Cawthron Report No. 1052

Paua reseeding trials in Marlborough: economic model and summary of results to date.

Prepared for

PAUMAC7

July 2005

Paua reseeding trials in Marlborough: economic model and summary of results to date

Prepared for

PAUMAC7

by

Rodney Roberts

Cawthron Institute
98 Halifax Street East
Private Bag 2
NELSON
NEW ZEALAND

Phone: +64.3.548.2319
Fax: +64.3.546.9464
Email: info@cawthron.org.nz

Cover Photo: Reseeded paua collected from a Tory Channel site and tagged to follow subsequent growth

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Report reviewed by: Approved for release by:

Kevin Heasman Henry Kaspar

SUMMARY

A 5-year project was initiated in 2003 to investigate the feasibility of reseeding black-foot paua (*Haliotis iris*) in Marlborough. This report summarises the research done, and the findings to date. It then discusses a simple spreadsheet model that evaluates the economic viability of reseeding.

The effect of seed size and seeding density on survival and growth were examined via short-term experiments on constructed boulder reefs. The most economically favourable seed size is estimated as 10 mm. This is a compromise between seed survival and cost, and the optimum is driven by the large improvement in survival of 10 mm vs 5 mm seed and diminishing gains for larger seed. Seed survival and growth tended to decrease with increasing seeding density, but there was wide variability in the data. On some reefs, initial seeding densities as high as 300 per m^2 gave good growth and survival. Seeding density will need to take into account factors such as food supply and the density of natural paua recruits.

Growth and survival to 125 mm were examined by releasing 2,600 to 20,000 seed at each of 8 “commercial” sites. Seed averaged 10 to 11 mm, and were seeded at 50 per m^2 of seafloor in September or December 2003. Five commercial sites were surveyed in May 2005 when seed were nearing the end of their under-boulder phase (47 to 60 mm average shell length). Survival to harvest size was extrapolated based on published data on growth and natural mortality.

Estimated survival to harvest ranged from 1.3 to 18.6% with an average of 10%. Two sites were affected by rock movement during storms. The average survival at the other 3 sites was 15%. Growth rates were very good, ranging from 25.2 to 34.7 mm per year.

A spreadsheet model was used to examine the economic viability of reseeding. Various values in the model can be changed to examine the effect on profit. Seed price and seed survival are key determinants of profitability. At a price of $0.32 per seed, the return on investment is 20% per year at 10% survival, and 30% per year at 15% survival.

Recommendations based on current knowledge:

Seed size:	10 mm
Seeding density:	50 seed per m^2 of good habitat annually
Seeding season:	Late spring or summer
Stress:	Minimise stress during reseeding
Competition:	Avoid areas with extremely high natural paua recruitment, or known to have poor growth rate.
Monitoring:	Measure the number of >90 mm paua in several seeded areas and several unseeded controls before and after reseeding.

1. INTRODUCTION

A 5-year project was initiated in 2003 to investigate the feasibility of reseeding as a tool to enhance paua stocks in PAU7. The objectives of the research are to:

1. Identify the optimum size for seeding
2. Estimate optimum seeding densities
3. Measure the survival of seeded paua through to 125 mm
4. Measure the growth of seeded stocks through to 125mm
5. Identify the best sites for seeding
6. Evaluate the economic viability of paua reseeding

Substantial progress has been made on all of these objectives in the first 2 years of the project. Topics 1 and 2 were addressed in Liz Keys' MSc thesis and during subsequent follow up experiments.

This report summarises the research done, and the findings to date. It then presents a simple spreadsheet model that evaluates the economic viability of reseeding, based on the results from the research.

2. METHODS

2.1 Seed size versus survival and growth

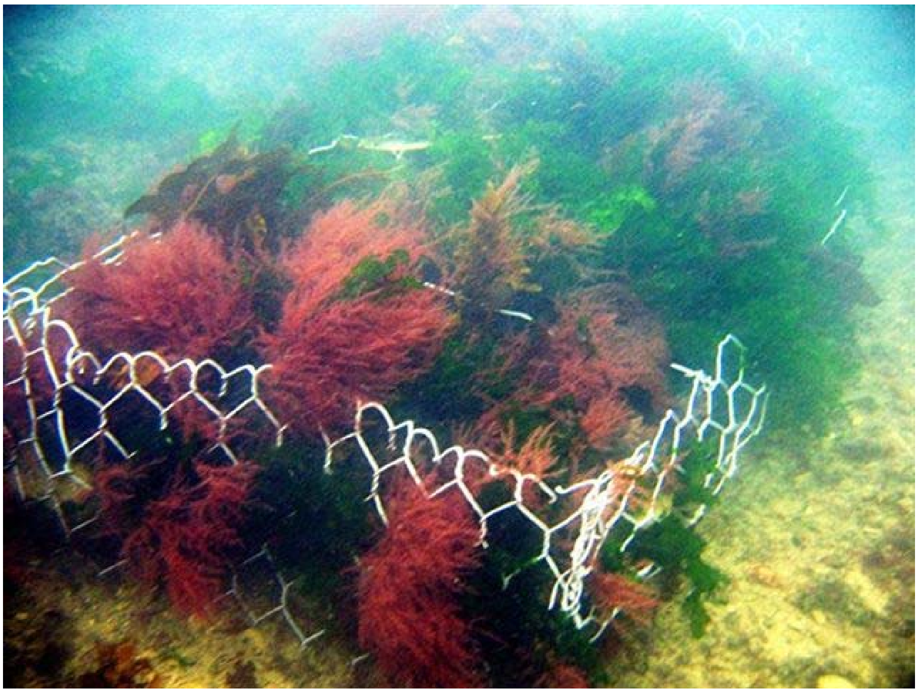
As part of her MSc Thesis, Liz Keys had about 10 "constructed boulder reefs" (CBRs) made in Tory Channel. These consist of a wire mesh basket (2 m x 1 m x 0.5 m, L/W/D) filled with 2-4 layers of natural boulders and placed onto bedrock, sand or gravel (Fig. 1). Small abalone are notoriously difficult to find in complex boulder habitats. The CBRs did a good job of containing paua, and ensuring that survivors were able to be accurately counted.

The CBRs were used to compare the survival of 5, 10, 15 and 20+ mm paua over 3 months from September to December 2004, as detailed in Liz Keys' MSc thesis (Keys 2005). Subsequently, five of the CBRs and six natural boulder shores were seeded with 25 x 5, 10, 15, 20 and 25 mm paua, on 21 Jan 2005. These CBRs were surveyed after 4-5 months of summer-autumn, and the natural shores will be surveyed in summer 2005/6.

2.2 Seeding density versus survival and growth

The CBRs were also used to examine the effect of seeding density on survival. Liz Keys ran two experiments. In the first experiment, 13 ± 5 mm seed were placed on 9 CBRs at densities ranging from 50 to 1281 seed per CBR, and surveyed after 3 months (April to July). In the second experiment, 17 ± 7 mm seed were placed on 4 reefs at densities ranging from 150 to 1200 seed per reef, and surveyed after 3 months (October 2004 to January 2005).

Figure 1 An example of a Constructed Boulder Reef (CBR) used to allow accurate survey of small reseeds.



2.3 Survival and growth of seeded paua through to 125 mm

Estimation of survival and growth to harvest size relied on 8 “commercial” sites (Figure 2) seeded with 2,600 to 20,000 paua in September 2003 (9.9 ± 0.11 mm length) or December 2003 (11.4 ± 0.12 mm). Surveys of reseed survival targeted reseeds at 50-70 mm shell length because:

- it is near the end of the vulnerable under-boulder phase;
- paua are relatively easy to find at this size, compared to smaller paua;
- published estimates of natural mortality (Table 1) allow us to extrapolate survival from 60 mm to harvest size with some certainty;
- the blue/green hatchery shell is still visible at this size but may be lost once paua emerge into open habitat.

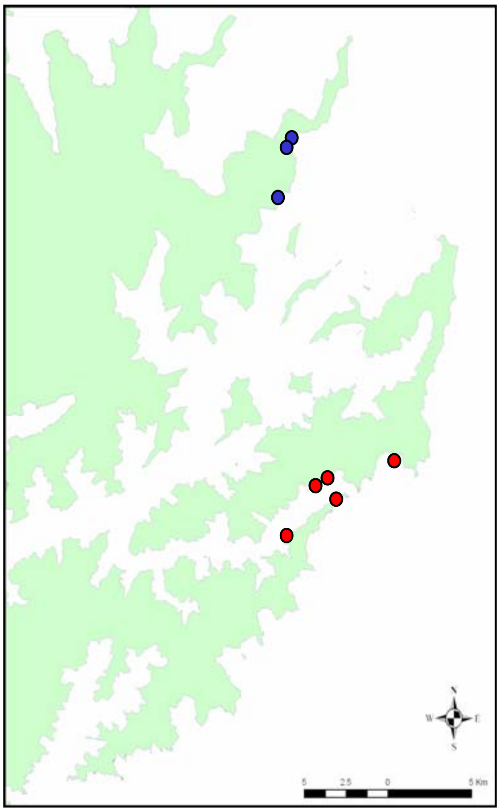
Reseeds at the five sites in Tory Channel and Cook Strait (Figure 2) reached the required size in May 2004. The three Northern Entrance sites are growing more slowly and will be surveyed in early 2006.

Survival at the five sites was estimated by counting and measuring paua recovered by one of two methods:

1. Random quadrats: A rectangular area containing the reseeds was delimited with tape measures, and 50 to 100 x 0.25 m^2 quadrats were placed “blindly” by Rodney Roberts according to a map of randomly generated locations. If substrate beneath a quadrat was unsampleable but potentially contained paua, the quadrat was moved left (facing shore) to the first sampleable location. If a quadrat, or part of a quadrat, was unsampleable but clearly contained no paua (eg embedded boulder) then a zero was recorded.

2. Complete survey: we attempted to find all reseeds released at a site, by searching in all boulder habitat and crevices. This method gives a minimum estimate of survival, as some survivors are not found.

Fig. 2 The eight "commercial" sites reseeded are shown at two scales. Red dots = Cook Strait and Tory Channel sites surveyed in May 2005. Blue dots = Northern Entrance sites yet to be surveyed.



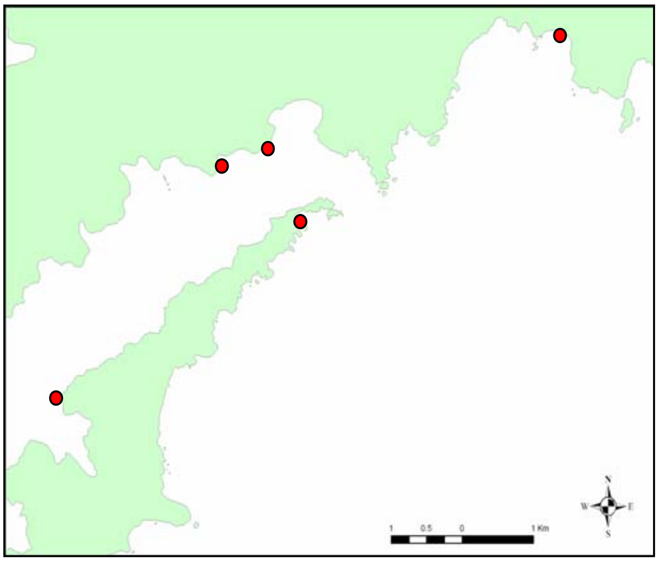


Table 1 Published estimates of natural mortality of black-foot paua *Haliotis iris*.

Source of estimate	Instantaneous rate of natural mortality (*M*)	Mortality per year (%)	Notes
Sainsbury 1982	~0.1	9.5%	Estimated from populations size structure and growth data of paua over 2 years old, Banks Peninsula.
McShane and Naylor 1997	≤ 0.1	≤ 9.5%	Measured directly on 22-165 mm paua in an enclosed population in Wellington, and by counting dead shell from wild populations at D'Urville Island.
Annala et al. 2004	0.15	13.9%	Estimated by NIWA stock assessment model for PAU7

In general reseeds were very easy to distinguish from wild paua by the blue/green colour of the hatchery shell, even at shell lengths of 80 mm or more (Figure 3). The Perano site was an exception, where 144 paua were of uncertain origin because some natural recruits had similar colouring. Half of the 144 were assumed to be reseeds. An additional 401 seed were definitively identified.

Fig. 3 The small blue-green hatchery shell can be seen near at the apex of these reseeds after they have grown to 60 - 85 mm.

Growth of animals surveyed in May 2005 was measured by recording shell length at time of recapture and assuming average size (10 or 11 mm) at time of release. We confirmed that the size at release was close to the average by measuring the hatchery shell on a subset of the seed recovered.

Growth from 60 mm to 125 mm is assumed to take 3 years, based on the growth curve of Poore (1972) in Kaikoura, and supported by unpublished data from three Cook Strait sites (NIWA unpublished data). Growth rate data for western D'Urville Island and the Staircase (Breen and Kim 2003) show slower growth than expected in Cook Strait and Tory Channel.

2.4 Identification of the best sites for reseeding

Progress on this objective accumulates from all of the reseeding work, including the time spent searching for research sites and looking at natural patterns of recruitment. The CBR and "commercial" sites described above relate largely to small boulder habitat in Tory Channel, Cook Strait and Northern Entrance of Queen Charlotte. Cook Strait shores generally contain large boulders that prevent accurate survival estimates, but probably have great potential for reseeding.

We have placed ~500 seed in a number of Cook Strait sites to get an impression of their reseeding potential. These should be examined in mid-late 2006.

2.5 Evaluation of the economic viability of paua reseeding

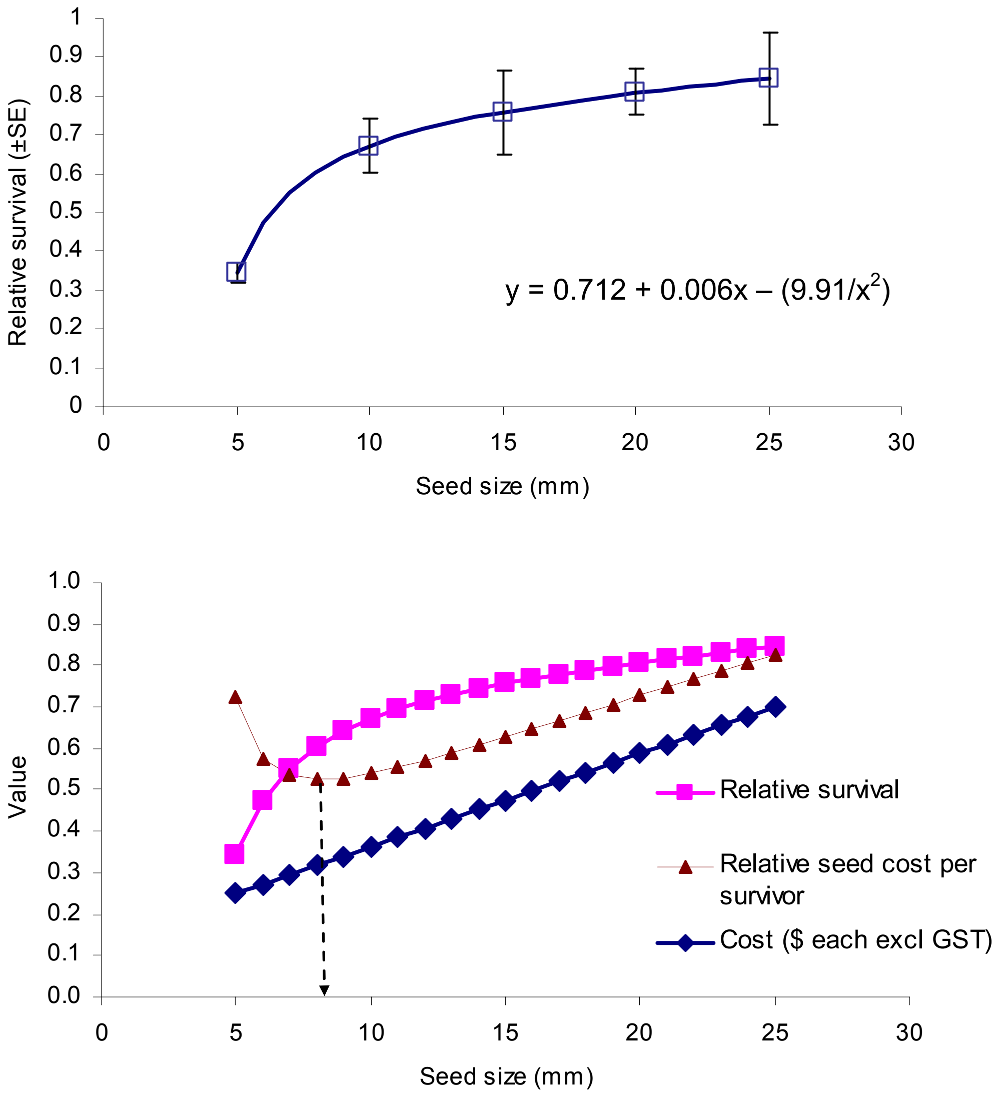
A simple spreadsheet model was constructed to examine the economic viability of reseeding in Marlborough. The model will be provided with this report.

3. RESULTS AND DISCUSSION

3.1 Seed size versus survival and growth

The most economically favourable seed size is a compromise between seed survival and cost, and in our case has been estimated at 10 mm. Seed survival on CBRs increased progressively with size, but the greatest gain was between 5 and 10 mm seed, with rapidly diminishing improvement in survival for larger seed (Figure 4). A curve was fitted to describe the relationship between seed size and survival. A curve for seed cost vs size was plotted assuming a cost of $0.25 at 5 mm increasing by $0.025 cents per mm thereafter (based on discussions with paua farmers). These two curves were then combined to examine the seed cost per survivor (Fig 4). The predicted optimal seed size was just under 10 mm. Given that we have not tested seed between 5 and 10 mm, I recommend that 10 mm seed be used.

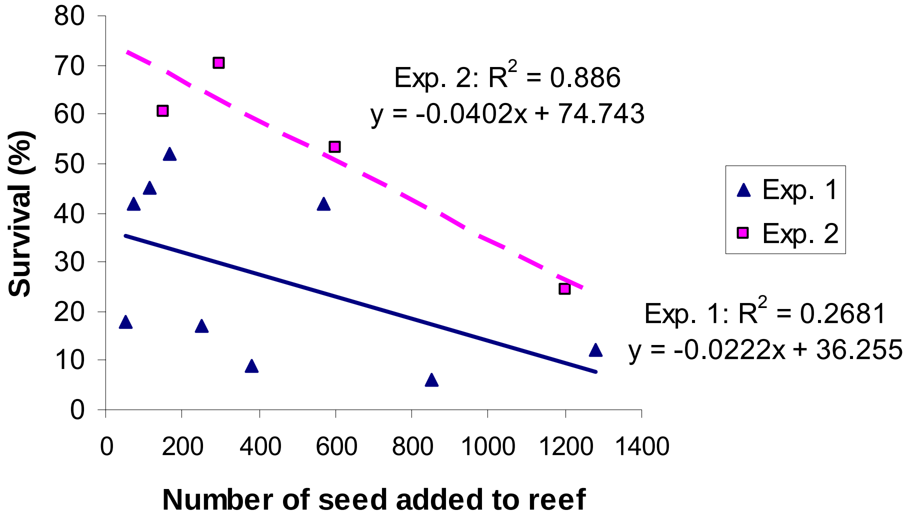
Fig. 4 *Top*: Relationship between seed size and survival based on combined data from two constructed boulder reef experiments. *Bottom*: Estimate of economically optimal seed size based on a combination of seed cost and seed survival data.

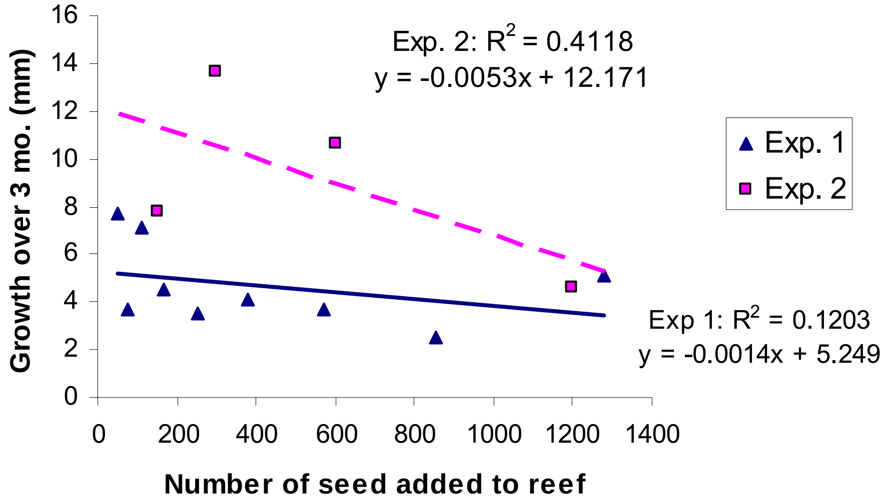


3.2 Seeding density versus survival and growth

Growth and survival of seed tended to decline with increasing seed density, in both CBR experiments (Fig. 5). However, there was also wide variation, probably due to differences in rock type, food supply and predators among reefs. Good survival and growth were recorded on reefs seeded with up to 600 paua (300 per m^2 of reef) reducing to about half that level with mortality over 3 months. These relatively high densities suggest that carrying capacity for reseeds is high if conditions are ideal. Seeding density will need to be considered on a site by site basis during reseeding until further experience is gained. Ideal natural habitat contains large juvenile paua at densities of at least 50 per m2, which is substantially more weight of paua than 300 per m^2 of the size tested here. We noted some reduction in growth rate of reseeds in natural habitat where juvenile density was high and the rocks were relatively bare (see 3.3) but growth was still quite rapid at these sites.

Fig. 5 Survival (top) and growth increment (bottom) versus density for paua released onto constructed boulder reefs for 3 months in winter (Experiment 1, 13 ± 5 mm) and spring (Experiment 2, 17 ± 7 mm).





3.3 Survival and growth of seeded paua through to 125 mm

Table 2 shows the survival and growth of seed at the five "commercial" sites surveyed in May 2005. Survival from the May 2005 survey to harvest size was extrapolated assuming 9.5% mortality per year (*M*=0.1) over 3 years of growth.

Survival to harvest ranged from 1.3 to 18.6% (Table 2). The worst site was Wellington Bay, which is exposed to southerly swell. Extreme storms occurred 1-2 months after seeding in January and February 2004, generating peak southerly swell heights of 10-12 m in Cook Strait. The boulder seabed in Wellington Bay was massively disturbed by these storms (D. Baker, pers. obs.), which no doubt contributed to the low seed survival.

The Perano Homestead site suffered from gravel movement, which filled much of the under-boulder space present at the time of seed release. In May 2005, seed at this site were extremely clumped. Subsequent to quadrat sampling, about 300 seed were recovered from just 3 large ideal boulders (Figure 6). The survival estimate is based on an incomplete total sampling attempt, which yielded a slightly higher survival estimate than random quadrats.

Gravel from slips clogged localised parts of the Whaling Station site, but some excellent habitat remained, and both survival and growth were good at this site. The West Head Tunnel site appeared to avoid significant storm damage due to protection by headlands, and gave very good survival. The Oyster Bay East site differed from the others in having only scattered large boulders on bedrock. We attempted to find all survivors at this site. Again the survivors were concentrated under large boulders around low tide mark.

Table 2 Survival, growth and other details for the five "commercial" sites surveyed in May 2005.

Site	% survival to May 2005 survey	% survival to 125 mm*	Av. size at survey (mm)	Time at liberty (mo.)	Growth rate (mm/yr)	Number seeded
Whaling Station	25.1	18.6	60.1	20	31.4	10,016
West Head Tunnel	18.7	13.9	46.9	17	26.1	5,000
Oyster Bay East	16.2	12.0	51.8	20	25.2	2,613
Perano Homestead	7.3	5.4	59.7	20	30.0	6,524
Wellington Bay	1.7	1.3	58.7	17	34.7	20,000
Average all 5	**13.8**	**10.2**				
Average first 4	**16.8**	**12.5**				
Average first 3	**20.0**	**14.8**				

* assumes 9.5% mortality per yr for 3 years to >125 mm harvest size

Fig. 6 An ideal rock for large reseeds at the Perano Homestead site. This rock housed about 100 reseeds and a similar number of natural recruits.

Growth rate ranged from good to very good (Table 2). At West Head Tunnel and Oyster Bay East, the high density of recruits and the lack on seaweeds on the very shallow rocks where most reseeds were recovered, led to a lower (but still good) growth rates. To provide some context, paua farms in New Zealand achieve average growth rates of between about 15 and 35 mm per year. The higher end of this range could only be achieved by holding water temperature near optimal year-round.

3.4 Identification of the best sites for reseeding

Various factors have a great influence on the suitability of a site for reseeding. Some are highlighted here.

Availability of suitable boulder habitat

Paua are very particular about their habitat. Not only do they require boulders (to avoid light) but the boulders need to have adequate space beneath them, and just the right balance between stability and mobility. Moreover, the requirements change as the paua grow. Small juvenile black-foot paua (< 30 mm) are found predominantly under small boulders from low tide mark down to several metres depth. Black-foot paua juveniles become rare as soon as reduced water movement or increased rock stability allow soft fouling or siltiness. Yellow-foot and white-foot paua juveniles are more tolerant of these conditions.

Larger juvenile black-foot paua move progressively onto very large boulders which have wider spaces beneath them. These boulders are typically around the low tide mark, where there is very little growth of fleshy seaweeds, and very little soft fouling.

Storm damage
Another key factor is susceptibility to storm damage, including crushing by boulders and clogging of under-boulder space by sand and gravel movement. We saw extensive damage to the shells of juvenile Cook Strait paua that survived the massive storms of early 2004. The low survival at our Wellington Bay site probably relates largely to boulder movement, whereas the Perano site was significantly affected by gravel clogging the space beneath boulders.

Competition for food
In extreme cases, competition for food may be a significant factor. This is discussed in Section 3.6.

3.5 Evaluation of the economic viability of paua reseeding

A simple Excel spreadsheet model will accompany this report. The model predicts the gross profit for reseeding in Marlborough. A more complex model constructed by SeaFIC is available from Gerard Prendeville, and predicts very similar economic returns.

In the model provided, the user can change the values highlighted in yellow to examine the way that profit responds to changes. Two sheets are provided. The one called "Model Brief" cuts out the detail and allows you only a few key variables like seed cost and survival rate. The sheet called "Model Full" allows you to vary many more variables like meat and shell value, levy costs, harvest costs etc. Seeding cost is fixed at $0.03 per seed and marine farm holding costs at $0.01 per seed (estimated by Gerard Prendeville). Seed cost and survival rate have the greatest effect on profitability, so deserve some further discussion (below).

The gross profit (income less costs) and return on investment over 5 years are highlighted in turquoise near the bottom of the sheet. To convert this to an equivalent annual interest rate, use the blue table. Compare this with what you consider to be the "opportunity cost" of tying up your reseeding costs for 5 years prior to harvest. Eg if you had the money in an investment scheme for those 5 years it may have accumulated interest at ~10% per year. On the "Model Full" sheet, opportunity cost is included at the bottom of the sheet.

Seed price
The going rate for paua seed in New Zealand is currently about $0.40 + GST per 10 mm seed. The largest hatchery in New Zealand (OceaNZ Blue Ltd) recently confirmed its price at $0.40 at 10 mm with a minimum price of $0.30 per seed for smaller sizes. They will consider lower prices for large, longer term orders e.g., $0.32 per 7-10 mm seed or $0.36 per 10-12 mm seed (Jimmy Miller, pers, comm.).

New Zealand paua seed prices are high by international standards, because the New Zealand industry is still very small, and does not have excess juvenile production. Once there are several large and efficient hatcheries, overseas experience suggests that seed cost is likely to fall to around $0.20 per 10 mm seed. Victoria, Australia is an extreme case where there is an excess of hatchery production, and seed sell for ~A$0.05 at 10-15 mm. A figure of $0.32 to $0.40 is more realistic at present, but some operators are determined to bring the price down in the future.

Survival rate

The "commercial" sites surveyed to date include both good and poor sites. Storms affected survival at Perano Homestead and Wellington Bay. Without the need to select sites with small boulders suitable for scientific surveys, you would hope to avoid "bad" sites in commercial reseeding. From what we have learnt so far, much of Cook Strait appears to be ideal habitat with its mixture of small and very large boulders in shallow water.

In choosing the survival level in the economic model, you could try three scenarios:

- the average survival across all five commercial sites (10.2% to harvest)
- the average survival across the four best commercial sites (12.5% to harvest)
- the average survival across all five commercial sites (14.8% to harvest).

Table 3 summarises the predicted return from a range of combinations of seed cost and survival rate.

Table 3 Estimated economic returns from reseeding in Tory Channel or Cook Strait, based on a simple spreadsheet model.

Seed cost (NZ$)	Survival to harvest	Return on investment	"Interest" rate per year
0.40	10%	103%	15%
0.40	12.5%	154%	21%
0.40	15%	205%	25%
0.32	10%	148%	20%
0.32	12.5%	209%	25%
0.32	15%	271%	30%
0.20	10%	267%	30%
0.20	12.5%	359%	36%
0.20	15%	450%	41%

3.6 GENERAL DISCUSSION

Is Cook Strait suitable for reseeding?

Cook Strait is a prime candidate for reseeding, but most of it can not be assessed accurately because the boulders are too large to survey. Sites with smaller boulders, such as Wellington Bay, are very susceptible to storm damage as we found out. For the following reasons, I believe that Cook Strait has excellent potential for reseeding:

- The large, shallow boulders that are abundant in Cook Strait proved to be ideal habitat for larger juveniles in our reseeding sites (Figure 6). These large boulders resist storm damage, and shelter smaller boulders amongst them. They also provide ample space for large juveniles.
- Cook Strait paua show excellent growth rate through to harvest size (NIWA unpublished data).
- Cook Strait has excellent habitat for all life stages.

Is reseeding competing with natural recruitment?

Natural recruitment remains good in many areas of PAU7, including Cook Strait. If reseeding were simply competing with natural recruitment for available carrying capacity, then there would be no point in reseeding. This is a complex issue which has not been fully addressed, but our data do offer some pointers. Section 3.2 showed that survival and density of seed tended to decline with increasing seed density, but the relationships were clouded by a lot of variation, and reseeds could do well at high release densities of up to 300 per m^2. Section 3.3 showed that commercial sites with very high densities of paua on almost bare rocks near low tide mark had somewhat lower growth rates, but importantly, growth was pretty good even under these conditions. If growth rate is good, then food competition is unlikely to have a big effect on survival, as paua are very starvation tolerant. I think that food competition is more likely to affect survival of small paua juveniles rather than large ones, as paua become increasingly reliant on drift seaweed as they grow.

Much of reseeding mortality occurs soon after release, and in smaller paua. To minimise the reseeding mortality, great care should be taken to minimise stress during reseeding. Reseeding during summer when the water is warmer and food availability is high will help reseeds grow quickly to a more robust size.

Sites with slower growth affect the economics of reseeding by increasing the period until return on investment. During this time, the money invested in reseeding could be accumulating interest in other investments. The amount and type of seaweed available, the density of adult paua, and the amount of water movement, will affect growth rate from 60 mm to harvest size.

To avoid potential competition effects on growth and survival of reseeds, reseeding should avoid areas with extremely high natural populations, and should use moderate seeding densities. In good habitat, I would seed at about 50 per m^2 per year. From a cost point of view it is preferable to seed 150 per m^2 of seafloor each 3rd year, but if competition is most intense in small paua, this may lead to higher initial mortality. These two options could be compared as part of future reseeding.

Because carrying capacity is very complex and will vary among locations and over time, it is difficult to provide definitive answers from small experiments. The best way to find out for sure whether reseeding truly enhances the fishery is to monitor commercial scale reseeding. A good way to do this is to measure the number of emergent paua (say >90 mm) at several reseeded sites, and at several unseeded controls. You can measure the degree of enhancement by comparing the change in the number of emergent paua at the reseeded sites compared to the controls.

Logistics of reseeding

At 12.5% survival to harvest, and 3.3 paua per kg at harvest, you need about 265,000 seed to yield 10 tonnes of paua. At a reseeding density of 50 seed per m^2 per year, this requires 5,300 m^2 of seafloor to be seeded. If the strip of reseeding habitat is only ~2 m wide, as in some parts of the Sounds, you would need to spread the seed along about 2.7 km of coastline. To reseed for 50 tonnes of harvest, you would need to seed about 14 km of 2 m wide strip.

Will reseeding produce a self-sustaining higher TAC?

Reseeding will mean that there are more spawning paua (>70 mm) in the population, but we can't assume that this extra spawning biomass will produce extra recruits. There may be "bottlenecks" in carrying capacity beyond the larval stage that prevent the extra larvae from translating into extra recruits. If these bottlenecks exist, they are most likely to involve food availability (especially for paua <10 mm), and perhaps under-boulder space or density-dependent predation.

4. RECOMMENDATIONS

There is still plenty to learn about reseeding in Marlborough. The following recommendations can be revised as further experience is gained.

Recommendations:

Seed size:	10 mm
Seeding density:	50 seed per m^2 of good habitat annually (compare with 150 per m^2 per 3 yr)
Seeding season:	Summer
Stress:	Minimise stress during reseeding
Competition:	Avoid areas with extremely high natural paua recruitment, or known to have poor growth rate.
Monitoring:	Measure the number of >90 mm paua in several seeded areas and several unseeded controls before and after reseeding.

5. REFERENCES CITED

Annala, J.H.; Sullivan, K.J.; Smith, N.W.McL.; Griffiths, M.H.; Todd, P.R.; Mace, P.M. and Connell, A.M. (Comps.) 2004: Report from the Fishery Assessment Plenary, April 2004: stock assessments and yield estimates. 690 p. (Unpublished report held in NIWA library, Wellington.)

Keys, E.F. 2005 Experimental enhancement of black-foot abalone, *Haliotis iris*, in Tory Channel, Marlborough, New Zealand. MSc thesis. University of Waikato.

McShane, P.E. and J.R. Naylor 1997. Direct estimation of natural mortality of the New Zealand abalone, *Haliotis iris*. *New Zealand Journal of Marine and Freshwater Research* 31:135-137, 1997.

Poore, G.C. 1972. Ecology of New Zealand abalones, *Haliotis* species (Mollusca: Gastropoda) 3: Growth. *New Zealand Journal of Marine and Freshwater Research* 6:534-559.

Sainsbury, K. J. 1982. Population dynamics and fishery management of the paua *Haliotis iris* : 1 Population structure growth reproduction and mortality. *New Zealand Journal of Marine and Freshwater Research* 16:147-161.

6. ACKNOWLEDGEMENTS

Gerard Prendeville is the PAU7 Project Leader for the reseeding project, and contributed to the work described in this report in numerous ways. The size/density versus survival/growth work described in this report was done by Liz Keys' with help from industry and supervision from Conrad Pilditch (University of Waikato) and Rodney Roberts (Cawthron). Many PAU7 industry people donated time, boat support and equipment. Bruce Hearn's contribution of expert advice and equipment for sea-based holding of paua is gratefully acknowledged. Funding came from the PAU7 quota holders, New Zealand Trade and Enterprise, and a FRST TIF grant for Liz Keys' MSc research. Jeremy Cooper was instrumental in the initiation of the project, and in gaining funding from external sources. Reyn Naylor of NIWA provided growth data from Cook Strait paua.