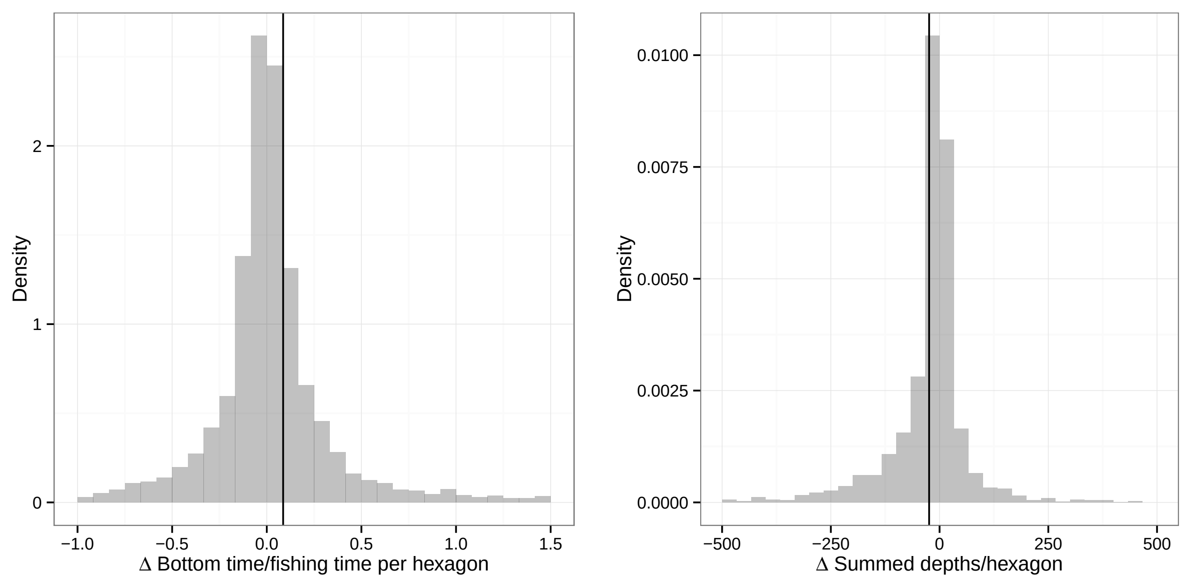

Figure 7: Difference in dive parameters between the 2012–13 and 2013–14 fishing years (to May 2014) calculated within overlapping areas (hexagons). The panels show differences in the distribution of a) total bottom time relative to fishing time within hexagons and b) summed median dive depths. Mean differences are indicated on the panels as vertical black lines.

slightly longer within hexagons revisited between years, with a mean increase in bottom time relative to fishing time of less than 10%. Summed depth data for hexagons suggested that dives were slightly shallower overall, however, the mean difference within revisited hexagons was close to zero.

3.3 Year differences in CPUE

3.3.1 Model inputs

Distributions for raw CPUE calculated from the logger database for the 2012–13 and 2013–14 fishing years suggested that the bulk of fishing in the latter fishing year occurred at slightly lower raw CPUE (Figure 8). Nevertheless, the distribution for the 2013–14 season also includes more diver-days with higher CPUE, and the geometric mean of raw CPUE was slightly higher in 2013–14 than in the preceding year.

Dive conditions were similarly distributed among years (Figure A-3), although mean swell was slightly lower and average visibility slightly higher in 2012–13 than in 2013–14.

3.3.2 Model results

The three models applied to the logger data gave qualitatively similar results, suggesting that standardised catches in the 2013–14 fishing season (up to May 2014) were slightly higher than catches in the 2012–13 season (Table 3, Figure A-4). The year change in the fixed year effect model was smallest in magnitude but had the highest estimated probability of being strictly positive, i.e., the highest probability that catches were higher in 2013–14 than 2012–13. The posterior distributions for the overall (i.e.,population mean) year change in both random year effect models (for divers and statistical areas) were also positively skewed (with higher posterior mean than in the fixed case), but were wider and overlapped zero in both cases (Table 3, Figure A-4), i.e., had substantial uncertainty in the results. Estimates for all other parameters were similar between all models; bottom time was most strongly related to catch, followed

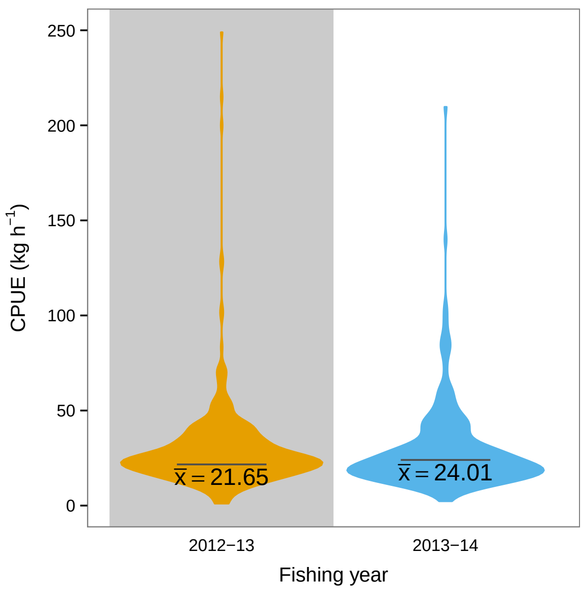

Figure 8: Distributions of raw CPUE for fishing years 2012–13 and 2013–14 (to May 2014) from the dive logger database. The indicated mean is the geometric mean of raw CPUE.

by overall fishing time and depth. Bottom time is thus the strongest predictor of differences in catch. Fishing conditions were also significantly related to catches but their effect was smaller in magnitude.

The random effects model allowed estimates of year change at diver and statistical area levels (depending on the model). The wide posterior distribution, containing zero (no effect) for the population mean in both cases suggested that the year change for individual divers and within individual statistical areas was variable. For divers, individual random effects were mainly distributed around zero (a catch multiplier of 1, see Figure 9a). Two divers had very high estimated increases in standardised catch between years, however, these divers contributed to only a small proportion of overall catches. Scaling random effects by divers' catch relative to the total catch shifted individual year effects towards the population mean by the scaling (Figure 9b). Thus, divers who contributed the largest proportion of catch over both years also experienced generally small changes in standardised catches and vice-versa, i.e., some divers caught slightly more in 2013–14 than in 2012–13, while others caught slightly less.

The results were similar for statistical areas, with the majority showing relatively small changes in catch rates between years (Figure 10a). Areas south of Cape Campbell had the strongest estimated increase (higher CPUE index) between 2012–13 and 2013–14. In contrast, areas in Cook Strait, which account for the majority of PAU 7 landings, had variable year trends in CPUE with both positive and negative trends, across the area. When scaled by catch, the small local changes within statistical areas in southern Cook Strait dominate, suggesting that in the most productive areas, the catch rates changed little between years (Figure 10b).

Table 3: Estimated posterior means, probability of being strictly positive and 95% credible intervals for model parameters, for models with a) fixed year effect, b) diver specific year effect and c) statistical area level year effect. For b) and c) the year effect parameter is the estimated population mean for divers and statistical areas, respectively.

(a) Fixed year effect

Parameter	mean(θ)	P($\theta > 0$)	2.5%	97.5%
2013-14	0.05	1.00	0.01	0.08
Bottom.time	1.38	1.00	1.34	1.42
Fishing.time	0.45	1.00	0.42	0.49
Median.depth	-0.33	0.00	-0.36	-0.29
Swell	-0.06	0.00	-0.09	-0.02
Visibility	0.11	1.00	0.07	0.14

(b) Diver year effect

Parameter	mean(θ)	P($\theta > 0$)	2.5%	97.5%
2013-14	0.14	0.81	-0.21	0.46
Bottom.time	1.41	1.00	1.37	1.45
Fishing.time	0.43	1.00	0.39	0.46
Median.depth	-0.30	0.00	-0.34	-0.27
Swell	-0.11	0.00	-0.14	-0.07
Visibility	0.14	1.00	0.10	0.18

(c) Statistical area year effect

Parameter	mean(θ)	P($\theta > 0$)	2.5%	97.5%
2013-14	0.10	0.90	-0.06	0.25
Bottom.time	1.39	1.00	1.35	1.43
Fishing.time	0.44	1.00	0.40	0.47
Median.depth	-0.33	0.00	-0.37	-0.30
Swell	-0.06	0.00	-0.09	-0.02
Visibility	0.08	1.00	0.04	0.12

(a) Random effects **(b) Scaled effects**

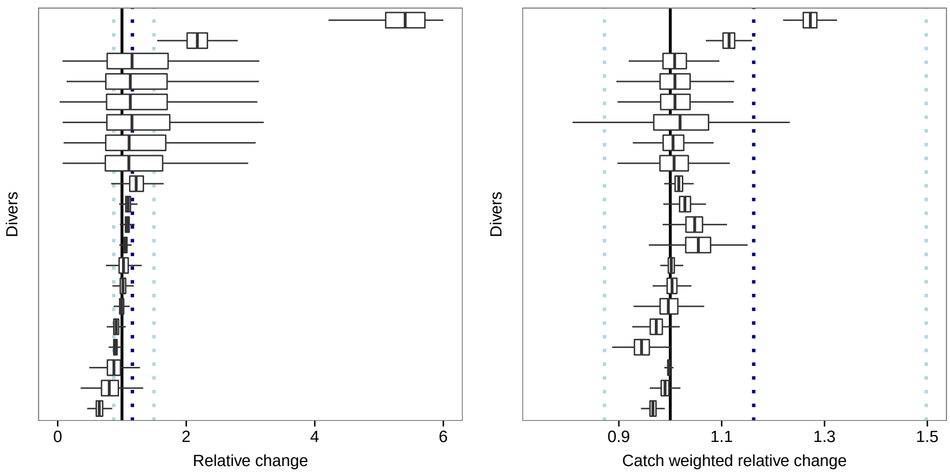

Figure 9: Estimates of relative year change in standardised catches from 2012–13 to 2013–14 (to May 2014) for individual divers in PAU 7. The light and dark blue dashed lines indicate the 95% interval and posterior mean for the population mean for all divers. The black vertical line indicates no change between fishing years. The ordering is unchanged between both plots. Individual diver random effects in a) that overlap the 95% interval of the population distribution are from divers that dived in only one of the two years.

(a) Random effect **(b) Scaled effects**

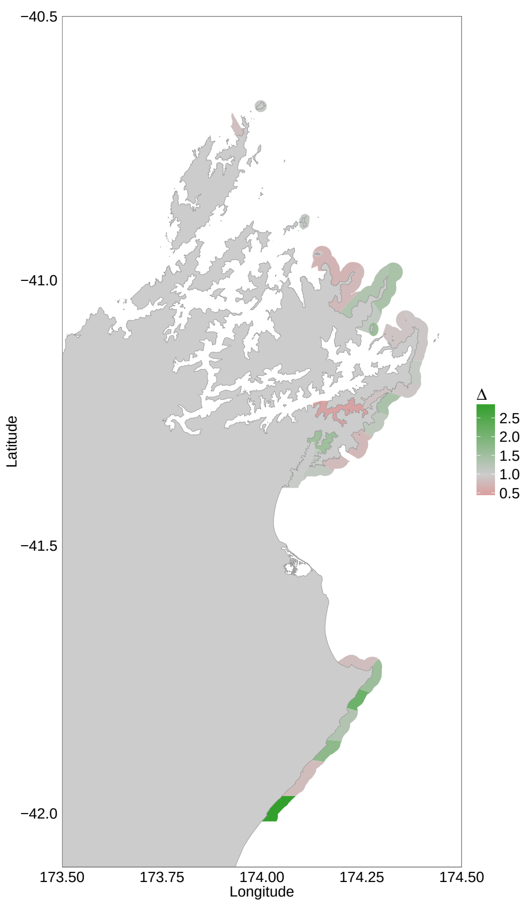

Figure 10: Estimates of relative year change in standardised catch rate from 2012–13 to 2013–14 (to May 2014) for statistical areas in PAU 7, showing a) the random effects directly from the model and b) the catch-weighted effects. Statistical areas are coloured by the change, with red indicating a decrease in standardised catch rate, and green showing an increase. A small amount of fishing on the northern West Coast is not shown.

4. DISCUSSION

The objective of this study was to monitor potential changes, in particular changes in CPUE, in the PAU 7 stock between the 2012–13 and 2013–14 fishing years. We found that both qualitative and quantitative (model-based) indicators of fishery performance showed no evidence of lower performance or lower CPUE in the 2013–14 fishing year

The data loggers are currently being used by a subset of all active divers in PAU 7, and the data used here represents approximately 47% of landings in 2012–13 (the exact coverage is uncertain for 2013–14 as the season was not concluded by the time this report was written). Nevertheless, most divers who regularly land substantial catches were included in the dataset, which should therefore provide an adequate sample of the overall fishery. This study shows the potential of the data logger programme to assist in fine-scale spatial and temporal monitoring of pāua fisheries. Increased participation in the voluntary programme will increase the robustness of the monitoring in the future.

Although the spatial extent of the fishery was smaller in 2013–14 than in the preceding year, this finding is difficult to interpret as it could be related to a number of factors. Patterns in spatial resource use may be related to trends in the fishery (Prince & Hilborn 1998). A expansion of fishing areas into less productive areas may suggest declining catches in core areas of the fishery and expansion into less productive secondary areas. A subsequent contraction back to productive core areas may be taken as a sign that less productive areas have been fished. This may be the case in PAU 7 in general, where fishing activity is concentrated within southern Cook Strait. To make strong inferences about the significance of the spatial patterns reported in this study, however, longer time series of spatially resolved fishing data are required (Walters 2003). Over the short time period of the present study, this trend would be confounded by short-term drivers. The latter include divers logging less catch in 2013–14 over equivalent periods in both years, or factors such as market prices and dive conditions in particular fishing grounds dictating catch volumes and spatial fishing patterns. Furthermore, divers have anecdotally reported to have their own rotational fishing patterns over years, and the decision to fish certain areas may depend on the time since their last visit.

Analysis of the bottom time and depth showed that dives were shallower and shorter in the 2013–14 fishing year, which was consistent across months within years. While bottom time and depth are strong predictors of catch (Neubauer et al. 2014), they are influenced by the resource distribution in space, and may reflect the differences in spatial resource use between years. Comparing dive parameters within repeatedly visited hexagons provided a way to assess whether this trend of shallower and shorter dives was due to different areas harvested in each season, or whether shorter and shallower diving also occurred within repeatedly harvested, and presumably productive reefs. These comparisons showed little evidence of consistent changes in dive parameters (e.g., Figure 7), and suggested that within repeatedly visited hexagons, the bottom time relative to fishing time increased slightly. There is thus little evidence to suggest that shallower and shorter dives reflect a change in the status of the resource over the two years examined here.

The pattern of slightly higher average raw CPUE from dive logger data in 2013–14 was confirmed by models of catch and dive effort. Raw CPUE suggested that the bulk of fishing activity was characterised by slightly lower CPUE, but that there were more fishing days with higher than average CPUE. Note, however, that we haven't analysed a full years data for 2013–14, and the results could change once all the fishing activity for the season is recorded. Models with random year effects for divers and statistical areas showed that this increased spread in CPUE reflects variability in between-year differences at both the diver and statistical area levels. Divers contributing high percentages of the total catch over both years showed an almost even mix of higher and lower CPUE between years. At the statistical area level, the most productive fishing grounds at the southern entrance to Cook Strait also showed variable trends in CPUE between years.

Overall, the logger data did not suggest lower performance of the fishery in the 2013–14 relative to the 2012–13 fishing year.

5. ACKNOWLEDGMENTS

We are especially grateful to Jeremy Cooper and Storm Stanley of the Paua Industry Council (PIC) for their continued support of and enthusiasm for the logger program, and to Julie Hills of the Ministry for Primary Industries for ensuring that the data loggers are used to deliver relevant results. We are also grateful to Tom McCowan (PIC) for valuable comments and discussions throughout the course of this project. We further thank the divers who commented on use patterns and analysis outcomes.

Statistical analyses were carried out using the software JAGS; supplementary analysis being carried out with R; data were stored in a PostgreSQL database; report writing used the LaTeX document preparation system. We are extremely grateful to the many people who contribute to these key open source software projects and make them available.

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APPENDIX A: Supporting figures

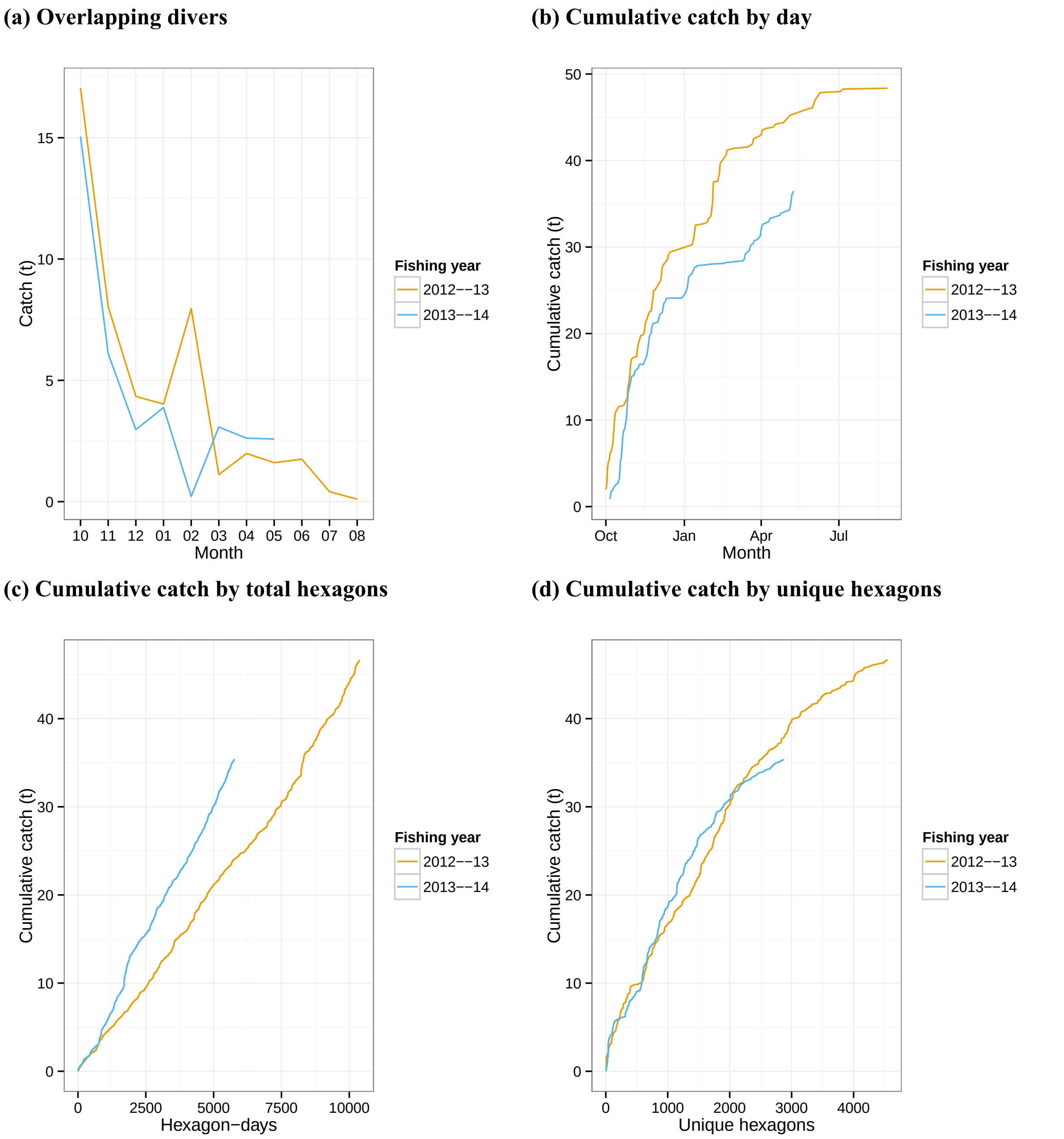

Figure A-1: Monthly catch (a) and cumulative catch (b-d) for fishing years 2012–13 and 2013–14 (to May 2014) for divers with data in both years as b) function of day into season, c) number of unique hectare hexagons fished and d) number of total hexagons fished (i.e., counting hexagons as many times as they were fished by different divers or on different days). In c) and d) hexagons are ordered by the (first) day in which they were visited.

(a) Bottom time

(b) Median depth

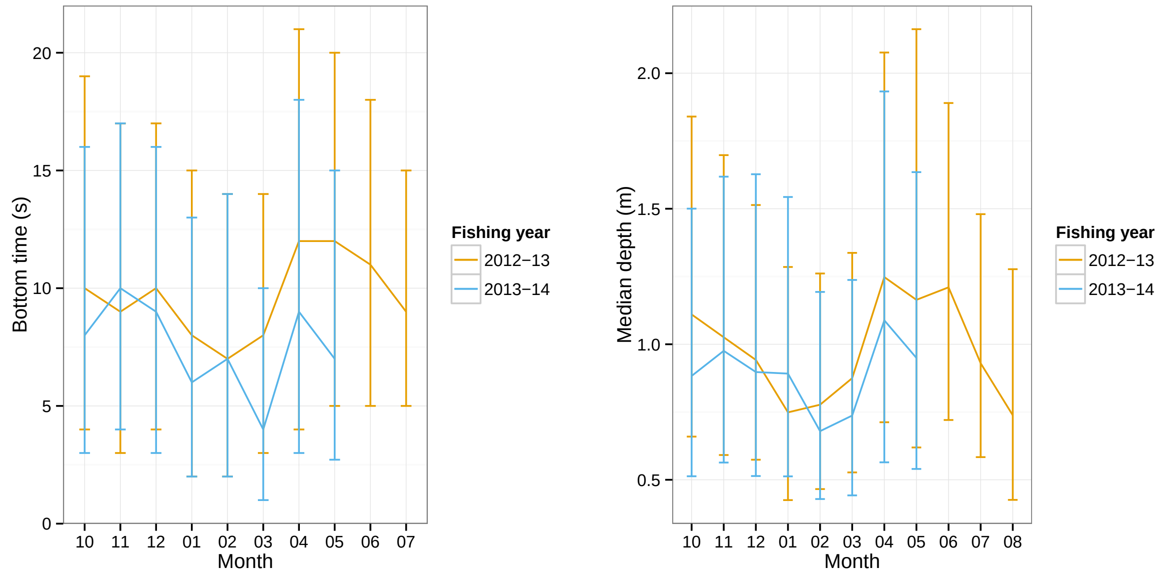

Figure A-2: Monthly median dive parameters and inter-quartile intervals for 2012–13 and 2013–14 fishing years (to May 2014). The panels show a) bottom time and b) median dive depth distributions from individual dives within months.

(a) Swell height

(b) Visibility

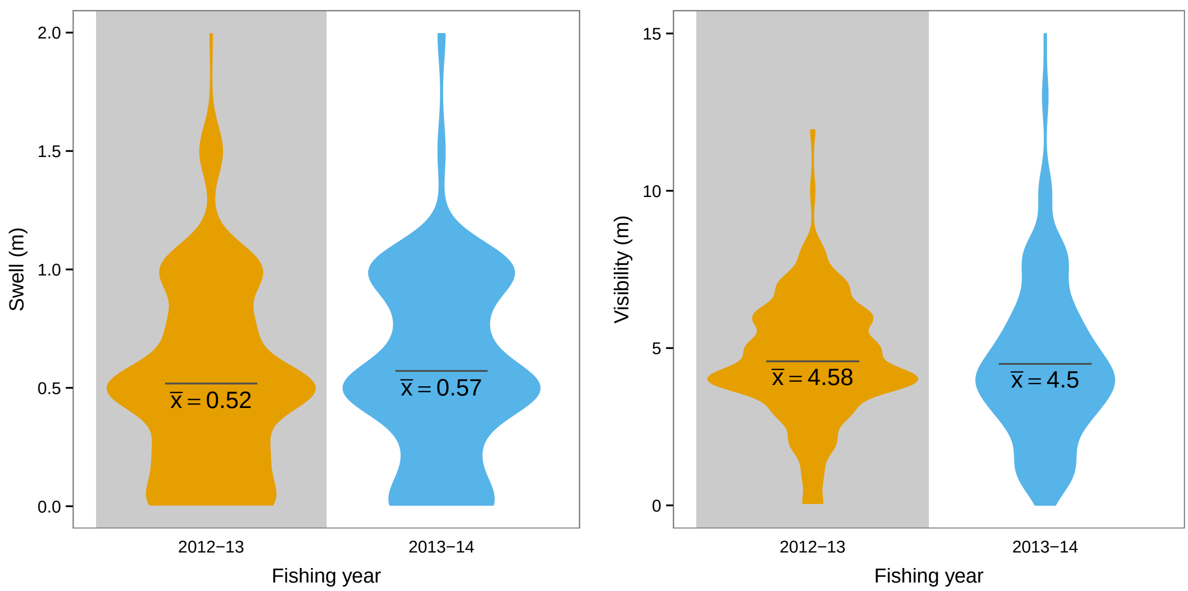

Figure A-3: Distributions for daily dive conditions by fishing year for 2012–13 and 2013–14 fishing years (to May 2014), including their mean values.

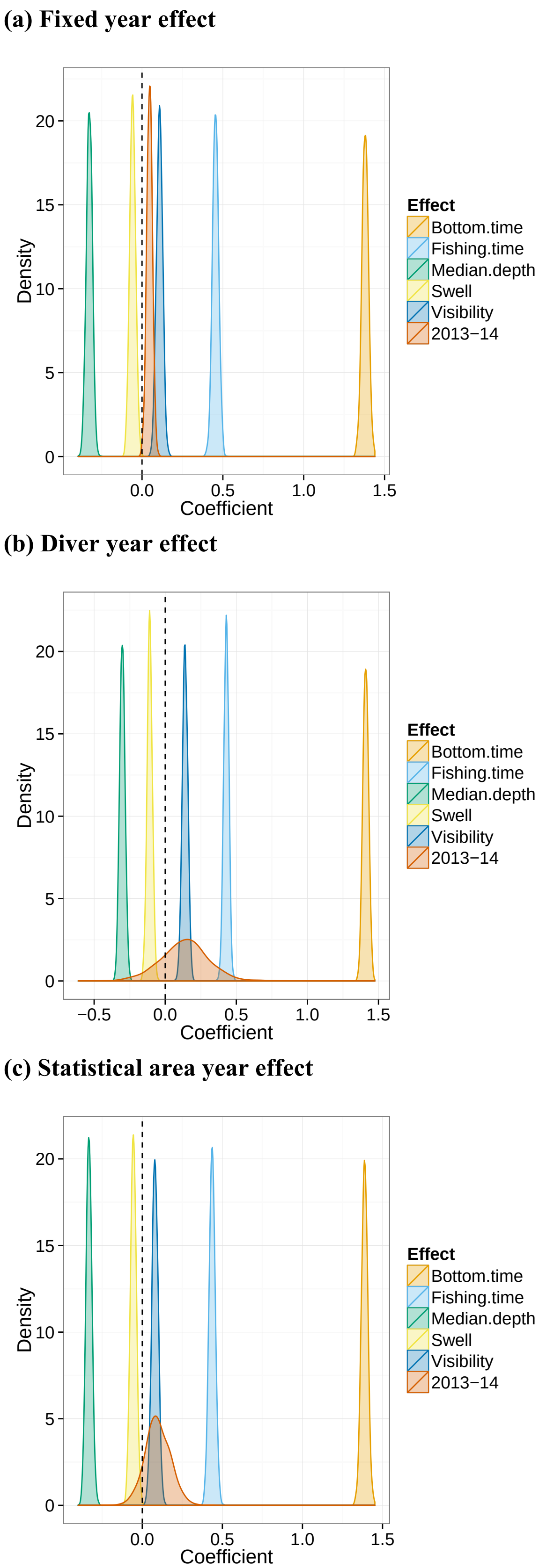

Figure A-4: Estimated posterior distributions of model parameters for models with a) fixed year effect, b) diver-specific random effect and c) statistical area level random effect. For b) and c) the year effect parameter is the estimated population mean for divers and statistical areas, respectively.