Pāua catch per unit effort from logger data

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Final Research Report prepared for the Ministry of Primary Industries

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To be cited as:
Abraham, E.R. (2012). Pāua catch per unit effort from logger data. Final Research Report for Ministry of primary Industries project PAU2010-03 (Unpublished report held by the Ministry of Primary Industries, Wellington). 28 pages.

Date: December 5, 2012
Research Provider: Dragonfly Science
Project Code: SRP2010-03
Project Title: Determining pāua abundance using dive-logger data
Principal Investigator: Edward Abraham
Project Start Date: November 1, 2011, 2011
Expected Project End Date: December 31, 2012

EXECUTIVE SUMMARY

Pāua (primarily *Haliotis iris*) fisheries in New Zealand are currently managed in Quota Management Areas (QMAs). An further assumption used in pāua stock assessment is that catch per unit effort (CPUE) provides an index of abundance There are several key problems that can confound the relationship between haliotid CPUE and abundance. In particular, abalone are vulnerable to serial depletion where accessible pāua are fished initially, but there is a progression of fishing to other reefs with a similar CPUE once the accessible pāua have been harvested. In addition, management of pāua is hampered by the limitations of current data collection that only gives aggregate data at a statistical area and daily scale.

To address these issues, pāua loggers were introduced into the New Zealand commercial fishery in October 2010. The loggers are compact units that fit in a pocket on the back of a diver's wetsuit. When the diver is at the surface they record their position, using a GPS, and when they are underwater the loggers record the diver's depth. A unit is also kept on the boat, and is used to record the location and time of catch bags being brought onboard.

In order to help develop methods for interpreting the pāua logger data, a fishdown experiment was carried out in Fighting Bay (in the outer Marlborough Sounds) in the summer of 2011–12. Fighting Bay was closed to all fishing in 1996, and so has a high pāua abundance. During the fishdown, a designated area within Fighting Bay was repeatedly fished, using commercial pāua divers, until the catch per unit effort was reduced to levels similar to a fished control site. Pāua loggers were used during the experiment to monitor changes in CPUE over a wide range of pāua abundance. Fishing was also carried out at Boat Harbour, a nearby fished site.

Catch per unit effort was measured using the loggers in two different ways: firstly, from the time that divers spent underwater (20 cm or more below the surface), and secondly by summing the half-hour blocks during which fishing activity is recorded on the boat loggers. The first measure was derived from the dive data and would allow effort to be mapped at a fine spatial scale, while the second measure is only dependent on data from the boat loggers. Over the course of the fishdown, a linear relationship between CPUE and cumulative catch was seen for both measures. This is consistent with a constant catchability. Depletion models were fitted to the data, with a separate catchability for each diver. The resulting models fitted the data well, with the c.v.'s of the model fitted using the underwater and fishing-time measures of effort being 0.17 and 0.10, respectively. It is striking that the simpler measure of effort fitted the catch data more closely. During the fishdown, 8 t of pāua were harvested from Fighting Bay. Using the fishing-time measure of effort, the depletion model estimated that there were 3 (2.3 to 3.9) t of harvestable pāua remaining at the end of the experiment.

Exploration of the data shows the power of the loggers to quantify the detailed distribution of the catch. The catch over the course of the experiment was mapped in 10 m^2 squares, with one of these 0.01 ha squares having a catch of 221 kg. In Fighting Bay, the hectare with the highest catch yielded 4635 kg (the actual yield would have been higher as, due to problems with the dive logger GPS units, only 64% of the catch was spatially mapped). It was expected that during the fishdown divers would move to deeper

water. No consistent change in the depth or duration of the dives was seen. Swim distances were variable, and no consistent change in the swim distance associated with dives (either on the surface or underwater) was seen. The other indicator that showed a marked change was shell length-frequency. Harvesting was size selective, with the larger pāua being preferentially harvested. On the first day in Fighting Bay, 2.7% of the shells had a basal length less than 130 mm, and on the final day 28.8% of the shells were less than this threshold.

The Fighting Bay data will be a valuable dataset for the future development of indices of pāua stock status. In this report we have carried out an exploratory analysis. There are more avenues that could be fruitfully explored. The next priority for analysis of the logger data, is to develop indices of spatial movement of the divers. There was evidence during the experiment that divers moved more slowly when catches were higher, and more rapidly when catches were lower. These spatial patterns have not yet been quantified.

1. INTRODUCTION

Pāua (primarily *Haliotis iris*) fisheries in New Zealand are currently managed at a regional scale in Quota Management Areas (QMAs). Due to limited data on pāua biology, stock assessments assume that the biology of pāua is uniform within the QMA (e.g., Breen et al. 2003, Breen & Smith 2008, Fu & McKenzie 2010). The dispersal of haliotid larvae is, however, generally limited to tens to hundreds of meters (e.g., McShane et al. 1988), and pāua growth may vary over scales of kilometres (McShane & Naylor 1995). In this sense regional fisheries may consist of thousands of micro-stocks (Prince 2003).

A further assumption used in pāua stock assessment is that catch per unit effort (CPUE) provides an index of abundance (e.g., Breen et al. 2003, Breen & Smith 2008, Fu & McKenzie 2010). There are several key problems that can confound the relationship between haliotid CPUE and abundance (Tarbath & Gardner 2010). Firstly, abalone tend to aggregate, with most of the individuals being concentrated in a small portion of each reef. When pāua are fished, the remaining individuals can re-aggregate, allowing the CPUE to remain high until the abundance has fallen to a low level (McShane 1995, Officer et al. 2001). Secondly, there may be serial depletion where accessible pāua are fished initially, but there is a progression of fishing to other reefs with a similar CPUE once the accessible pāua have been harvested. Thirdly, there may be changes in the fishing efficiency with time that make the assumption of a relation between abundance and CPUE problematic. Fishers are continually incentivized to improve efficiency, but there is little documentation of changes in practice that would allow the effect of improved efficiency on CPUE to be quantified. These issues may lead to hyper-stability, where initially there is little change in CPUE as abundance decreases, but the CPUE declines rapidly once the abundance falls below a critical level.

In addition to these issues that are common to many abalone fisheries, management of pāua is hampered by the limitations of current data collection. Data on commercial fishing effort and catch are collected on Paua Catch Effort Landing Return (PCELR) forms. On these forms, the daily time spent fishing and the total catch of each diver are recorded. Effort is recorded within Paua Statistical Areas (that may encompass tens of kilometres of coastline), with no information collected at the reef scale. Data collected on the PCELR forms are unable to detect small-scale serial depletion where divers move from reef to reef. Moreover, the time spent fishing that is recorded on the PCELR forms is only a crude index of effort.

In Tasmanian abalone fisheries, similar issues are being addressed by introducing detailed electronic monitoring of abalone harvest (Tarbath & Gardner 2010, Mundy 2012). Following this initiative, pāua loggers were introduced into the New Zealand commercial fishery in October 2010 (Figure 1). The loggers are compact units that fit in a pocket on the back of a diver's wetsuit. When the diver is at the surface they record their position, using a GPS, and when they are underwater the loggers record the diver's depth. Typical settings are for the loggers to record the surface position at 10 s intervals, and the depth underwater at 1 s intervals. These units give unprecedented spatial resolution of diver effort. A unit is also kept on the boat, and is used to record the location and time of catch bags being brought onboard. The development and deployment of the loggers is being managed by the fishing industry, through the Paua Industry Coucil Limited (PICL), supported by Seafood Innovations Limited (SIL) and the Ministry of Primary Industries (MPI). The current intention is to work towards complete monitoring of all commercial pāua diving in New Zealand.

In order to help develop methods for interpreting the pāua logger data, a fishdown experiment was carried out in Fighting Bay (in the outer Marlborough Sounds) in the summer of 2011–12. Fighting Bay was closed to all fishing in 1996, to protect the Cook Strait cable (Submarine Cables and Pipeline Protection Act 1996). Under the legislation the Ministry of Primary Industries is permitted to carry out research within the closed area. During the fishdown, a designated area within Fighting Bay was repeatedly

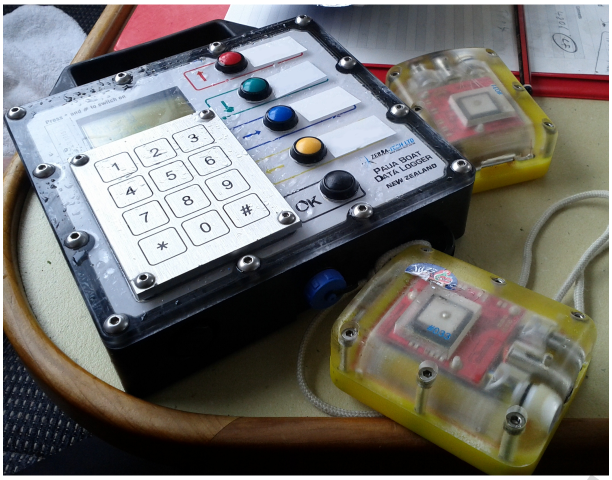


Figure 1: Boat unit and two turtle units, photographed after the data upload process, during the fishdown experiment.

fished, using commercial pāua divers. Pāua loggers were used during the experiment to monitor changes in CPUE over a wide range of pāua abundance. These data will be used for developing CPUE indices that can be applied to the commercial fishery. In Australia, the difficulties of managing abalone fisheries have been addressed by moving beyond formal stock assessments to using a range of stock indicators that may be derived from industry collected data (Mayfield et al. 2012). The Fighting Bay fishdown also allows exploration of potential indicators that are not directly related to catch per unit effort. Indicators could include changes in shell length, changes in the depth of fishing, or changes in the area visited per unit time. The fishdown allows the absolute abundance of harvestable pāua to be estimated (Leslie & Davis 1939). The fishdown gives a unique opportunity to relate the catch per unit effort and status indicators to a known biomass and density.

2. METHODS

2.1 Site selection and survey

Two sites were chosen for the fishdown experiment, one site on the south-western side of Fighting Bay (within the protected area), and a second control site in the bay known locally as Boat Harbour (Figure 2). The control site was chosen because it was close to Fighting Bay and had a similar aspect. It was known to be an area that supported commercial pāua harvest. Both sites had a steep greywacke coast, with a shallow subtidal reef extending to a sandy bottom at between 10 m and 15 m.

Before the fishdown experiment, a survey of the two sites was carried out (on December 2, 3, and 10, 2012) by divers and staff from the Cawthron Institute. The divers used approximately evenly spaced lead-line transects (initially 50 m long, but the transect line was replaced with an 80 m line during the survey to allow it to extend to deeper water). The transects were laid using a boat, so that the positioning of the transect was not determined by the divers. One diver swam each transect, allowing for more than one transect to be swum at the same time. All pāua within 50 cm either side of the transect were counted and measured (full shell length) using electronic calipers (developed by Zebratech, Nelson). The calipers recorded the depth every time a shell measurement was made. The habitat was qualitatively classified into six different types (based on bottom type and algal community), and the type was recorded at 2 m intervals using the calipers. These data were used to provide an initial estimate of pāua abundance, and are reported elsewhere (Keeley & Watts 2012). The calipers also recorded the depth at these button-presses, and this allowed the depth of the transect line to be recorded.

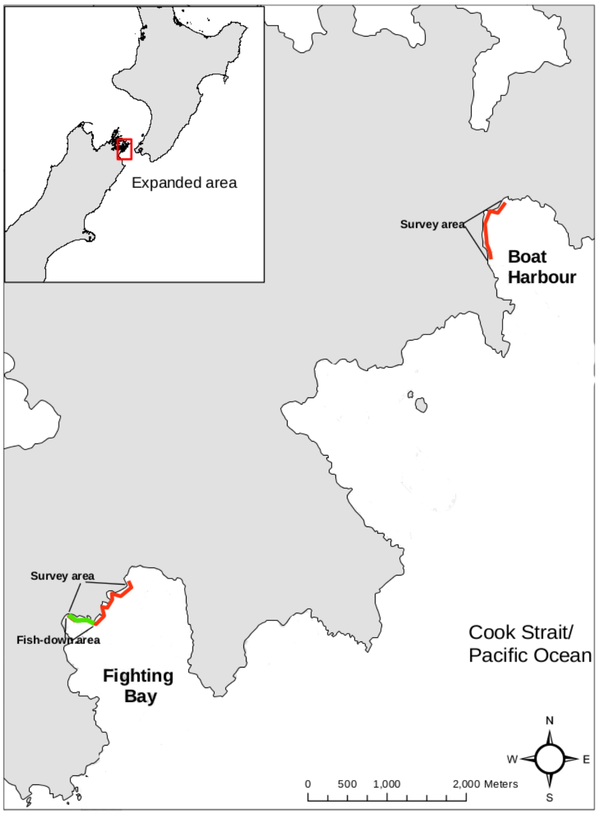


Figure 2: Experimental location, showing the areas surveyed prior to the experiment, and the location of the fishdown experiment within Fighting Bay (from Keeley and Watts 2012).

Following the survey, a small area of coast of between 300 m and 400 m length was selected in Fighting Bay for the fishdown. The area was naturally bounded on the western side by a sandy bay, and on the eastern side by a steep headland that fell quickly to the bottom. These features, together with the sandy floor of the bay, made a naturally enclosed area that was estimated from the survey to hold between 7 and 13 t of legal-sized harvestable pāua, depending on the estimation method used. Pāua were not expected to move in or out of the fishdown area during the experiment.

At Boat Harbour, pāua densities were lower, and an approximately 800 m length of coast was chosen as the control site. The area was marked by a small bay with a sandy beach at the northern end and a prominent rock to the south. Because of the length of the area, no substantial migration was expected across the boundaries of the area during the experiment.

2.2 Pāua harvesting

Pāua harvesting was carried out by a commercial crew, using their normal fishing methods. All pāua were harvested as part of the fisher's Annual Catch Entitlement (ACE). No instructions were given to the divers on how to fish, beyond defining the areas. The crew consisted of a skipper, four divers, a boat boy, and deck hands that were responsible for measuring and stacking the catch. Two vessels were used, a larger vessel and a small inflatable runabout. Pāua were harvested by free divers, using a flat tool to lever the pāua off the rocks. The pāua were harvested into catch bags that were able to hold up to 50 kg of catch. The catch bags were collected by the boat boy in the inflatable, who then brought them back to the main vessel. As part of the experiment, each bag was weighed when it was landed on the main vessel. The bags were then tipped onto a sorting table and the pāua were checked for size (Figure 3). Any

Figure 3: Sorting the catch. In the left-hand photo, a half emptied catch bag is shown on the sorting table. The upside down pāua are waiting to be measured and stacked in the bins. The bins are seen in the right-hand photo, and in the background the area of the fishdown experiment can be seen. These photographs were taken on December 15, 2011, in Fighting Bay.

sub-legal pāua ($<$ 125 mm shell length) were put aside to be returned back to the reef by the boat boy. The legal-sized pāua were stacked in bins, with each divers catch being put in different coloured bins. At the end of the day, or when the vessel moved between sites, the bins were counted, the greenweight of the catch by each diver was estimated, and the estimated weight was recorded in the boat logger and on the PCELR forms. Particular care was taken to keep the catch of each diver separate, as the divers were paid based on their individual catches. This payment structure motivates the divers to maximise their individual catches.

The fishdown experiment was carried out on 14 December 2011, 15 December 2011, 12 January 2012, 1 February 2012, and 23 February 2012. Fishing was carried out at Fighting Bay on every day of the experiment, with Boat Harbour being fished on 14 December 2011, 1 February 2012, and 23 February 2012. After the initial pass through the fishdown area in December, fishing days were spaced out to allow the remaining pāua some chance to reaggregate.

2.3 Pāua loggers

Two data loggers were used. A turtle logger for recording diver effort, and a boat logger for recording the catch. The turtle logger used a GPS to measure the diver's location, and a pressure sensor to measure the diver's depth when they are underwater. The loggers were activated by a saltwater switch, with a surface sensor used to change from surface to underwater mode. During the experiment, the turtle loggers were carried by the divers in a neoprene pouch on the outside of the divers wetsuit, on their backs between the shoulder blades. The exception was one diver who used a harness similar to backpack straps to hold the logger on his back. This diver wanted to be able to remove the logger in case they became trapped underwater. The turtle loggers were set to record position information at 10 s intervals when the loggers were on the surface, and to record depth at 1 s intervals when the loggers were underwater.

The boat logger recorded position continuously at 10 s intervals. The logger had four waterproof buttons. These buttons were programmed with the divers identifier (their Seafood Industry Training Organisation (SITO) number), and the number of the turtle logger. The boat logger was carried on the runabout. When a catch bag was brought onto the boat, the boat boy pushed the corresponding button on the logger, and the time and position of the button-push were recorded. When a fishing session was finished (typically at the end of the day, or when fishing moved to a different area), the estimated greenweight harvested by each diver during the fishing session was entered into the boat logger.

2.4 Data grooming

2.4.1 Data files

Data from the pāua loggers were saved as comma separated files, with new records being written sequentially to the files. The files were transferred from the loggers onto a computer at the end of every day's fishing. They were then groomed and uploaded to a database (PostgreSQL) for archiving and analysis.

2.4.2 Grooming the time record

The time data on the dive loggers was key for interpreting the records. While the logger was underwater, time was recorded by the logger's internal clock, and while the logger was on the surface, and collecting GPS data, time was recorded by the GPS. There were often discrepancies between these two clocks. In particular, the internal clock tended to drift, or to become reset when the battery was changed. When the GPS switched on the internal clock was synchronized to the GPS clock, but the synchronization was not always successful. The time data were groomed so that they were sequential. The GPS clock was assumed to be correct, and the internal clock was adjusted to match. Occasional dive records were dropped where the dive extended beyond the start of the following surface period. This ensured that the time data collected by a turtle logger were strictly increasing. The same problems were not encountered with the boat logger, as it was not switching modes.

2.4.3 Grooming position data

The dive and boat logger position data were noisy. It was subsequently found that there was an internal error in the processing of the GPS data, which introduced a spurious offset onto some records. This error could not be corrected for data that had been collected during the experiment. The turtle logger data are affected by the switching in and out of surface mode. Many of the surface intervals were short (less than 30 s), and so few surface GPS fixes were obtained. The position data were groomed by fitting a running mean filter to the GPS data, with a total window length of 4 minutes. Positions that were more than 100 m away from the running mean, or that were missing, were assumed to be errors, and were replaced with the running mean position. Boat logger positions were not groomed.

2.4.4 Defining dives

Data from the turtle logger were divided into dives, and associated surface periods. Dives were defined as sequential records where the depth was deeper than 20 cm below the surface. To define these dives, drift in the recorded surface depth was first corrected using the following procedures:

1. Surface fixes were identified as all depths within 1 m of the median depth when the turtle logger was in surface mode (occasionally the surface mode would be activated at depths over 1 m and these fixes were ignored).
2. A running average surface depth was constructed by taking the median of the surface depths from 1, in 10 minute blocks, and then linearly interpolating between those averaged surface depths.

3. This running-average surface depth was subtracted from all depths, so that they were zeroed.

For each dive, three positions were recorded: the start of the preceding surface period, the GPS position immediately before the dive, and the GPS position immediately following the dive. The dive duration was defined as the time between the first and last underwater time. The swim duration was defined as the time between the start of the surface period and the start of the dive. The maximum speed during the surface period was recorded to assist with identifying boat movements. The depth of the dive was the maximum depth of any of the points during the dive.

2.4.5 Catch weights

The weights of the catch bags were measured as they were landed, using floor scales. These weight measurements were recorded on paper forms, with each bag being identified by the time and the diver. They were later reconciled with the catch bags recorded on the boat logger. The estimated greenweight was recorded on the boat logger for each diver at the end of the day, or when changing sites. An estimated weight was calculated for each bag by dividing the estimated catch by he number of bags that contributed to it. From the weight of each bag, a catch was allocated to each dive that contributed to that bag in proportion to the duration of each dive. The measured bag weights were compared with the estimated weights. The measurements were made on a moving boat, while the pāua were in the catch bag, and while they were still wet. A calibration was determined by fitting a linear regression between the estimated weights and the measured weights. This allowed a calibrated weight to be determined for each bag, and so for each dive.

2.5 Shell length

During the experiment, selected bins were tagged. The bins were selected haphazardly, with up to 6 bins being chosen through each days fishing at Fighting Bay. At least one bin was chosen from each diver, and one bin was chosen from each days fishing at the control site. After the catch had been processed, the shells from these bins were set aside for shell measurement using the standard industry catch-sampling programme method. Shells were measured on an electronic measuring board. The board measured both the basal length of the shell (the maximum length of the shell at the shell opening), and the full length (the maximum projected length). For pāua the difference between the basal and the full length is that the hump of the shell may extend beyond the shell opening. The legal length of pāua is determined by the full length, but the basal length is used for monitoring pāua growth. Data from Fighting Bay shells were not included with shell-length data collected as part of the commercial catch-sampling programme.

2.5.1 Catch landing returns

Data from pāua catch effort landing return (PCELR) forms were obtained from the MPI data management group. These allowed data from the loggers to be be compared with the paper records that are usually used for recording catch.

2.6 Data analysis

An exploratory analysis of the data was carried out to investigate features of the data that may be useful for managing pāua fisheries. The analysis provided insight into the strengths and limitations of the loggers. The analysis focussed on spatial distribution of the catch, depth distribution, dive characteristics, and the boat logger catch data.

2.7 Catch per unit effort

Catch per unit effort was defined by dividing the estimated catch by a measure of effort. Two measures of effort were used. The first was the total time fishing. This was defined by dividing the days into half hour periods and adding up the half hours, for each diver, that had fishing activity recorded in them. This could be derived either from the boat logger data (so that a diver was declared to be fishing in a given half hour if there was a button press associated with that diver in that half hour), or from both the turtle and boat logger data. This effort measure was only calculated at a daily resolution.

The second measure of effort was the time that a diver spent underwater (20 cm or more below the surface). This was reliably derived from the dive logger data. More complex ways of classifying the dive logger data were tried, but were not to be shown to be reliable. There was no reliable way of identifying when a diver was actively fishing, or when they was searching, as searching occurred on the surface and underwater.

Using these CPUE measures, the relationship between CPUE and abundance was determined within the Fighting Bay fishdown site. A Leslie depletion methodology was used (Leslie & Davis 1939): from the fishdown data a catchability was determined that was the proportionality constant between the CPUE and the abundance. If during an interval, t, there was a fishing effort, f_t, that resulted in a catch, C_t, then the CPUE over that interval was C_t/f_t. If it is assumed that the CPUE was proportional to the population which was available to be harvested, N_t, then the catchability, q, is defined through the relation

$$\frac{C_t}{f_t} = qN_t. \tag{1}$$

The catchability represents the proportion of the population that is removed through a unit of fishing effort. In a fishdown experiment, it is assumed that the population remaining at time t is the initial population, N_0, less cumulative catch until that point, K_t. For this assumption to be satisfied it is required that there is no movement of animals in or out of the fishdown area while it is proceeding, and that the increase in the biomass from growth is small relative to the biomass at the start of the fishdown. With this assumption, the catchability equation may be used to estmate the catch during the interval t:

$$C_t = q(N_0 - K_t)f_t. \tag{2}$$

By fitting this linear equation to the data, the catchability q and the original biomass N_0 within the fishdown area may both be estimated. In analysis of the Fighting Bay fishdown, a separate catchability was estimated for each diver. The depletion equation was generalised so that for each diver d in a time interval t, the catch is

$$C_{td} = q_d(N_0 - K_{td})f_{td}. \tag{3}$$

Fitting this equation to the data requires the time course of the catches to be known, but does not require the effort to be fully known (the equation was fitted to catches C_{td} for which the associated effort f_{td} was known). It is well suited to the pāua logger data, which has some missing effort data. The cumulative catch K_{td} is taken as the average cumulative catch associated with the effort f_{td} by the diver d in time interval t.

In applying the depletion equation to the Fighting Bay data, the time interval was taken to be a days fishing. First, the cumulative catch was calculated for each bag by summing the estimated weight from all the bags that had been reported earlier. For bags that had dives associated with them, the effort was calculated as the total time underwater for all dives associated with that bag. Bags that did not have any effort associated with them (because of problems with the turtle logger) were not included in the analysis. Catch and effort data from the remaining bags were aggregated by diver and by day. For each diver and day, the effort was calculated as the total time underwater, the catch was the total catch, and the cumulative catch was the average cumulative catch over all the associated bags. A Bayesian model was used to fit Equation 2 to the data. A second model was fitted with an identical structure, but with the effort being derived from the fishing time for each diver and day.

The daily catches were assumed to be drawn from a gamma distribution with mean $q_d(N_0 - K_{td})f_{td}$ and with rate θ. The use of the gamma distribution reflects the constraint that the catches are always positive, while allowing for a range of differently shaped distributions around the mean. The initial population N_0 was given a uniform prior between 1 and 10 times the total catch for the whole fishdown K_{max}; the catchabilities, q_d, were given broad log-normal priors; and θ was given a uniform shrinkage prior (see Gelman et al. 2006). The model was fitted using MCMC methods with the software JAGS (Plummer 2005), the model was run for 1 000 000 iterations, following a burn-in of 100 000 iterations. The JAGS code used to fit the model is given below:

```
model {
   N0 ~ dunif(kmax, 10*kmax)
   for (d in 1:divers){
       q[d] ~ dlnorm(0.1, 0.01)
   }
   uniform.theta ~ dunif(0, 1)
   theta <- (1.0/(1.0 - uniform.theta)) - 1.0
   for (i in 1:N){
       catch[i] ~ dgamma(q[diver[i]]*(N0 - K[i])*effort[i]*theta, theta)
   }
}
```

From the model, posterior distributions of the initial harvestable pāua within the fishdown area and of the catchabilities for each diver were estimated. Model fit was checked by comparing the actual daily catches with the estimated catches for each diver and day, obtained from samples of the posterior distribution.

3. RESULTS

3.1 Site survey

Pāua length and depth data were obtained from 8 weighted line transects within the fishdown area in Fighting Bay, and 10 transects in Boat Harbour (data were also obtained from transects outside the Fighting Bay fishdown area, but they are not presented here). Depths were measured every 2 m along the transects, and were subsequently corrected for tidal height to be depths below mean sea-level (MSL). The transects extended out from the shore, and bottom depths in the Fighting Bay survey were concentrated between 2 and 4 m below mean sea-level (Figure 4), while depths at Boat Harbour peaked between 4 and 6 m. The depths of pāua along the transects were strongly concentrated at shallow depths. At the Fighting Bay site, the median depth below MSL of pāua along the transects was 1.8 (95% c.i.: 0.5 to 4.5) m. At the fished site, Boat Harbour, the pāua were deeper, with a median depth below MSL of 2.9 (95% c.i.: 0.8 to 5.7) m.

A total of 545 pāua were measured during the site survey (Figure 5). Of these, 64 were at Boat Harbour, and 481 were at Fighting Bay. There were 50 individuals at Boat Harbour that were less than the legal length of 125 mm (78.1% of measured individuals). At Fighting Bay, there were a smaller number of 43 individuals that were less than the legal length, and this was only 8.9% of the total number. During

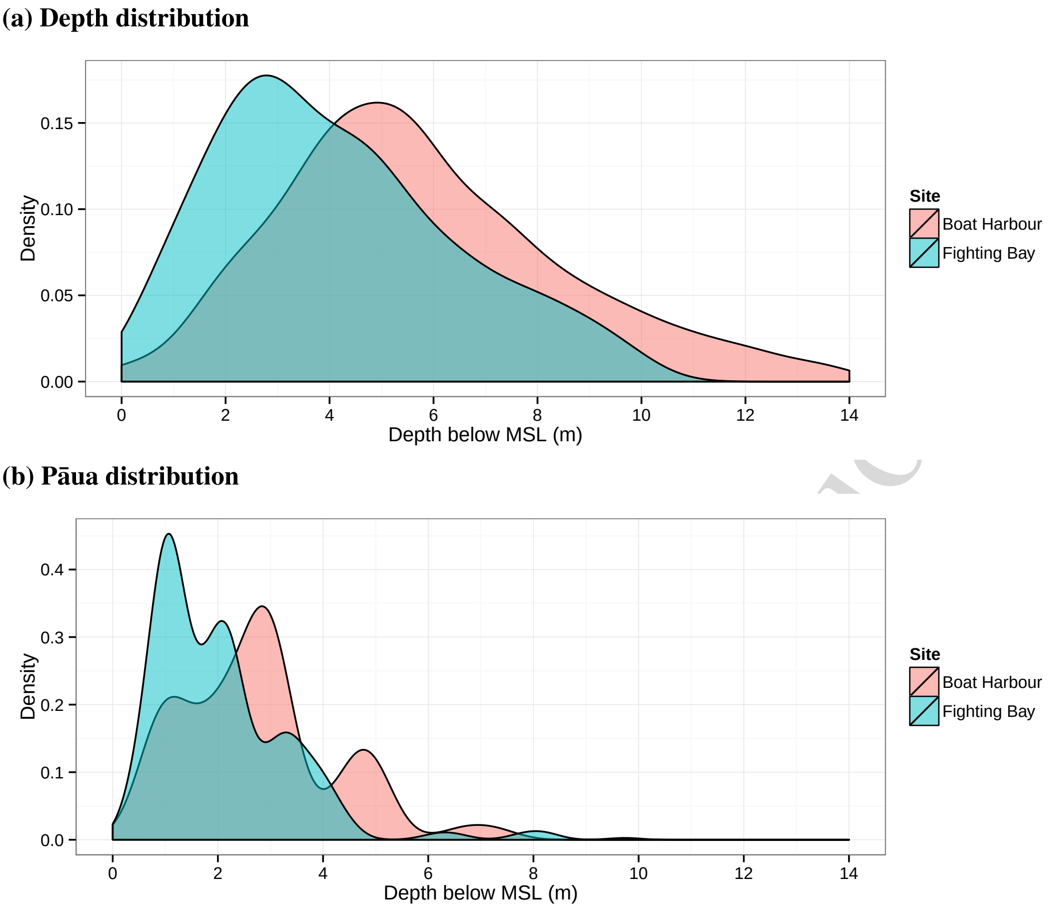


Figure 4: Distribution of (a) bottom depth and (b) pāua depths during the survey, at the two sites. Depths were corrected for tidal height and are relative to mean sea level (MSL).

the transects, there were 1.8 times as many depths less than 4 m recorded at Fighting Bay than at Boat Harbour (with each depth record corresponding to an area of around 2 m). Although there were many more legal pāua within the Fighting Bay fishdown area, it appears from the transects that there was a lower density of sub-legal pāua.

3.2 Experimental synposis

The experiment was carried out over five days, between 14 December, 2011, and 23 February, 2012. Harvesting was carried out in Fighting Bay (the unfished site) on all five days, and was carried out at Boat Harbour (the fished site) on three days. On all days the weather was fine, with low swell (< 1 m) at the sites and with adequate visibility. Conditions were recorded on the PCELR forms as Average (A) on the first three days (in December and January), and Good (G) on the final two days (in February). On each occasion, the divers covered the Boat Harbour site in less than four hours. On the first visit to Fighting Bay (14 and 15 December, 2011), it took two days for the divers to fully cover the fishdown area. On the second and third visits, it took a day to cover the fishdown area, and on the final visit, two full sweeps of the fishdown area were made in a single day.

Over the five days, there was a total of 7950 kg harvested from the unfished site (Table 1). At the fished site, 550 kg of pāua were harvested over three days. As expected, total catches within the unfished area decreased over the course of the experiment. Four divers participated in the experiment. In presenting

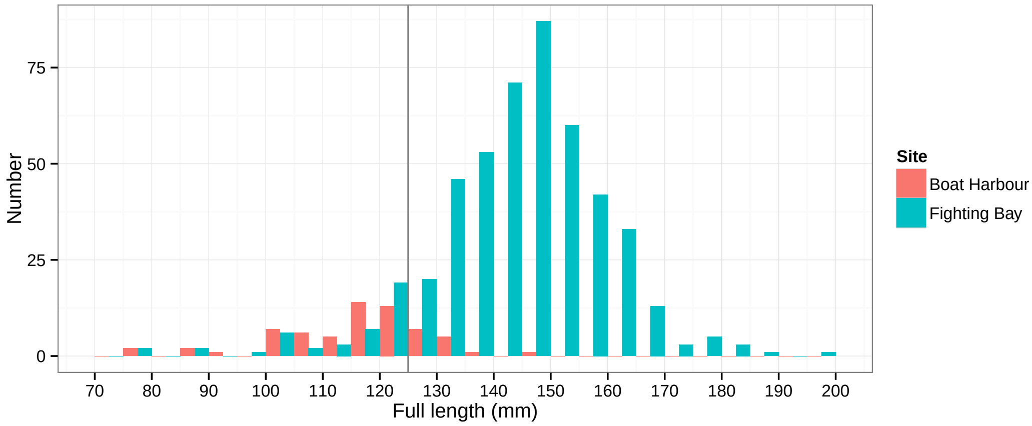


Figure 5: Length frequency data from the survey before the fishdown. The plot shows the number of measured pāua in 5 mm length bins, from the two sites. There were 64 pāua measured at Boat Harbour, and 481 measured in Fighting Bay, within the fishdown area. The line at 125 mm marks the legal length limit.

Table 1: Total greenweight (kg) of pāua harvested at the two sites during the experiment, summarised by day and by diver, from the boat logger data.

(a) Fighting Bay

Date	Diver A	Diver B	Diver C	Diver D	Total
2011-12-14	735	585	620		1940
2011-12-15	850	705	690		2245
2012-01-12	635	510	565		1710
2012-02-01	430	400	280	220	1330
2012-02-23	340	190		195	725
Total	2990	2390	2155	415	7950

(b) Boat Harbour

Date	Diver A	Diver B	Diver C	Diver D	Total
2011-12-14	50	35	30		115
2012-02-01	75	50	45	40	210
2012-02-23	85	70		70	225
Total	210	155	75	110	550

the results, the divers are referred to as divers A, B, C, and D. Two divers (A and B) harvested pāua on every day; one diver (C) harvested pāua on three days but was unable to participate in the final day; and one diver (D) joined the experiment for the final two days. With the exception of diver D on February 1 (who started later than the others), all divers were able to fish for the same length of time. On each day, and at both sites, diver A had a higher catch than the other divers.

The estimated greenweight in Table 1 was reconciled against the official returns on the PCELR forms. These forms gave the total catch by each diver, within each area. The catches for each diver-day were the same, with the exception of an additional 20 kg of pāua that were harvested by diver D on 23 February outside the experimental area. This catch was not part of the experiment, and so was reported on the PCELR forms, but was not included in Table 1. One diver was recorded on the PCELR forms with two different diver identifying codes on the different days, due to a spelling error in their surname.

Fishing effort is recorded on PCELR forms as time spent in the water. Total time (by all divers) at the Fighting Bay site ranged from 21 h to 39.5 h per day (Table 2), while at Boat Harbour the total time ranged from 10 h to 14 h. On each day and at each site, the time spent fishing was recorded as the same for each of the divers, with the exception of 1 February 2012 at Fighting Bay, when divers A, B, and C were recorded as having spent 10.5 h fishing, but diver D spent 8 h.

Table 2: Number of divers and total time fishing (h), as recorded on PCELR forms.

Date	Divers	Site	
		Fighting Bay	Boat Harbour
2011-12-14	3	21.0	10.0
2011-12-15	3	30.0	
2012-01-12	3	33.0	
2012-02-01	4	39.5	14.0
2012-02-23	3	30.0	13.5

Table 3: The number of recorded bags that have dive data associated with them (as a percentage of the total number of bags recorded for each diver on each day).

Date	A	B	C	D
2011-12-14	96.6	16.0	100.0	
2011-12-15	94.1	41.9	96.2	
2012-01-12	28.0	29.2	100.0	
2012-02-01	100.0	100.0	100.0	100.0
2012-02-23	100.0	100.0		100.0

Fighting Bay is closed to fishing, and so there was no other fishing activity in the bay during the experiment. Other people may have fished at Boat Harbour during the experiment, however. Commercial catch is reported by Pāua Statistical Area, and area P722 includes Boat Harbour. It extends from the point to the south of Boat Harbour to Jordy Rocks to the north, and includes Boat Harbour, Lucky Bay, and the coastline in between. During the course of the experiment, 550 kg was harvested from area P722 in Boat Harbour as part of the experiment, and 30 kg was harvested outside of the experimental area but also in P722 during the fishdown. An additional 1955 kg was harvested by other fishers from P722 between 14 December 2011 and 23 February 2012. It is not known how much of this additional harvest came from the site within Boat Harbour that was used as part of the experiment.

3.3 Dive data

In total, there were 6895 dives recorded during the experiment, however not all dives were recorded (Table 3). Turtle units used by two divers had problems with not switching on when the divers entered the water after a break. The units had a salt-water switch, and were designed to switch on when in the water. For the units used by diver B, this switch did not operate correctly on the first three days of the experiment, and so only partial data were recorded. The unit used by diver A also failed to record data for much of the harvest on January 12.

Given that the turtle units were operating, there is still an issue of whether they collected satisfactory data. There were five turtle units used by the divers in the experiment. In all cases, the depth loggers on the units collected data. Four turtle units had GPS positions for between 96.9% and 99.6% of all dives. For one unit however, the GPS did not routinely acquiring a fix while the unit was at the surface. For this unit (used by diver C), locations were only obtained for 43.4% of all dives. This diver was wearing a harness (rather than putting the unit in a pocket on the back of the harness). At the time it was thought that the problems may have been caused by the position of the unit on the diver's back. After the first three days of the experiment (14 December, 15 December, and 12 January) the unit was replaced. With a new unit, position information was satisfactorily collected, and so the problems appeared to have been

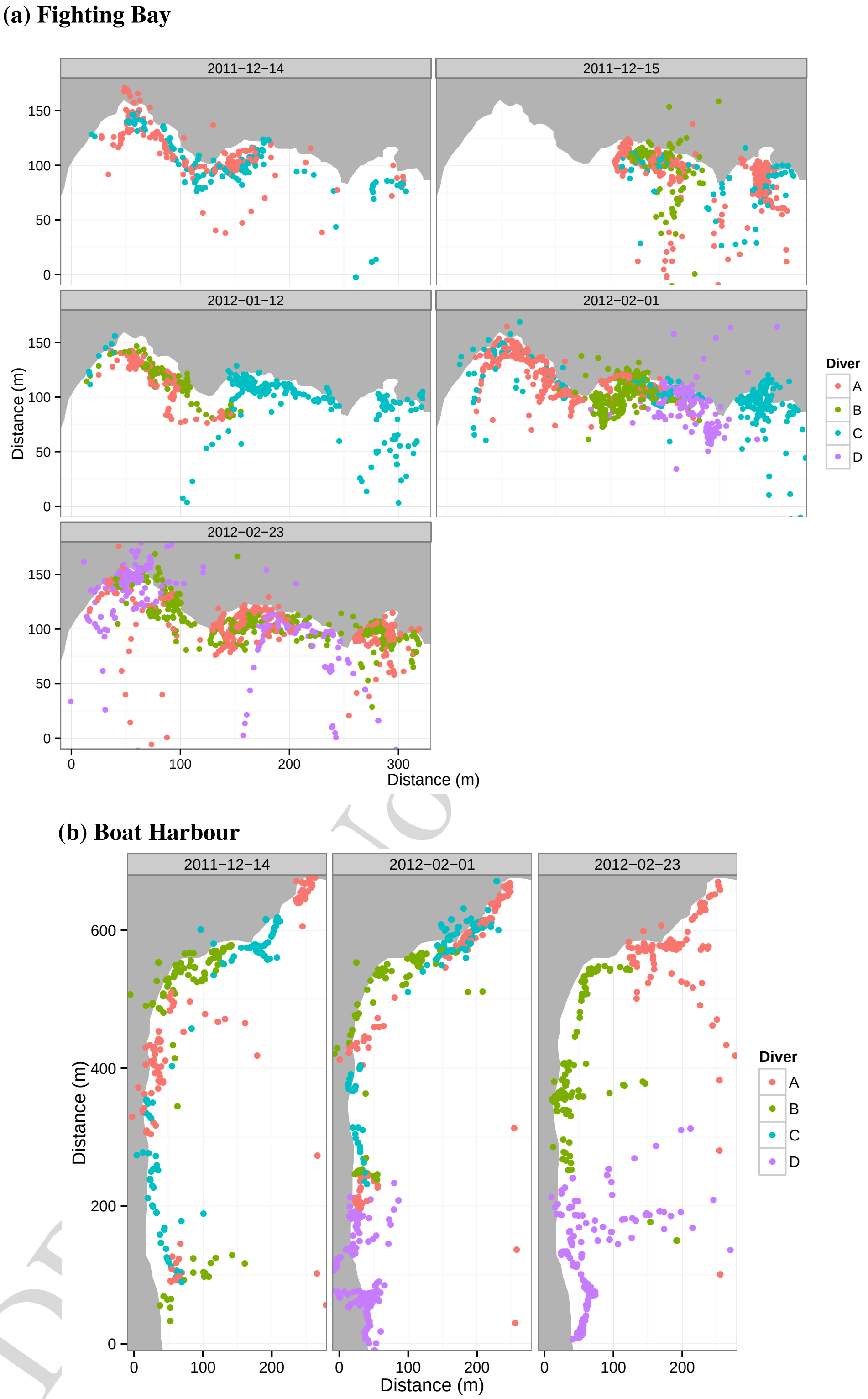


Figure 6: Maps giving the positions of dives at the two sites on each day of the experiment. The points are groomed fixes from GPS data at the start of each dive, coloured by each diver. The land is indicated in darker grey.

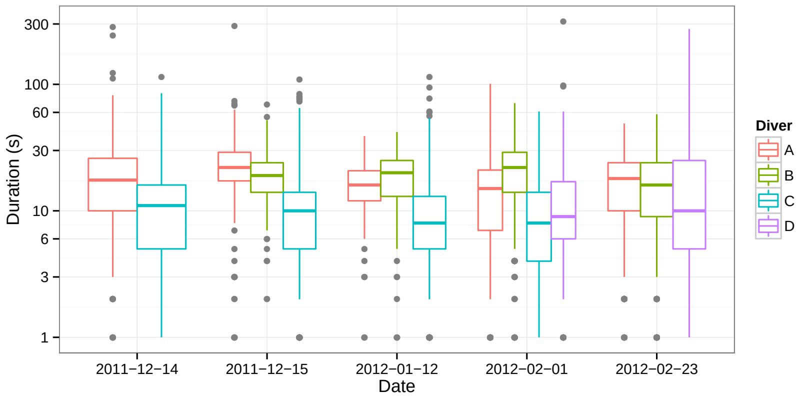


Figure 7: Boxplot showing the distribution of dive durations for the five dayss fishing at Fighting Bay, for each of the four divers.

caused by a faulty unit, rather than with the harness system.

The missing data obscure a change in behaviour of the divers as the fishdown proceeded. During the initial two days, the divers worked methodically as a group. On the first day they all worked in the densest patch, staying close to each other and harvesting systematically. On the second day they fished the other half of the area for the first time, again staying close to each other. As the pāua density decreased in the later stages of the experiment, they separated and fished relatively independently of each other. This pattern is seen on 1 February 2012 (Figure 6(a)), where the divers each tended to fish their own areas of the reef. On the final day of the fishdown, two full searches were made through the area for remaining pāua. At Boat Harbour, the divers fished independently, and this pattern is seen most clearly on 23 February 2012 (Figure 6(b)).

3.4 Dive duration and depth

There were 5098 dives longer than 5 s. The average duration of all dives was 15 s, with the average duration of dives longer than 5 s being 19 s. Most dives (around 99%) were less than one minute long, with 95% of all dives being less than 37 s. Longer dives were shallower. The maximum dive duration was 314 s, however this is likely to be an artefact of the method used for defining dives (the diver may have taken air between the 1 s interval of the depth recorder). There was no indication of any change in dive duration over the course of the fishdown (Figure 9). Divers A and B tended to make longer dives, while diver C made shorter dives, and this pattern was consistent throughout the experiment.

The dives were shallow, with the average depth of the dives longer than 5 s being 1.7 m. Of all dives, 95% had a maximum depth less than 3.6 m. There were no short deep dives, reflecting the time needed to descend and ascend (Figure 8). Around an additional 5 s duration was taken for every additional meter of depth. There was only one maximum depth recorded at greater than 10 m. At Fighting Bay the median catch-weighted depth was 1.4 (95% c.i.: 0.5 to 5.2) m. At Boat Harbour the catch was deeper with a median catch-weighted depth of 1.6 (95% c.i.: 0.5 to 4.1) m. The median depths were shallower than the median depths of pāua found during the survey transects (see Figure 4), although the catch depths have not been corrected for tidal height.

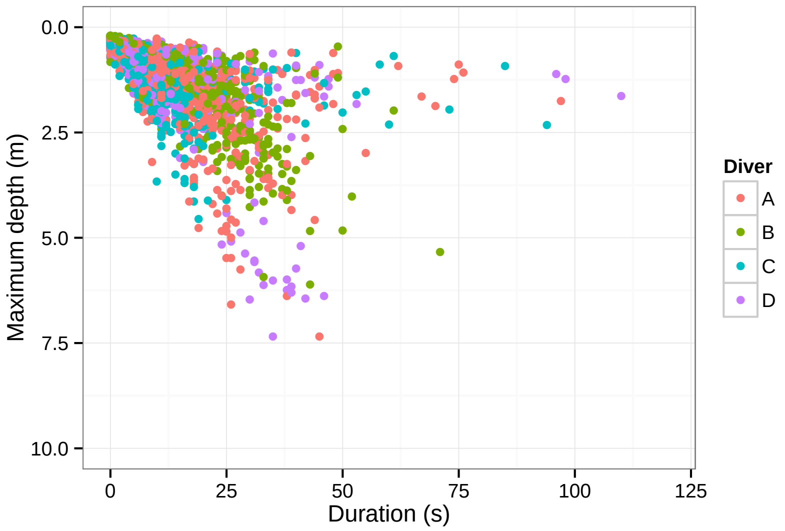


Figure 8: Relationship between dive depth and dive duration, for each of the four divers, for dives from Fighting Bay.

(a) Fighting Bay **(b) Boat Harbour**

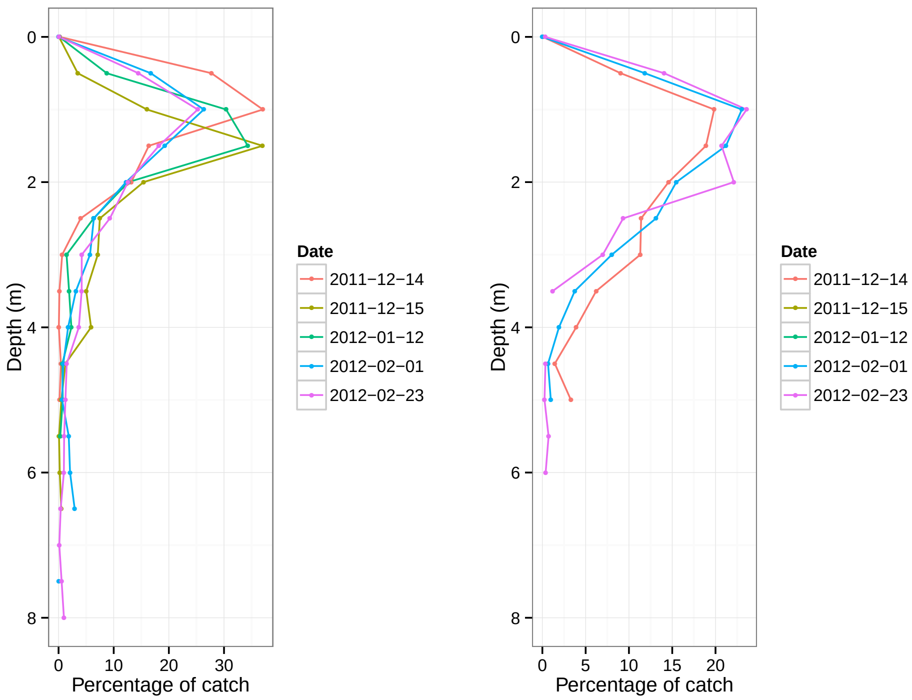
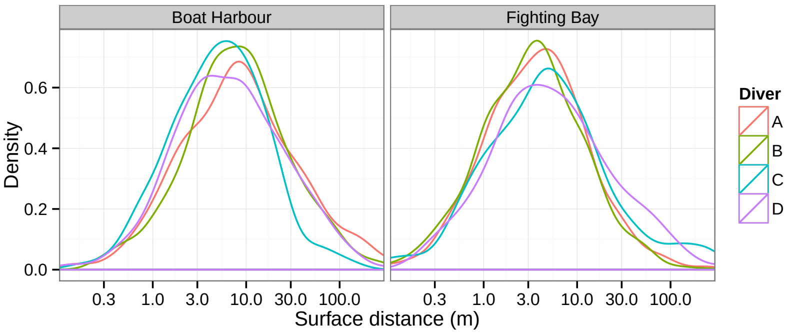


Figure 9: Relative distribution of catch with depth. The density is calculated in 0.5 m depth bins, on each day of the experiment, at the two sites. The depths are raw depths, and have not been corrected for tidal height.

3.5 Swimming distance

Swimming distances were derived from the distance between pairs of points, and so were sensitive to errors in the GPS position. The distribution of swimming distances was broad and appeared approximately log-normal (Figure 10). In many cases (51.1% of underwater swims and 40.7% of surface swims), GPS fixes were not obtained for one or both ends of the swims, and either one position was missing, or the same position was inferred for both ends of the swims. These swims were excluded, by restricting the distances to be greater than 10 cm, and exceptionally long swims (200 m or more) were also excluded, as these may correspond with boat movements.. The median underwater swim distance in Fighting Bay was then 2.5 m (IQR: 1.1 to 6.3 m). This was shorter than the median underwater swimming distance at Boat Harbour of 3.7 m (IQR: 1.6 to 9.2 m). Surface swimming distances between dives were longer than underwater distances, with the median surface swimming distance in Fighting Bay being 4 m (IQR: 1.6 to 9.5 m), and in Boat Harbour being 6.8 m (IQR: 2.7 to 15.5 m). Although the pattern in the median swimming distance was as expected (further swimming on the surface, further swimming at the fished site), the large variability, and the impact of instrumental error on the calculated distance, makes swimming distance not yet useful as a potential indicator of pāua stock status.

(a) Surface swim distance



(b) Underwater swim distance

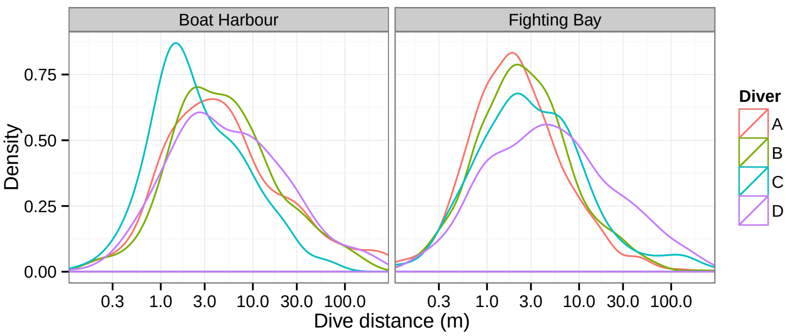


Figure 10: Density distribution of swimming distance (a) on the surface of the water, and (b) while underwater. Long distances (over 300 m) and short distances (less than 10 cm) have been excluded. The densities are calculated on a logarithmic scale.

3.6 Catch bags

The weights of the catch bags were measured as they were landed, and they were also estimated by applying the daily catch of each diver. Over the whole experiment, 390 were weighed on the vessel, and there were 386 button presses on the boat unit recording the recovery of catch bags from the divers. After reconciliation between the weighed bags and the bags recorded on the boat unit, there were 12 button presses that could not be matched with a weighed bag.

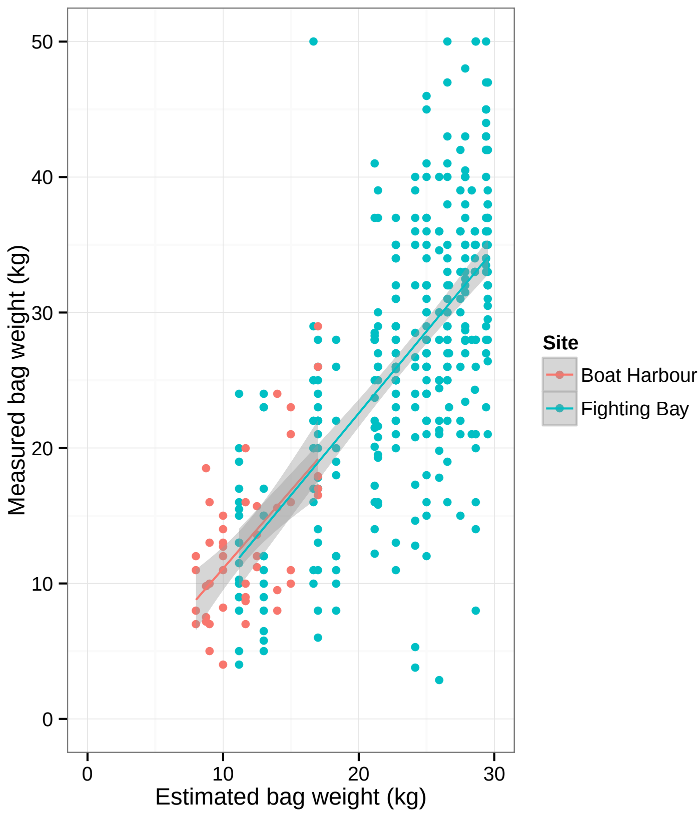


Figure 11: Relationship of the measured weight of each catch bag, on the estimated weight. The lines are regression lines fitted to the data from each site, with the shading indicating the standard error of the mean value.

Weights measured on the vessel were higher than weights estimated for each bag from the daily greenweight (Figure 11). There are several possible reasons for this: poor taring of the scales used for weighing the bags due to accumulation of water in the container used for holding the bags on the scales; cleaning of shells during packing; loss of water from the harvested catch during the day; and difficulties in weighing the bags on a moving vessel due to the scales not stabilising. There were 5 bags that reached the scales' limit of 50 kg. The weight of these bags was recorded as 50 kg. The measured weights were calibrated against the estimated weights using a linear regression: if w_m is the measured weight and w_e is the estimated weight, the regression equation was $w_m \sim (-1.17 \pm 1.41) + (1.19 \pm 0.06) w_e$. The offset was not significantly different from zero, but the measured weights were around 20% higher than the estimated weights. The calibrated weight of each bag was then $w_c = (w_m + 1.17)/1.19$.

The measured weights give an indication of the uncertainty caused by applying the daily catch across all the bags (rather than estimating the weight of each bag). The standard deviation of the ratio between the calibrated weight and the estimated weight of each bag is 0.3, with the ratio having a 95% confidence interval of 0.44 to 1.57. Although the estimated weights were calculated by applying the daily catch across all bags recorded by a diver on same day and site, there was a relatively small variation in the estimated catch when compared to the measured catch, with most (81.3%) estimated bag weights being within 2/3 and 3/2 of the calibrated measured weights.

There was a decrease in bag weights as the fishdown progressed (Figure 12). On the first day in Fighting Bay, the mean calibrated catch per bag was 31 kg, by the last day it had decreased to 13.7 kg. In contrast, at the fished site the mean calibrated catch per bag varied between 10.9 and 14.1 kg. When the pāua

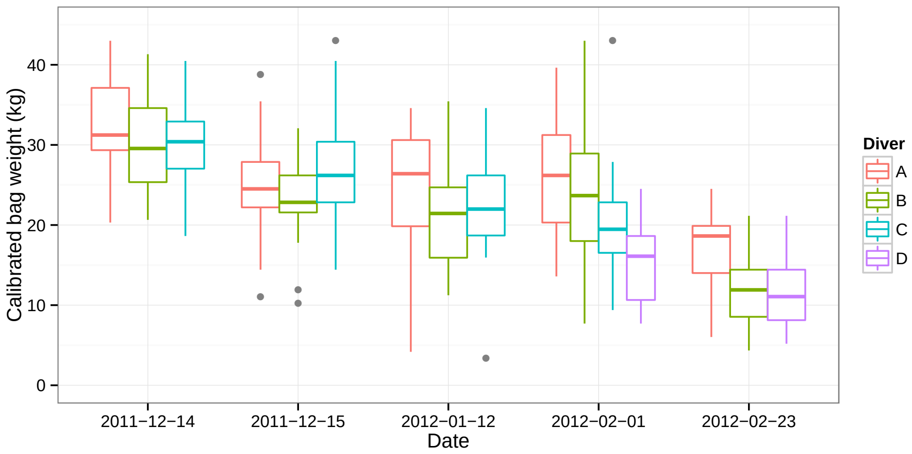


Figure 12: Boxplots showing variation in calibrated bag weights by date and by diver, for fishing in Fighting Bay. The boxplots indicate the median, interquartile range, and range of the data.

density was high, bags were filled in the time taken for the boat to return to the main vessel and empty the catch. Divers filled their bags to capacity. At lower densities, there was time to swap bags with the boat boy, and the bags were not filled completely.

From the estimated bag weights, a catch per dive was calculated. Because of the problems with the turtle units, dives could not be assigned to 78 bags (20.2% of all bags). Of the bags that could have dives allocated to them, the mean number of dives per bag was 22.3 (with an interquartile range of 11 to 30). The average underwater time per bag increased from 2.6 min on the first day of fishing at Fighting Bay to 7.2 min on the final day. At Boat Harbour the mean daily underwater time per bag varied between 7.2 and 8.5 min.

3.7 Spatial distribution of catch

The catch in Fighting Bay was concentrated in a small area (Figure 13). Because of missing dive data from the turtle units, only 64% and 87% of the catch was spatially located at Fighting Bay and Boat Harbour, respectively. Despite these missing data, the maximum harvest per unit area at Fighting Bay was 221 kg from only 0.01 ha (100 m^2). The harvest was spatially concentrated: although the dives recorded by the GPS covered an area of 3 ha, 50% of the catch came from an area of only 0.23 ha, and 80% of the catch came from an area of 0.6 ha. In absolute terms, the harvest from 1 ha of the areas with the highest catches was 4635 kg. Because of the missing catch, the actual harvest from this area would have been higher.

In contrast, at the fished site at Boat Harbour, the maximum harvest per 0.01 ha was only 11 kg. The relative concentration of the catch was not too dissimilar from Fighting Bay, with 50% of the catch coming from an area of only 0.53 ha, and 80% of the catch from an area of 1.5 ha. In absolute terms, however, the harvest from the 1 ha with the highest catches was 327 kg, 7% of the catch from the same area at Fighting Bay (although the effort in these areas was very different).

These statistics will be affected both by the missing data, and by scatter in the GPS positions. The scatter will tend to increase the area that has apparently been fished, and will cause a larger number of apparent cells with small harvests. This will make the harvest appear to be more relatively concentrated than it may actually be. There are also problems comparing total catches from Boat Harbour and Fighting Bay

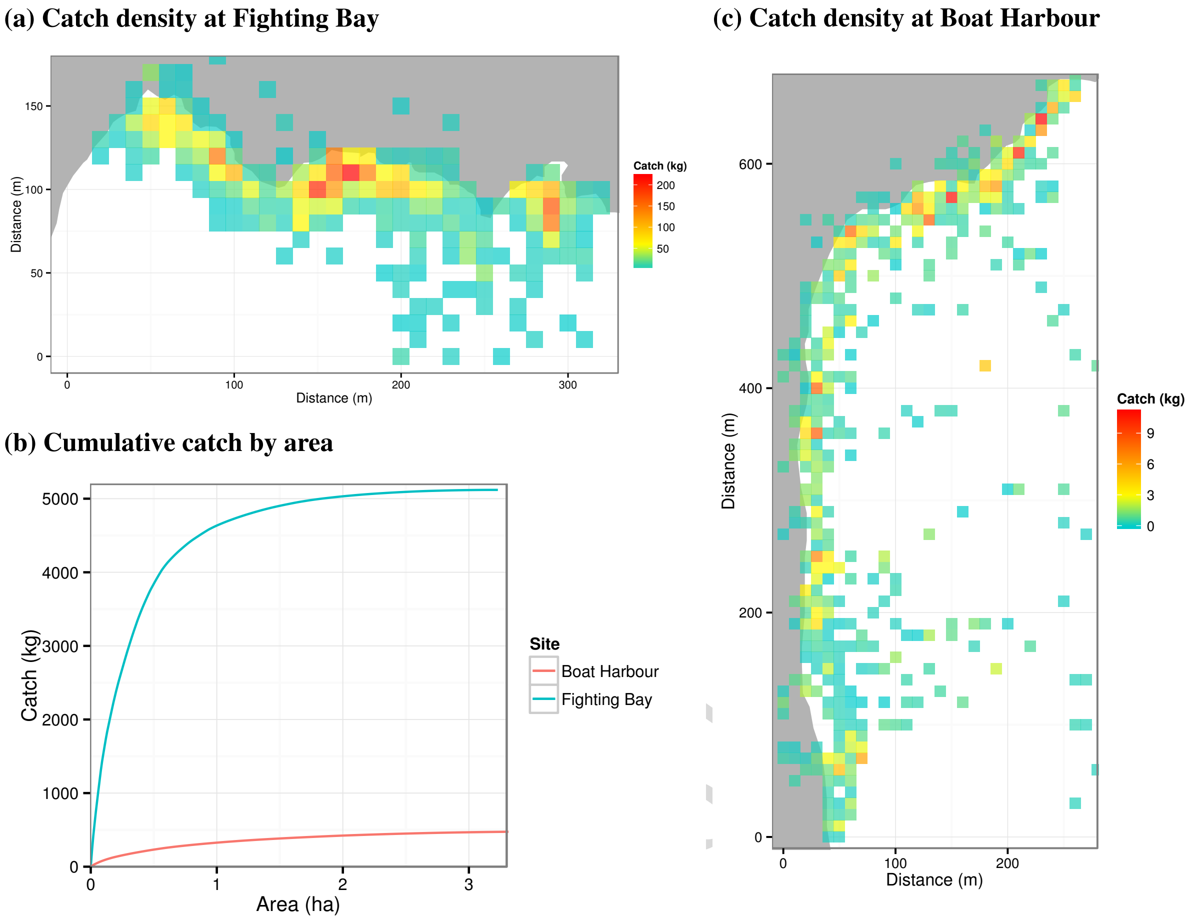


Figure 13: Total harvest per unit area, from recorded dives. In (a) and (c) the harvest is shown in 10 m $\times$ 10 m areas (each 0.01 ha) for Fighting Bay and Boat Harbour. In (a) cells with less than 2 kg harvest are not shown. At Fighting Bay and Boat Harbour respectively, 64% and 87% of the catch was spatially located. The cumulative catch per area is shown in (b).

due to the very different fishing effort at the two sites. There would have been growth during the season, and Boat Harbour may have been fished by other people during the experiment.

3.8 Shell length

There were a total of 1122 shells measured from 20 samples in Fighting Bay. The largest measured shell from Fighting Bay had a basal length of 179 mm (although a shell with a total length of 199 mm was recorded during the survey). Over all measurements, the median length was 142 (95% c.i.: 126 to 165) mm. There was a decrease in the shell length over the course of the experiment. On the first day the median length was 146 (95% c.i.: 130 to 167) mm, but by the final day the median length had reduced to 133 (95% c.i.: 124 to 162) mm. There were marked changes in the proportion of both large and small shells (Table 4). Over the course of the experiment, the proportion of shells larger than 140 mm decreased from around three-quarters to around one-quarter. The harvesting was size-selective: at the beginning of the experiment divers selected pāua that they didn't need to measure. On the first day only 2.7% of the shells had a basal length less than 130 mm. As the experiment progressed the divers were more thorough, there were fewer larger pāua available, and the proportion of shells less than 130 mm increased tenfold to 28.8%.

Table 4: Proportion (%) of measured shells on each date that are in each length category, for shells from Fighting Bay.

Basal length	Date				
	2011-12-14	2011-11-15	2012-01-12	2012-02-01	2012-02-23
Less than 130 mm	2.7	0.5	5.6	11.0	28.8
Greater than 140 mm	72.7	76.1	57.2	48.6	24.8

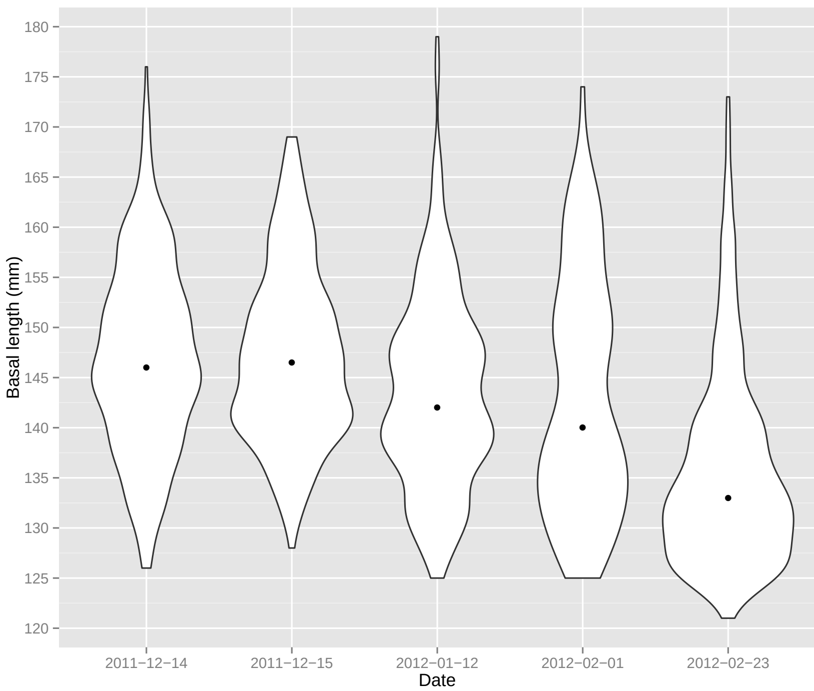


Figure 14: Change in shell length as the fishdown progressed. The plots shows the frequency distribution of basal shell length on each day of the fishdown, for pāua harvested from Fighting Bay. The dots mark the median shell length from all samples on each day.

3.9 Catch per unit effort

Two measures of effort were considered: a fishing time, that was derived for each diver by adding up the half-hour blocks during which either a bag was landed or a dive event was recorded; and an underwater time, that was derived from the logger data from the time spent underwater. The total fishing time in Fighting Bay for each diver was consistent between days. For 15 of the 16 diver days, the total fishing time was in the range 5 to 6.5 h. For the remaining diver day (diver B on the first day) the fishing time was 4 h. These times are less than the fishing times recorded on the PCELR forms (see Table 2). In total, there were 153.5 h fishing recorded on PCELR forms from Fighting Bay, whereas summing the half-hour blocks with fishing events for each diver gave a total of 91.5 h.

The median proportion of the time fishing that divers spent underwater was 29.5 (IQR: 23.8 to 31.9) % (Figure 15). There were consistent differences between the divers. The oldest diver was diver C, and they were always the diver that spent the least of the fishing time underwater. Diver D was the youngest diver, and was recreational spear fisher. They recorded the highest percentage of time underwater. The proportion of time underwater varied from day to day, but was typically similar for divers at Boat Harbour

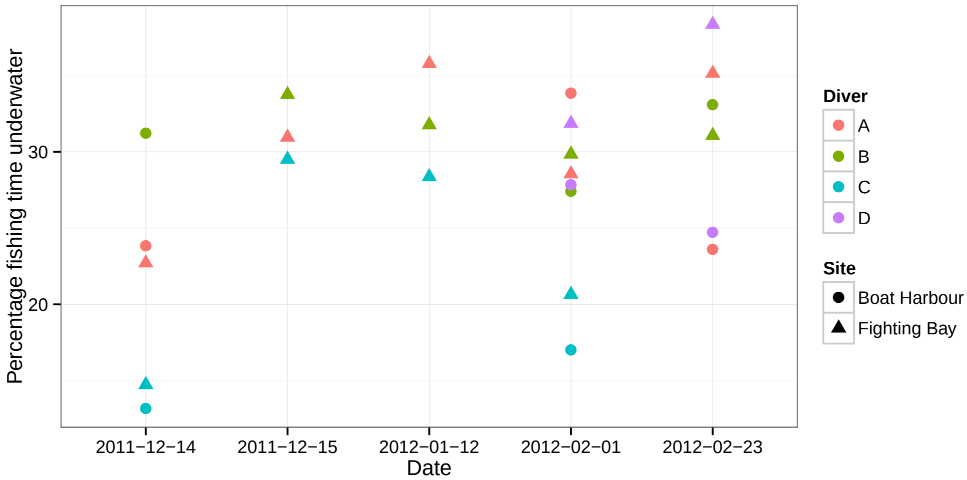


Figure 15: Ratio of time spent underwater to time spent fishing, for each diver over the course of the experiment.

Table 5: Mean daily CPUE (kg h^{-1}), calculated using the two different methods. Fishing effort is measured by (a) time underwater, and (b) total fishing time from half-hour periods that include bag records.

(a) Time underwater

	Boat Harbour	Fighting Bay
2011-12-14	77.0	703.1
2011-12-15		403.4
2012-01-12		282.5
2012-02-01	93.4	205.3
2012-02-23	107.7	116.0

(b) Fishing time from bag records

	Boat Harbour	Fighting Bay
2011-12-14	23.6	161.7
2011-12-15		136.1
2012-01-12		106.7
2012-02-01	26.2	65.8
2012-02-23	32.3	47.7

and at Fighting Bay on the same day. This ratio appeared to be primarily determined by diver behaviour and possibly by sea conditions (which were similar between Boat Harbour and Fighting Bay on the same day).

For both measures of effort, there was an apparent linear relationship between cumulative catch and CPUE for fishing in Fighting Bay Figure 16. The linear relationship supports the use of the depletion method. Moreover, the catchability of the different divers appears similar, as the data from each diver lie close to the same line. There was a significant reduction in the CPUE over the course of the experiment, allowing the relationship between CPUE and abundance to be explored over a wide range.

Although both measures gave a linear relationship, the relative decrease was different (Table 5). Using the time underwater as the effort measure, the CPUE on the final day was 16.5% of the starting value. On the other hand, using fishing time as the effort measure the CPUE on the final day was 29.5% of the starting value. Much of this difference is due to the increase in the amount of time spent underwater after the initial day (Figure 15), which leads to relatively high CPUE on the first day when CPUE is measured using time underwater (Figure 16).

Using time underwater as the effort measure, the CPUE on the final day appeared similar between Boat Harbour and Fighting Bay (Figure 16, Table 5). Using total time as a measure, the CPUE at Boat Harbour was less than the CPUE at Fighting Bay. Using the different measures of CPUE, different conclusions would be reached about the relative status of the two populations on the final day.

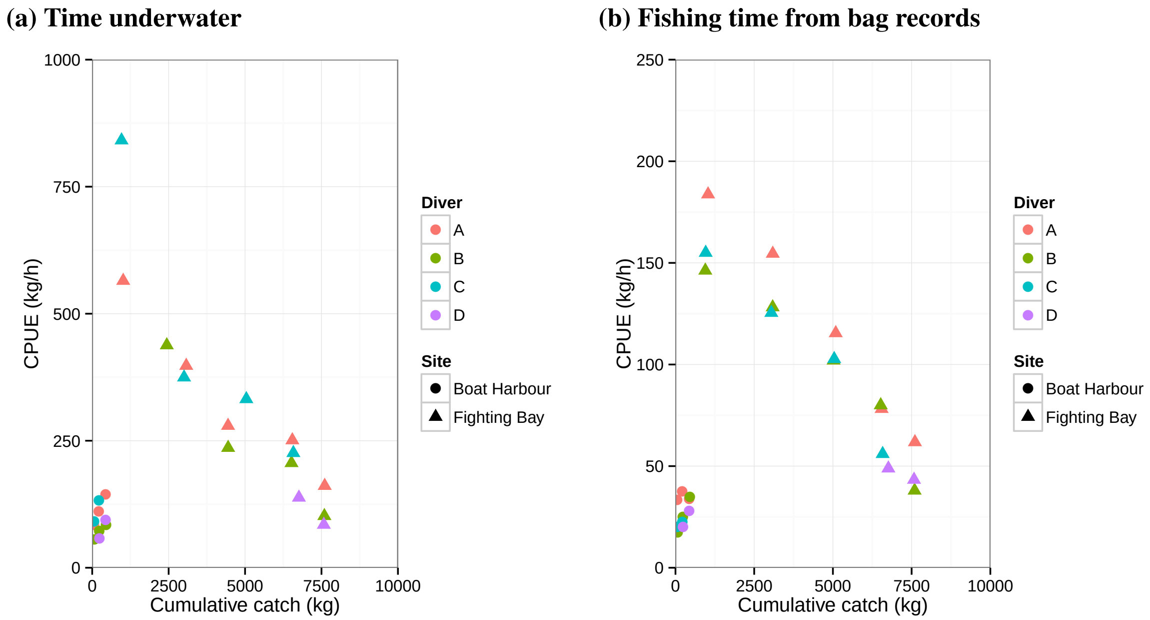


Figure 16: Relationship between cumulative catch and daily CPUE, with effort measured by (a) time underwater from turtle unit data (b) fishing time from bag records. Data from Boat Harbour are shown with circles.

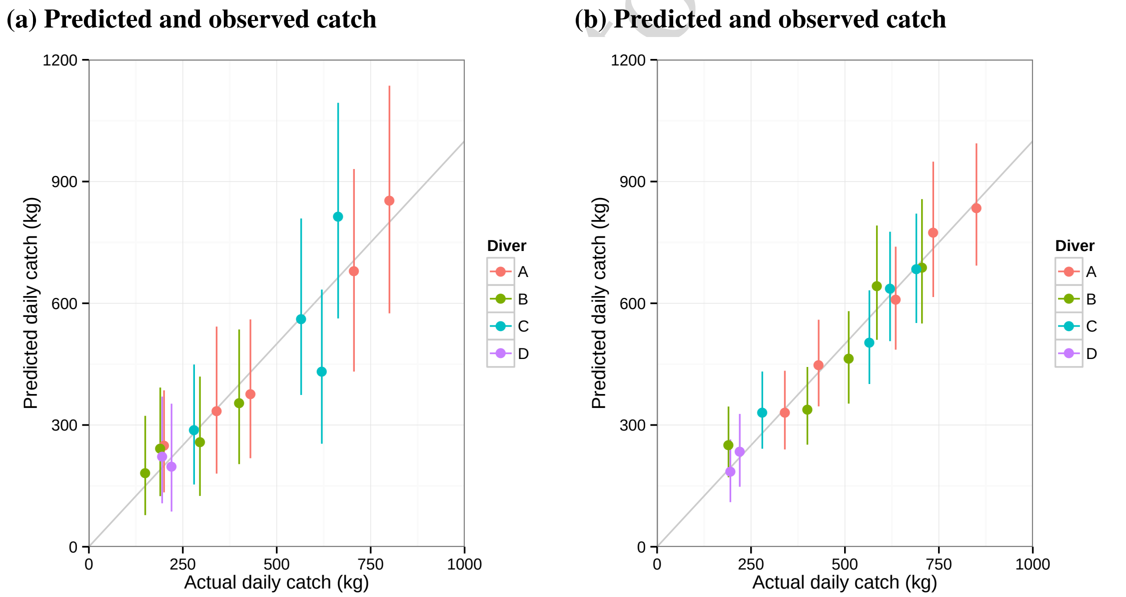


Figure 17: Comparison between actual daily catches, and catches predicted from the fitted depletion model, with effort measured by (a) time underwater from turtle unit data (b) fishing time from bag records.

The depletion model was successfully fitted to the data for both effort measures (Figure 17). There was no evidence of deviation from the linear model. The c.v. of the ratio between the actual catches and the mean predicted catch was 0.17 with effort derived from time underwater, and was 0.10 with effort derived from total fishing time.

A summary of the fitted model parameters is given in Table 6. Both models estimated that the total abundance of pāua in the area selected for the fishdown was around 10 to 11 t. At the end of the experiment, there was estimated to have been around 3 t of harvestable pāua left within the fishdown area. As expected from Figure 16 the catchabilities of the divers were similar. When effort was measured by time underwater, diver C had the highest catchability, but when effort was measured by total fishing time, diver A had the highest catchability. In both cases, the youngest and least experienced diver, diver D, had the lowest catchability.

Table 6: Summary of parameters derived from fitting the depletion model, with effort derived from time underwater

(a) Effort from time underwater

		Mean	2.5%	Median	97.5%
Initial biomass (kg)	N_0	10 355	9 248	10 216	12 186
Catchability (h^{-1})	d_A	0.059	0.042	0.059	0.076
	d_B	0.050	0.031	0.049	0.070
	d_C	0.063	0.046	0.063	0.081
	d_D	0.037	0.019	0.036	0.062
Rate	θ	0.079	0.029	0.075	0.151

(b) Effort from total time fishing

		Mean	2.5%	Median	97.5%
Initial biomass (kg)	N_0	10 598	9 895	10 558	11 547
Catchability (h^{-1})	d_A	0.020	0.017	0.020	0.024
	d_B	0.017	0.014	0.017	0.019
	d_C	0.017	0.014	0.017	0.019
	d_D	0.014	0.010	0.014	0.019
Rate	θ	0.212	0.079	0.200	0.405

4. DISCUSSION

4.1 Measures of CPUE

The fishdown experiment was successfully completed, and a linear relationship between CPUE and abundance was demonstrated over a wide range of abundance. While simple in principle, depletion experiments can be difficult to achieve, because of growth of the stock, movement in and out of the region, and because of harvesting the population either too quickly or too slowly. The pāua population within the fishdown area had not been harvested for over 15 years, and by the end of the experiment the CPUE was close to levels at the fished control site, a reduction to around one quarter of the initial value, depending on the CPUE metric used.

Two measures of CPUE were tested, both based on duration of fishing. One measure was derived from the time the fishers spent underwater, and the other was a simple measure of activity, derived solely from the boat logger data. While both measures were correlated, and showed a linear relationship with CPUE, the simple measure gave the tightest relationship between cumulative catch and CPUE. This measure of effort was calculated for each diver by adding up the half-hour blocks during which a button-press was recorded by the boat unit, indicating that they had filled a catch bag.

The different measures gave different apparent reductions in the CPUE between the first and the last day. When fitted with the depletion model however, which is able to account for the different catchability of different divers, both measures gave similar mean estimates of the total abundance within the fishdown area (mean estimates of 10.4 to 10.6 t). The estimate using the total fishing time had smaller confidence intervals. The recorded harvested greenweight was 8 t, and there was estimated to be around 3 (95% c.i. 2.3 to 3.9) t of harvestable pāua remaining in the fishdown area at the end of the experiment (with the estimate using the fishing time measure of CPUE).

The simple measure of CPUE had the advantage that it could be calculated from the boat unit alone. Two of the turtle units had problems during the experiment, one with the saltwater switch, and another with the GPS receiver. A boat unit based measure of effort allows the CPUE to be calculated without the turtle unit data. More sophisticated measures of fishing activity could be constructed. The division into half-hour blocks was arbitrary: it was suitable for the fishing patterns of the fishers' used for the experiment, but might need refinement before being applied more widely.

4.2 Spatial distribution of catch

Although there were some problems with the turtle units, the dive data gave a detailed map of the catch at a 10 m scale. This resolution is unprecedented. The map of the fishdown area demonstrates the concentration of the fishery, with 4635 kg coming from the hectare with the highest catches. Because not all the dive data were located, this was an underestimate of the catch in this hectare.

It was only possible to map the fishing at such fine scales because of the intensity of fishing during the experiment, but this map illustrates the potential of the pāua loggers for understanding the distribution of the pāua catch. Similarly the pāua loggers give a highly resolved measure of the distribution of the pāua with depth.

Spatial shift of fishing effort was not possible within a fishdown experiment, but the high resolution map demonstrates that shifts in the fishing areas could readily be tracked through time. With variation in pāua abundance over 10 m scales, very small spatial shifts in fishing effort may signal localised depletion. Similarly, although there was no movement to deeper water over the course of the experiment, the logger data would allow a shift of this kind to be detected.

4.3 Other indicators and future work

In order to use the loggers for management of the pāua fishery, broader indicators of stock status are sought (e.g., Mundy 2012, Mayfield et al. 2012). In this experiment, the focus was on deriving CPUE measures from the data, and the current level of analysis of the data is relatively simple, with effort data being derived from time spent fishing. As the logger technology develops, more sophisticated descriptions of the diver behaviour may be derivable from the data, and these may allow for other measures to be derived that reflect changes in stock status. A clear reduction is shell length was seen in the fishdown, as the divers preferentially harvested pāua that were well above the size limit first. Shell length-frequency distribution is one of a suite of measures used for assessing abalone stocks in South Australia, and the New Zealand pāua industry routinely carry out shell sampling. It may be possible to use length-frequency as an indicator for New Zealand pāua status.

An example of an indicator that is derivable from the logger data is the movement of the divers. In low density areas, divers are expected to move more rapidly from area to area, and in high density areas they are expected to remain fishing in one place. These patterns were seen qualitatively in the fishdown data, with the divers initially taking two days to move through the fishdown area, compared with two passes through the area on a single day at the end of the experiment. There was also a marked contrast with the Boat Harbour site, where they swam rapidly over the reef. These patterns are not captured in the time based measure of effort. Spatial analysis is inherently hierarchical, and an analysis in terms of swim distance during individual dives was not successful. Developing metrics that capture diver movement at an appropriate scale is a priority for future work.

5. ACKNOWLEDGMENTS

We are extremely grateful to the many passionate people who have helped with this work. Firstly, special thanks to Dave and Jason Baker and the fishers who carried out the harvest (Craig Perano, Barry Chandler, and Geoff Laing), and the other crew, for being so keen on improving the knowledge and understanding of the fishery. They were a pleasure to work with. The initial survey was organised by Nigel Keeley and Ellie Watts from Cawthron, and we appreciate their willingness to help at short notice. Thanks are due to Transpower, Seaworks, and the crew of the SeaPatroller, for access to Fighting Bay, which is only the special place it is through their careful stewardship. The pāua logger project has depended on the innovation of John Radford from Zebratech, and the preparation of this report depended on a number of people at Dragonfly who helped with the data processing, principally Marc Hasenbank and Finlay Thompson, whose willingness to wrestle data into shape is much appreciated.

Thanks also to the Ministry of Primary Industries staff (especially Julie Hills, Martin Cryer, and Allen Frazer) who supported the project through the delicate initial stages and are always looking ahead to the next steps. We also appreciate the continued encouragement from the Australian abalone researchers (especially Craig Mundy and Malcolm Haddon) who inspire with the progressive management of their fisheries.

Above all however, we wish to acknowledge the steady persistence of Jeremy Cooper and Storm Stanley of the Paua Industry Council, who have pursued the pāua logger programme since the beginning, and who have been supportive of this work throughout.

The research was funded by Ministry of Primary Industries project PAU2010-03, with co-funding from Seafood Innovations Limited.

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