Biomass assessment of Geoduc *Panopea zelandica* from northern Golden Bay in Fishing Management Area 7

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Contents

1. Introduction

Panopea zelandica (*Hohehohe*) are known commonly as geoduc[k] a word derived from the Salish Indian word for the *Panopea* genus which means “dig deep”. They are also known in New Zealand as deepwater clams or king clams, and are being marketed overseas as golden geoduc. This species inhabits shallow (0-25 m) subtidal sandy and muddy habitats throughout New Zealand where they remain submerged for the entirety of their adult life and filter feed through a pair of elongated siphons (Breen et al. 1991). Geoduc are harvested by divers using underwater breathing apparatus and a hydraulic jet or “stinger” to liquefy the sand around the geoduc to allow extraction with minimal damage. Currently the geoduc fishery in NZ is small, with less than 6 t harvested in the last few years (Table 1).

PZL Harvesters Ltd., the only company that is currently fishing for geoduc, suggest that, in order for the fishery to gain momentum and be economically sustainable within Fishing Management Area 7, at least 100 t of catch per annum is required. Expanding to other Fishing Management Areas of NZ could further expand the industry to over 2000 t per annum with a potential export value in excess of NZ$60m.

To facilitate this growth, PZL Harvesters Ltd. obtained a New Purpose Special Permit from the Ministry for Primary Industries (MPI) in 2014, which allows quota holders to “to take fish from stocks in excess of their annual catch entitlement without paying deemed values, in conjunction with a research programme that is likely to provide sufficient information to establish a total allowable catch (TAC) in accordance with statutory requirements.”

As part of this Special Permit, with funding from PZL Harvesters Ltd. and Seafood Innovations Ltd., and with consultation with the Shellfish Working Group (SFWG) of MPI, we developed a novel survey technique based on modified fishing procedures (as explained below) to allow precise control of fishing effort, and enabling estimation of biomass per unit area. This was designed so that MPI can use these data to consider changes to the TAC for PZL7. Our methodology was approved by the Shellfish Working Group of the Ministry for Primary Industries in a meeting held on February 11 2014.

Table 1. TACCs and reported landings (t) of deepwater clam by FMA from 1989-90 to present, taken from CELR and CLR data. There have never been any reported landings in PZL 2, 4, 5, 8, or 9. (Source: Ministry for Primary Industries, 2017).

	PZL1		**PZL3**		**PZL 7**		**Total**	
Fishstock	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1989-90	0.315	-	0	-	95.232	-	95.547	-
1990-91	0	-	0	-	29.293	-	29.293	-
1991-92	0	-	0.725	-	31.394	-	32.119	-
1992-93	0	-	0.053	-	0	-	0.053	-
1993-94	0	-	0	-	0	-	0	-
1994-95	0	-	0	-	0	-	0	-
1995-96	0	-	0	-	0	-	0	-
1996-97	0	-	0	-	0	-	0	-
1997-98	0	-	0	-	0	-	0	-
1998-99	0	-	0	-	0	-	0	-
1999-00	0	-	0	-	0	-	0	-
2000-01	0	-	0.146	-	0	-	0.146	-
2001-02	0.003	-	0.068	-	0	-	0.071	-
2002-03	0	-	0.001	-	0	-	0.001	-
2003-04	0	-	0	-	1.444	-	1.444	-
2004-05	0	-	0	-	2.944	-	2.944	-
2005-06	0	-	0	-	0	-	0	-
2006-07	0	1.2	0	1.2	0	23.1	0	31.5
2007-08	0	1.2	0.132	1.2	0.320	23.1	0.450	31.5
2008-09	0	1.2	0.016	1.2	5.100	23.1	5.116	31.5
2009-10	0	1.2	0	1.2	4.578	23.1	4.578	31.5
2010-11	0	1.2	0.076	1.2	7.880	23.1	7.956	31.5
2011-12	0	1.2	0.036	1.2	10.849	23.1	10.885	31.5
2012-13	0	1.2	0	1.2	1.746	23.1	1.746	31.5
2013-14	0	1.2	0	1.2	6.072	23.1	6.072	31.5
2014-15	0	1.2	0.03	1.2	3.927	23.1	3.93	31.5
2015-16	0	1.2	0	1.2	4.686	23.1	4.686	31.5

2. Methods

2.1 Study Site

This study was conducted in the northern part of Golden Bay, inside Fisheries Management Area PZL7. The delineation of this area was determined in consultation with PZL Harvesters Ltd. and broadly based on historical fishing effort and anecdotal information on the distribution of geoduc in Golden Bay. As no formal surveys have been carried out in these areas, the outer boundaries of the beds were not known, although preliminary surveys in the northern (Collingwood) indicate that high density of geoduc extends far beyond the traditionally fished beds. The survey area extended from MLWS to the 10m contour and consisted of 21,554,077m^2.

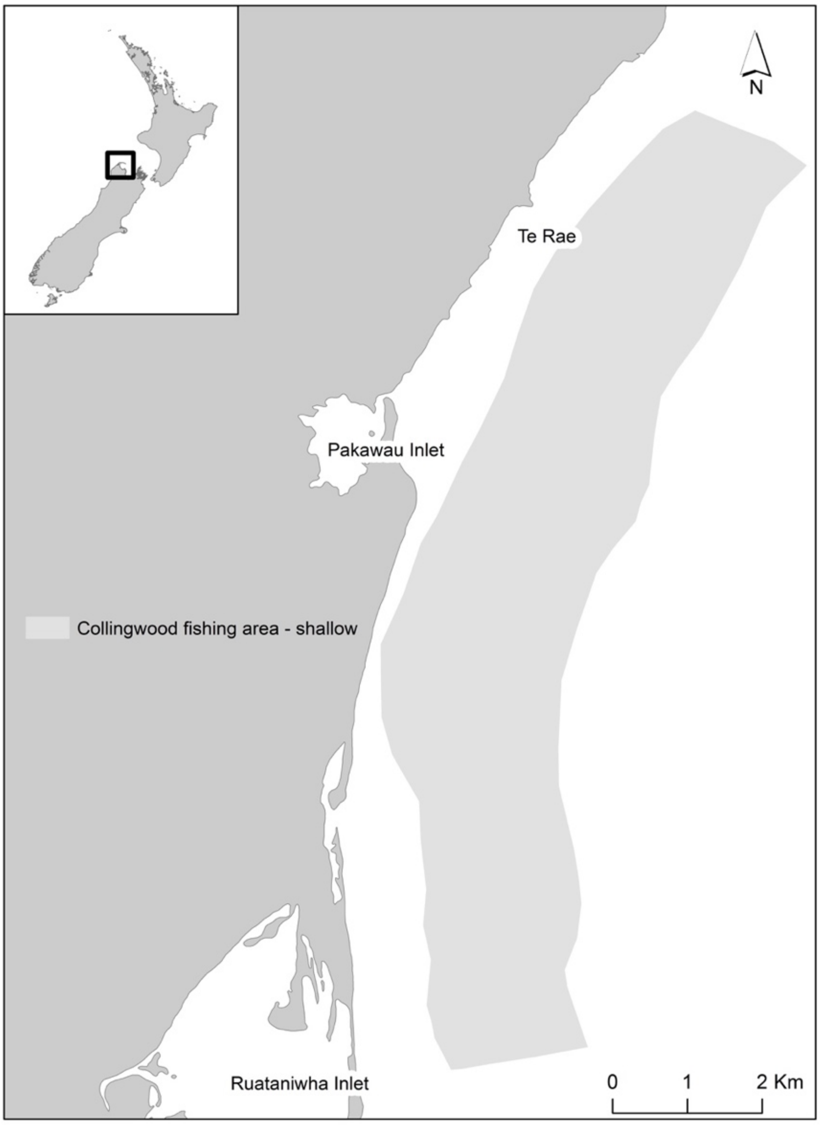

Figure 1. Map of Collingwood study area (delineated in light grey)

2.2 Survey technique using modified fishing proceudres

Under normal fishing procedures the fisher has 100m of hose that is played out over the back of the boat. The fisher enters the water and runs out from the boat to the length of the hose and fishes back along the hose towards the boat. Each geoduc foind (by locating its siphon hole, is fished by placing one hand on the siphon hole, while applying the water jet (stinger) next to the animal, liquefying the sand and allowing the fisher to extract the animal and place it in a catch bag. When a geoduc is extracted the stinger creates a plume of sediment that make it impossible to locate adjacent animals, so the fisher must then move out of the plume to find the next geduc. When the bag is full, the fisher follows the hose back to the boat and connects the full bag to a weighted line, collects an empty bag from the line and proceeds with more fishing.

We modified this fishing procedure to allow quantification of the fishing effort. Transects were delineated by running out the water hose (80m) and worked back along the hose (towards the boat) for 50m, with the skipper monitoring the diver's progress for safety. Where detectable water current was present the direction of the particular transect line was approximately into the direction of the current to facilitate sediment clearance from the line of travel along the transect. Surveying was abandoned when a) the sea became too rough to carry out surveys, b) if the underwater visibility was too low to fish or c) for the safety of boat or crew. Transects were also abandoned if the hose moved during the fishing due to being dragged by the boat.

2.3 Sampling equipment

The vessel to used in this work was the Takapu (Registration No. 901062). The *Takapu* is 12.5m in length, 4.3m in width and 15 tonnes powered by a Caterpillar 3208 V8 diesel engine. The latitude and longitude of each waypoint were fixed by a Simrad CP44 GPS plotter with the depth of each site confirmed by a Navman depth sounder. The recorded depths were transformed to chart datum depth utilising New Zealand Hydrographic Authority Tide Predictions (LINZ, 2014; LINZ, 2015.)

A 13hp Honda petrol motor runs the compressor supplying the diver with surface supplied air through a modified pony bottle (with enough air for approximately 20 minutes of bottom time in the case of equipment malfunction) and standard dive regulator, the water pump for the "stinger" and the alternator. 80PSI of water pressure is given at the diver's end of the stinger.

2.4 Study Design

50 locations were randomly chosen from the northern (Collingwood) fishing area using a transformation of random points into a polygon and back into GPS co-ordinates. At each location, two transects, each 50m long and 1m wide, were fished, making for a total of $100m^2$ searched per site. Every geoduc landed in these transects was measured (maximum anterior-posterior length) to the nearest mm with vernier calipers (sensu Gribben and Creese 2005). The total weight of all geoduc collected from each transect was weighed at the licensed fish receiver (LFR) in Tarakohe.

Up to the five individual geoduc were collected from the bottom of the catch bag, ie the first five to be fished, these animals were labelled and kept for aging by examining the growth rings in the shells as in previous studies (Breen, 1991; Gribben and Creese, 2005). After drying the shells, we cut a section through the umbo and mounted it onto a glass slide using heated glue and allowed them to dry. The sections were then ground and polished and viewed and photographed with a compound microscope. All of the images were printed and annual growth rings counted by two independent observers.

We were fortunate to have 4 shell samples of individuals that had been cultured at the Cawthron Institute and were known to be four years old (supplied by Le Viet Dung of Cawthron Institute and AUT.) We analysed these as above to validate that we were in fact finding the year one ring and that the rings we were counting were indeed annual ones.

2.5 Survey efficiency

There are at least three factors that could impact on the efficiency of the surveys conducted by the modified fishing method as outlined above:

1. As the diver walked the hose out over the area to be surveyed, the geoduc may be disturbed and withdraw into their hole to a point that they will not be detected.
2. As the diver fishes the geoduc, a cloud of sediment is formed that can (depending on the current flow) occlude the transect in front of the diver, so any fish under this cloud may have been obscured and therefore, not picked up.
3. It is well established that many geoduc are cryptic at any given point, with no siphon showing for some lengths of time (Gribbens et al. 2004).

To address these potential sources of underestimation we carried out experiments to assess survey efficiency. Two sites in the Collingwood area (Pakawau) at depths of approximately 6.5 m were haphazardly chosen for the experiments. At site 1, six 50m transects were laid and at site 2 four 50m transect were laid. These transects were marked out by placing a stake into the sediment at the start of the transect playing out a line for 50m and attaching it to another stake. A float was attached to the end of the transect so it could be found again. Once all of the transects were marked out, each one was fished 50cm either side using the water jet as outlined in the survey methods above, but instead of using the water hose at the transect, the marked out lines were used instead. For the next 4 days, each transect was re-surveyed on SCUBA by two divers, searching for geoduc holes and marking each one with a labelled 15cm length of No.4 galvanised wire.

2.6 Statistical analysis

The 50 locations were randomly chosen within the study area, and hence average density and its standard error were calculated using the standard formula for iid normal samples. Density of geoduck was modelled as quasi-Poisson. This models expected density on the log scale (multiplicative effects) and also assumes standard deviation in observed density is proportional to expected density. Analyses of morphometry used nonlinear modelling, assuming lognormal errors. All analyses were performed in the R language.

3. Results

3.1 Geoduc biomass and distribution

All of the transects from the 50 sites allocated to the Collingwood area were sampled between 25/09/2014 and 29/08/2015. In total 665 individual geoduc were collected and landed in the 100 transects (Figure 2 and Table 1), totalling 311kg green weight. The average density across all transects was 0.0619 kg/m^2, with a CV of 0.205. The total parent biomass estimate from the Collingwood area was 1,337t.

s9(2)(b)(ii) Commercially sensitive information

Figure 2. Distribution of geoduc in the Collingwood area

Table 2. Summary statistics from geoduc survey

Transect	N	Aged	kg/m2
C01A			0
C01B			0
C02A	4	4	0.0270
C02B	5	5	0.0427
C03A			0
C03B	1	1	0.0101
C04A			0
C04B			0
C05A	3	3	0.0247
C05B	4	4	0.0328
C06A			0
C06B			0
C07A			0
C07B			0
C08A	2	2	0.0184
C08B	1	1	0.009
C09A	6	5	0.0543
C09B	12	5	0.0914
C10A	24	5	0.2332
C10B	25	5	0.2298
C11A	1	1	0.0092
C11B			0
C12A	5	5	0.044
C12B	2	2	0.0246
C13A			0
C13B			0
C14A	3	3	0.0256
C14B	4	4	0.036
C15A	1	1	0.0015
C15B	7	4	0.0544
C16A			0
C16B	1	1	0.0034
C17A	17	5	0.1904
C17B	11	5	0.124
C18A	5	5	0.0398
C18B	3	3	0.023
C19A	2	2	0.0174
C19B	40	5	0.3246
C20A	24	5	0.204
C20B	40	5	0.3304
C21A	5	5	0.0558
C21B	17	5	0.189
C22A	4	4	0.0331
C22B			0
C23A	2	2	0.0219
C23B	2	2	0.0134
C24A	1	1	0.0134
C24B	2	1	0.0246
C25A	5	4	0.0404
C25B	3	3	0.0266
C26A	10	4	0.0794
C26B	11	4	0.0726
C27A	6	5	0.0593
C27B	6	4	0.0669
C28A	16	5	0.195
C28B	14	5	0.158
C29A	1		0.002
C29B	1	1	0.0236
C30A	24	5	0.2356
C30B	11	4	0.1125
C31A	6	5	0.0604
C31B	4	4	0.0396
C32A	19	4	0.2164
C32B	15	5	0.1724
C33A	1	1	0.0105
C33B			0
C34A	1		0.0076
C34B			0
C35A			0
C35B			0
C36A			0
C36B	4	4	0.0484
C37A			0
C37B	2	2	0.0196
C38A	1	1	0.0072
C38B			0
C39A			0
C39B			0
C40A			0
C40B			0
C41A	29	5	0.3178
C41B	30	5	0.3414
C42A			0
C42B	1	1	0.0108
C43A	2	2	0.0215
C43B			0
C44A			0
C44B			0
C45A	11	5	0.0881
C45B	11	5	0.0983
C46A			0
C46B			0
C47A	4	3	0.0296
C47B	1	1	0.0038
C48A			0
C48B			0
C49A	42	5	0.2996
C49B	48	5	0.3895
C50A	21	5	0.2106
C50B	13	5	0.1493

Chart datum depth was the most significant predictor of density with a predicted density of approximately 0.15kg/m2 occurring at slightly shallower than 4m datum depth (Figure 3).

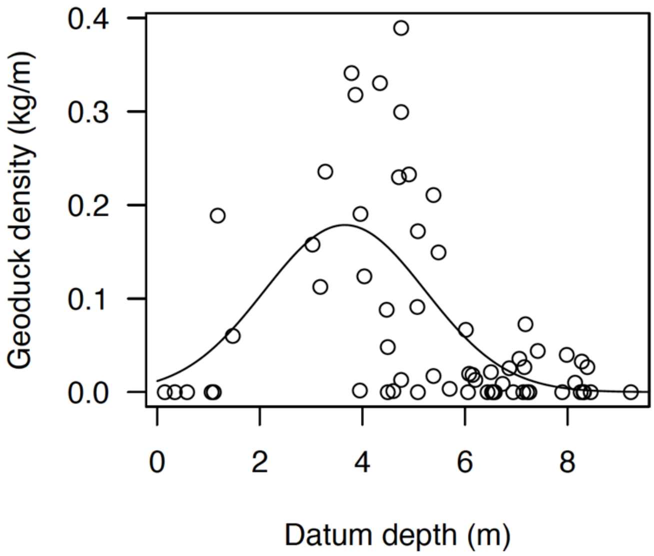

Figure 3. Relationship of *Panopea zelandica* Density (kg m^{-2}) to Datum Depth (m)

There is also a highly significant association between grain size and density (Figure 4). Grain size was expressed using the Krumbein phi, where phi = $-\log_2$(diameter). For ever unit increase in phi (i.e., grain size diameter becoming finer by a factor of 2), density is reduced by 54%. The model that includes both depth and grain size as covariates explains 51% of the variation in density.

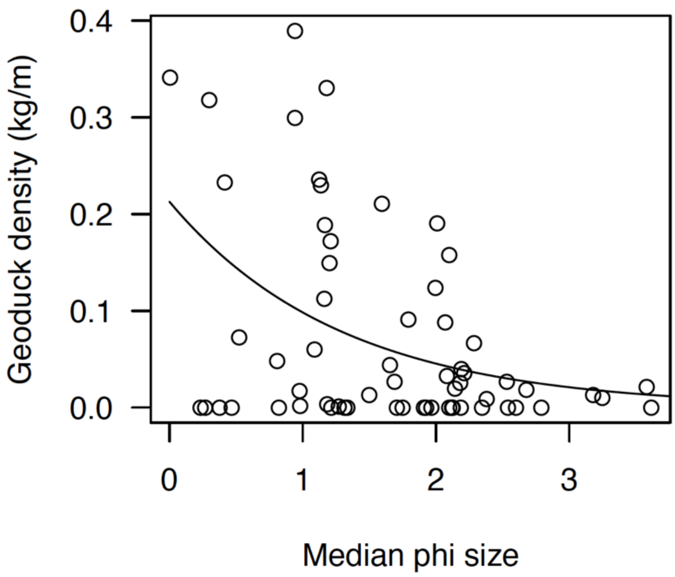

Figure 4. Relationship of *Panopea zelandica* Density (kg m^{-2}) to Median Sediment Grain Size (phi) in FMA7.

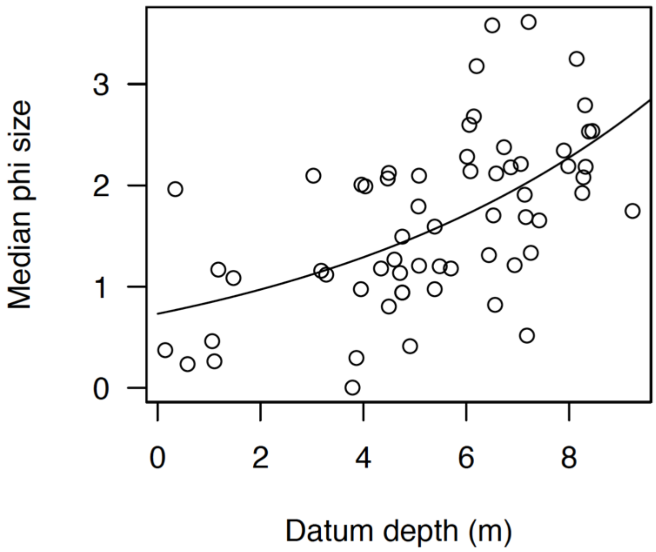

Figure 5. Relationship of Datum Depth of Sampled *Panopea zelandica* to Median Sediment Grain Size (phi) in FMA7

Phi is estimated to increase by 15.22% for every metre increase in datum depth. That is, in terms of grain size, there is a reduction in diameter of 10.01% for every metre depth increase.

3.2 Growth and Mortality

All 665 geoduc collected were measured (ranging from 69 to 153mm, with an average of 112mm) (Figure 6).

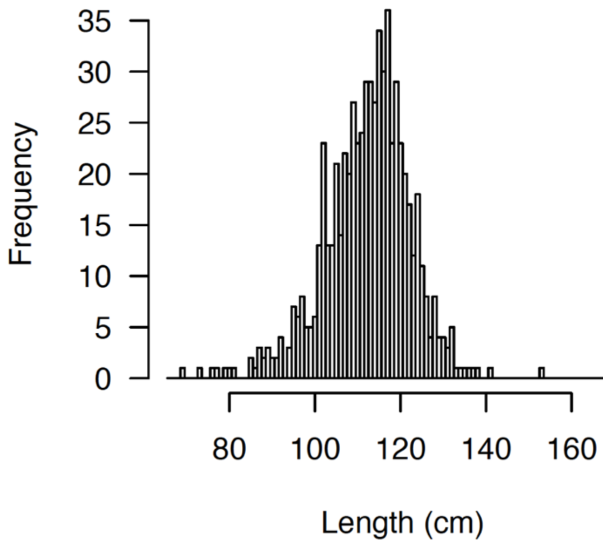

Figure 6. Frequency of Shell Length Classes (mm) of *Panopea zelandica* in FMA7.

The estimated instantaneous mortality Z (inclusive of both natural mortality and fishing mortality) is 0.209 (SE 0.047) (Millar, 2015). Estimated annual mortality is 0.189 (SE 0.042). In this analysis the first 8 age classes were removed since there is aged-based selectivity bias.

A von Bertalanffy growth curve fitted to the aged individuals estimated (Figure 7) a L_{inf} of 127.5mm (SE 4.8mm), growth rate (K-value) of 0.11 (SE 0.027) and an age-at-length-zero of -4.24 years (SE 2.15.)

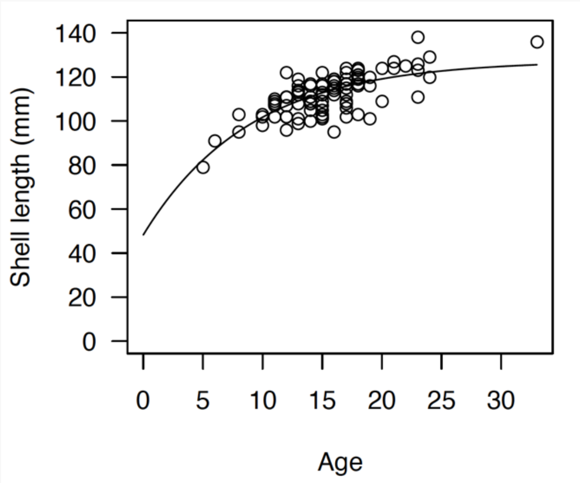

Figure 7. Von Bertalanffy Growth Model (VBGM) of Shell Length (mm) to Age (years) of *Panopea zelandica* from FMA7.

3.3 Survey efficiency

The mean efficiency of fishing on day one was just 22% (Table 3). A double bootstrap was implemented to obtain a confidence interval. This includes the between transect variability in show proportions by resampling both transects, and clams within transects. The 95% bootstrap confidence interval was 15.9 to 30.8%. There was no statistically significant relationship ($p = 0.3$) between the density of geoduc per square metre and the efficiency (Figure 8).

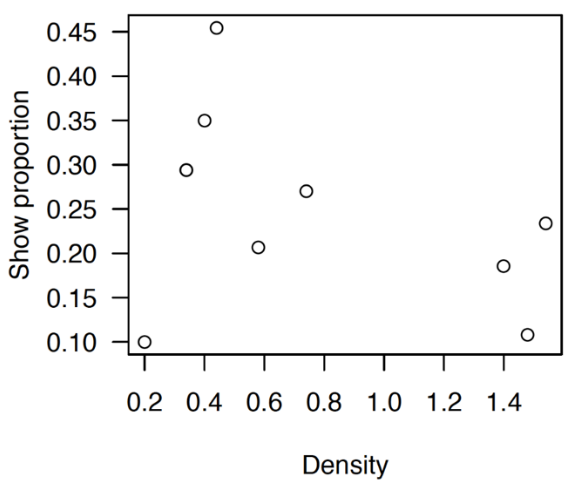

Figure 8. Relationship of Show Proportion to Density (kg m^{-2}) of *Panopea zelandica* in FMA7.

Table 3. Number of geoduc found within transects over a 5 day period.

Site	Trans.	Fished	Day 2	Day 3	Day 4	Day 5	Total	% Eff.
1	1	5	4	4	1	3	17	29.41
	2	10	5	2	4	1	22	45.45
	3	5	6	3	1	2	17	29.41
	4	6	5	8	6	4	29	20.69
	5	1	4	1	2	2	10	10.00
	6	7	6	4	1	2	20	35.00
2	1	13	23	18	12	4	70	18.57
	2	8	18	25	15	8	74	10.81
	3	18	20	27	7	5	77	23.38
	4	10	15	5	4	3	37	27.03

4. Discussion

The results of this study are broadly comparable to previous work. Our maximum age (33 years) is extremely similar to the 34 years old found in Breen (1994) contrasting with the maximum of 34 years from Kennedy Bay and 85 years from Shelly Bay described in Gribben & Creese (2005.) Our instantaneous mortality (Z) of 0.209 (SE 0.047) is similar to Breen's 1991 instantaneous mortality M (0.20) and Gribben & Creese's (2005) M being lower at between 0.05 and 0.07 (Kennedy Bay) and 0.02 to 0.04 (Shelly Bay) with the key difference being that our mortality Z is instantaneous mortality determined from both natural causes and fishing. The catch-curve analyses used by Breen (1991) as well as Gribben & Creese (2005) operate under two assumptions; firstly, recruitment rates are approximately constant during the time that aged geoduc were recruited and secondly, mortality is similar for all age classes. Gribben & Creese (2005) concluded that catch-curve analyses may not be appropriate for estimating natural mortality in geoduc with Millar (2015) suggesting general linear mixed modelling (GLMM) is superior in predicting mortality due to the inclusion of recruitment involving annual variation and substantial variability known to exist in population dynamics (Myers et al, 1995.)

The size and age data have been used for comparison with the age-weight growth curve and natural mortality values used in the study of geoduck sustainability of Breen (1994). When estimating recruitment, Breen (1994) used only animals 8 years or older for recruited biomass; we also did the same when estimating mortality as there appears to be an aged-based selectivity bias. The maximum realistic exploitation rate of 0.35 was based upon Goodwin's (1977) show-factor and the disturbances created by the fishing method causing nearby individuals to retract their siphons. In comparison, the upper bound of our 95% confidence interval for show-factor was 31%.

Our growth rate (k) of 0.1123 appears to somewhat smaller than other species found in the same study; Aragon-Noriega et al (2015) suggested that this could be due to primary productivity differences, however, no enviromental data was taken that could decisively explain these differences.

We found a maximum theoretical length of 127.5mm with standard error 4.75mm. K value (growth rate) of 0.112 $year^{-1}$ annually, standard error of 0.027. T_0 of -4.23 with standard error of 2.15. Given our standard errors, our results are not dissimilar to other findings by Breen (1991) that found a maximum theoretical length of 116.5mm, K=0.16 $year^{-1}$ and t_0 of -3.80 years and 111.5mm (Kennedy Bay) and 103.6mm (Shelly Bay) from Gribben & Creese (2005.)

We also gathered data of other factors possibly relating to distribution of geoduck, namely sediment type and depth and we found that, unlike the findings of Gribben, Helson & Millar (2004), P. *zelandica* in Collingwood appear to prefer sediments with a larger diameter than those of the aforementioned study.

Our maximum observed length of 141mm is somewhat larger than the largest individual (127mm) found by Gribben & Robert (2005) as was our maximum theoretical length (Linf) (127.5mm) compared with their 111.5.mm. Our rapid increase in growth of shell length and subsequent tapering off appears to be consistent with Breen (1991) as well as Gribben & Creese (2005.)

4.1 Density

Geoduc densities in North America are calculated by the use of established methods that include counting the siphon holes through which geoduc filter feed. Problematically, not all geoduc "show" their siphon holes at the same time and thus could lead to an erroneous population estimate (Hand & Dovey, 1999).

This is solved by the use of a "show-factor" which is the number of geoduc siphons that are visible or can be felt versus the total number of individuals present in a given area and is expressed in the formula, S = n / N, where S = show factor, n = the number of visible geoduc shows within a defined area and N = the absolute number of harvestable geoduc present within the area. In Washington, "show plots" are utilised at sites to estimate the show factor and entails permanently marked subtidal areas in which N is known due to repeated tagging studies and n is obtained from divers counting all visible geoduc as if they were completing a standard survey (Campbell, Yeung, Dovey & Zhang, 2004). The number of geoduc that "show" their siphon holes is variable upon different environmental and physiological factors; with more showing during the summer months during periods of feeding and breeding (Campbell, Harbo & Hand, 1998) and when local water currents are not overly severe with no mechanical disturbances of the bottom due to events such as storm activity (Goodwin, 1977), (Campbell et al., 1996). Some of the show factors used in the major geoduc fisheries are: 0.90 in British Columbia (Campbell, Yeung, Dovey & Zhang, 2004), 0.73 in Washington (Bradbury, Sizemore, Rothaus & Ulrich, 2000) and 0.80 in SE Alaska (Rumble, Hebert & Siddon, 2012).

Gribben, Helson and Millar (2004) investigated whether the North American methodology used for determining population abundance estimates is transferrable to New Zealand's *P. zelandica*. Line transects were used in Kennedy Bay and in Wellington Harbour. Both sites were restricted to less than 17m in water depth; geoduc in Kennedy Bay were found from 4-8 metres in water depth whereas the population in Wellington occurred from 4-16 metres. Analysis of sediment samples indicates that *P. zelandica* is found in similar habitats to *P. generosa.* Experiments to determine how many geoduc are visible at a given point in time (Show/no-show factors). There was no significant difference in the show-factor with regard to season or tidal height. Thus, a mean show-factor of 0.914 was used to adjust the density estimates from both populations which gave mean densities of 0.058 geoduc/m^2 in Kennedy Bay and 0.489 geoduc/m^2 in Wellington Harbour, and coefficients of variation were generally less than 0.2. The density estimates for *P. zelandica* are much lower than those reported for *P. generosa.* The authors suggested that more research should be conducted on diver variability on counts of geoduc, the role that geoduc occurring deeper than 17m perform and the effects of fertilization success upon densities. But they also suggest that the North American methodology for estimating geoduc populations is transferrable to *Panopea zelandica*.

Gribben, Helson and Millar (2004) found densities of 0.058 geoduck/m^2 in Kennedy Bay and 0.489 geoduck/m^2 in Shelly Bay with Gribben & Creese (2005) showing mean maximum drained wet weights of 275.5g in Kennedy Bay and 223.1g in Shelly Bay. This would give 0.016kg/m^2 average density for Kennedy Bay and 0.109kg/m^2 for Shelly Bay compared with our average density of 0.0619km/m^2. and so, even accounting for water lost in draining, the Collingwood area appears to have higher density than Kennedy Bay and Shelly Bay. Despite this comparison only being loosely applicable due to slight differences in measurements. This difference in density could be explained by local environmental and productivity factors as well as Shelly Bay being a part of PZL1; a fishing management area that has seen no landings since these studies were performed whereas Collingwood, in PZL7, has seen 43.667 t in landings in between the course of the aforementioned studies and our surveying (2004-2015.)

Extrapolating this density to the Collingwood area delineated in this study of Collingwood (21,554,077m^2), yields an estimate of total parent biomass in that area of 1,334t. Even employing the very conservative upper confidence interval of 30.8% efficiency of the survey effort as a multiplier to the parent biomass in the Collingwood area, one would obtain a mean density of 0.201kg/m^2 and a parent biomass of 4331.17t. Using a 3% setting for estimating a potential TAC, this would equate to 129.9t.

5. References

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