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FRDC FINAL REPORT

Workshop on Post Settlement Processes Affecting the Southern Rock Lobster, *Jasus edwardsii* In Southern Australia

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1. Project Summary

1998/362 Workshop on Post Settlement Processes Affecting the Southern Rock Lobster, *Jasus edwardsii* In Southern Australia

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OBJECTIVES

1. To identify the current status of knowledge in post-settlement spiny lobster research, including technological advances, which will be useful in the study of post-settlement processes in southern rock lobsters.

2. To bring together key industry, government and research partners to discuss a collaborative research plan aimed at investigating post settlement processes in southern rock lobster.

3. To foster international links in this field of research.

NON TECHNICAL SUMMARY

Research into the southern rock lobster in Australia has concentrated on the catching sector (primarily commercial) with limited research being undertaken on the post-settlement and juvenile stages. To maximise the outputs of investigating these stages, while at the same time minimising costs, a comprehensive understanding of the latest developments in the field is necessary. It was considered that this was best served by holding a workshop to review existing research, facilitate discussion amongst those involved in the area of research, and plan future research in relation to southern rock lobster.

Key issues for the workshop were considered to be: (1) the relevance of juvenile research to catch prediction; (2) growth information for stock assessment modelling; (3) impact and management of puerulus extraction for aquaculture; and (4) contribution to broader management in relation to conservation of egg production vs perceptions of stability of recruitment due to density dependent mortality.

Participants at the workshop reviewed the current status of knowledge in post-settlement rock lobster research, including methods used to research these cryptic stages. Participants included key industry, government and research partners and their discussions resulted in a collaborative research plan aimed at investigating post-settlement processes. Key areas were documenting macro-habitat requirements, growth rates, mortality estimates of juveniles and puerulus, identifying predators and competitors. The over-riding goal was considered to be the identification of "bottlenecks". That is, identifying the stages and factors during juvenile development where density dependent mortality influences abundance. These factors reduce the signal between puerulus abundance indices to fishery recruitment and are important in understanding the effect of puerulus removal or habitat changes.

International participation at the workshop (from NZ, Japan & USA) was helpful in fostering links in this field of research.

KEYWORDS: Southern rock lobster, resource sustainability, recruitment, aquaculture, mortality, density dependence.

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2. Background

This report describes the outcomes of a ten-day workshop and field trip funded by FRDC to focus research directions into the post-settlement process in southern rock lobster (*Jasus edwardsii*). International experts from the USA, New Zealand and Japan attended. The workshop commenced at the Marine Research Laboratories of the Tasmanian Aquaculture and Fisheries Institute (TAFI) in Hobart with presentations from experts in early lobster life histories updating the workshop participants on their latest findings. The Hobart session was followed by visits to existing and potential research sites in Tasmania, Victoria and South Australia. Visiting the sites proved invaluable as participants were able to see the differences between habitats utilised by *Jasus edwardsii* and the logistics of sampling these often remote and complex environments. An added benefit was the 'hands on' experience which Australian scientists gained in locating puerulus and post-puerulus from Japanese colleagues.

The final two days of the workshop were held at South Australian Research and Development Institute (SARDI) in Adelaide where a research strategy was developed utilising the advantages of the three States (logistics, habitat complexity, habitat differences). A project was drafted which involved short, intense periods of fieldwork and capitalised both on the differences in habitat structure between States, as well as existing puerulus collection projects underway in each State. Since the workshop, a proposal was developed and submitted into the 2000–01 FRDC application cycle.

3. Need

The workshop was initiated due to recognition of the limited research on the juvenile stages of southern rock lobsters. Most research on this species has concentrated on the catching sector, primarily commercial. Our understanding of the processes affecting survival of juvenile lobsters is poor.

Key applications of planned research into post-settlement processes are:

- the relevance of juvenile research to catch prediction;
- growth information for stock assessment modelling;
- impact and management of puerulus extraction for aquaculture; and
- contribution to broader management philosophy in relation to conservation of egg production vs perceptions of stability of recruitment due to density dependent mortality.

To maximise the outputs of future research on the post-settlement processes of southern rock lobsters, while minimising costs, a comprehensive understanding of the latest developments in the field is necessary. It is recognised that the reef habitat utilised by post-puerulus and juveniles is complex, both structurally and ecologically. Suspected ontogenetic behaviour shifts and a relatively cryptic lifestyle further complicates the study of juvenile southern rock lobsters. Understanding techniques and methodology available for juvenile rock lobster research is vital for working within these constraints.

With increasing interest in rock lobster culture by puerulus removal, it is important that age-mortality keys are established to adequately protect the resource from further exploitation. Knowledge of the post-settlement processes is necessary for determining mortality rates.

Research into post-settlement processes of spiny lobsters is difficult and complex. As such, maximum efficiency will be achieved through a united approach between South Australia, Victoria, and Tasmania and there is scope for international collaboration.

4. Objectives

1. To identify the current status of knowledge in post-settlement spiny lobster research, including technological advances, which will be useful in the study of post-settlement processes in southern rock lobsters.
2. To bring together key industry, government and research partners to discuss a collaborative research plan aimed at investigating post settlement processes in southern rock lobster.
3. To foster international links in this field of research.

5. Papers Presented

5.1 TAFI, Hobart

5.1.1 **Recruitment of the Caribbean spiny lobster in a dynamic nursery**; Mark Butler, Old Dominion University, USA.

Butler's studies spanning 15 years in the Florida Keys/Bay have a strong ecological basis. He emphasised it is necessary to know the "animal" before modelling population dynamics of the species.

Larvae are transported from the open sea to Florida Bay through channels. This transport mechanism has allowed some valuable work assessing mortality of larvae in relation to where they are in the channel on a horizontal and vertical plane. The channels allow unique opportunities to sample puerulus with nets set in channels.

Half hour checks of plankton nets has shown that most puerulus are carried inshore during new moon, and on the incoming tide.

"Witham" collectors are the standard sampling substrate for *P. argus* in the Caribbean. In Florida it is unfortunate there are no long-term sets of settlement data. There has been a high correlation between the numbers of pueruli taken by plankton nets, Witham collectors, and the numbers observed by divers on the bottom.

Settlement predominantly occurs in the Bay in waters < 2m. Larvae and early juveniles remain cryptic and solitary for some time before an aggregated ("social") stage later.

Substrates are selected, with a red macro-algae preferred. The substrate complexity is important. The distribution of the preferred substrate is dynamic making it difficult to protect critical habitat. Low prey abundance will also cause juveniles to leave an area. Salinities are also very dynamic and the post larvae have a narrow range of tolerance.

Tethering was used to look at relative mortality in several experiments. A relative rate of predation of incoming puerulus over different regions of the reef was evaluated by tethering to floating structures. Predation was highest around the outer reef although relatively less time is spent in this area as puerulus swim to inshore areas. The relative importance of shelter to juvenile stages was also evaluated by tethering.

Studies of the benthic life history have used tagging with microwire tags. These have been very successful for marking the second benthic stage (12–15 mm), but less successful for marking the first (5–7 mm) where mortality was high and growth rates were reduced 10–15% over 9 months. (Larger animals of 50 mm CL are tagged with sphrion tags).

Between 2 and 4% of microwire-tagged lobsters were recovered after 9 months from releases of a total of 11,000 animals. There has been no density effect on growth between high and low density treatments in a macro-algae habitat. Principal predators were nurse sharks and octopuses.

Ontogenetic changes occur in aggregating behaviour. How the animals aggregate is a topic of study. Animals of 40-80 mm CL respond significantly to chemical cues.

There is a high correlation between larval supply and juvenile abundance, provided shelter is not limiting. In areas of high shelter the correlation is 0.87, and in areas of low shelter the correlation is 0.48. Even in areas of high shelter larval supply may sometime exceed the habitat's carrying capacity. The importance of shelter was also evaluated by tethering (mentioned earlier).

The Jackson Square method has been used to census juvenile populations. This method is an offshoot of the Jolly-Seber census method (Manly 1984). The method used with tagging has been successfully employed to estimate natural mortality. Setting up the experiment requires baseline information on the pattern and distances that the animals typically move so that the spatial scale of the experiment is appropriate. It was noted that there is some evidence of homing ability of *P. argus* from studies of magnetic "navigation" (Larry Boulls) and observations of the movement patterns of *J. edwardsii* in New Zealand (Ali MacDiarmid).

Major movements of lobsters from outside the "square" have been noted from time to time. Interestingly, these animals moved on and residents in the "square" remained. It is important to be able to readily distinguish between "resident" and "non-resident" animals in the experiment.

The recruitment fluctuations of *P. argus* were modelled by an individual based model which attempted to look at the implications of sponge die-offs, as have been seen recently during periods of extended anoxia. Juvenile abundance in the model was influenced by habitat availability. It appeared that observed patterns in juvenile abundance were due to a natural, fortuitous compensatory mechanism – as sponges died off, shelter in sponges became less available. However, this also resulted in scouring of the seafloor, which resulted in increased availability of shelter in solution holes.

5.1.2 **Enhancement Ecology of *Jasus edwardsii*;** Ali MacDiarmid**,** NIWA New Zealand.

New Zealand's catch of southern rock lobster is about 2500 tonnes. As in Australia, there is interest in improving our understanding of the life stages less than 70-80 mm CL for fisheries management. There is also interest in the potential to enhance production through intervention in the natural process.

The possibilities are to:

1. Increase the natural rate of recruitment;
2. Seed areas with animals from the wild (this could be by shifting animals from one area to another or by re-introducing animals that were husbanded through a period of high natural mortality);
3. Seed areas with hatchery reared animals;
4. Increase the survival of wild animals; or
5. Increase the growth of animals in the wild.

To assess these possibilities it is necessary to know rates of settlement, movement, survival and growth in the wild (and in captivity).

Studies have been done to determine foraging radius of wild and naive lobster. Lobsters in both groups disappeared from the study site quickly (50% after 1–2 days). There was no significant difference between groups. Seven percent of coded, wire-tagged animals were present one year later.

Work in New Zealand indicated that any homing behaviour of released animals (magnetic?) is short lived.

Ontogenetic changes in social behaviour were split into the following groups: 10-30 mm CL animals were solitary; 30-70 mm CL animals were aggregated; and animals greater than 70mm CL were varied, or with more complex behaviours, presumably due to reproductive cycles.

Numbers of juveniles remaining at a release site were not dependent on the numbers released or whether or not body size scaled artificial shelter was provided. Among site variation caused by some unknown factor appeared to be important in determining the numbers of released juveniles remaining at a site.

Growth of release micro-wire tagged juveniles was high with mean carapace length one year after liberation increasing from 17.9 mmC L to 51.7mmCL. This compared favourably with laboratory held control animals which, over the same period, increased from a mean of 16.2mmCL to 42.3mmCL.

5.1.3 **An experimental approach to post settlement processes of *P. japonicus* using artificial structures;** Taku Yoshimura, Sekai National Fisheries Research Institute, Nagasaki, Japan.

Mr Yoshimura has used both artificial and natural habitat to observe settlement in *P.japonicus* juveniles. Artificial substrates known as 'brocks' were cement blocks with a range of holes of different diameters and depths. The brocks also had attachments for artificial algae. The brocks were designed after extensive field observations of puerulus in the wild.

Individual puerulus and early stage juveniles were individually marked by clipping of the tip of the antennae and/or tying silk thread around the antennae.

Puerulus and early stage juveniles of *P. japonicus* prefer solitary holes and a close correlation between the diameter of the hole and the size of the juvenile has been shown. Importantly, it was shown that shelter availability of a range of sizes was required if juveniles were to survive through early stages. Where either a range in sizes was missing or there was a gap in the size ranges offered, early stage juveniles tended to leave the brocks. This was assumed to be in search of an appropriate sized hole although increased predation in an incorrect sized hole could not be ruled out.

Around 65% mortality was observed during the first three weeks after settlement. This consisted of approximately 45% mortality during the puerulus stage and 35% during the first juvenile stage.

There was increased settlement on brocks when there were greater numbers of smaller holes provided, even when the overall number of holes remained the same. This indicated that puerulus of *P. japonicus* have specific requirements for settlement. A boring Pholad bivalve creates holes for settlement in the wild. The holes are available to the puerulus after the bivalve has died. The availability of holes is thus dependant on the successful recruitment of the bivalve. Although oysters can fill and block holes, there are a number of crustaceans and fish which also utilise the holes. Thes crustacean and fish are considered to keep the holes 'clean' and prevent oysters from blocking them. No work has as yet been undertaken to look at the rate of new hole formation or the competition between species for holes.

Observations in the wild showed that puerulus were most commonly found in holes where an algal clump was present. When artificial algae were attached to brocks there was enhanced settlement and increased survival. Night time dive observations showed that juveniles moved onto the algae to feed at night.

Predation of early stages was often due to a carnivorous gastropod and the use of holes for shelter by the puerulus made them more vulnerable to entrapment by this predator.

5.1.4 **Studies of pueruli and post-pueruli of *P. japonicus*;** Chris Norman, Chiba University, Japan.

There are strong settlement peaks in August and September in Chiba and July to September in Nagasaki. Settlement can be followed on many "two dimensional" substrates, eg. vertical rock faces, in less than 10 m. Settlement peaks over a ten day period on the full moon.

Studies have previously shown there is a strong relationship between the size of the animal and the diameter of the holes used for shelter. This relationship is as strong as it is partly because of the uniformity of the small holes resulting from their formation by pholad molluscs that bore into the soft rock faces. Other naturally occurring holes are typically larger and not of the same uniformity. The relationship between the size of the juvenile lobsters using these and the hole size is not as clear, and not of the same form. Selecting the "preferred" hole size may not be an option for many lobsters as they grow beyond the size that can be accommodated by the pholad holes. The inference was that shelter appears limiting for juveniles larger than the size that can fit into pholad holes.

On one rock face studied, lobsters were found to be using different parts of the face at different stages. On a wall which solely had a vertical face, the puerulus preferred to settle on the medium section and not on either the top or the bottom. It was suggested that the top due to wave action and the bottom due to sand action were less desirable places to live.

Another study looked at the angle of incline of the reef face. Stage I and II puerulus used the middle vertical face and lower under-cut face of the reef. Stage III puerulus used the upper face, which tended from vertical to horizontal. This demonstrated that there was movement between holes by puerulus despite no change in their size and thus hole requirement.

Pueruli and post-pueruli leave their daytime shelter holes at night. Some of this behaviour has been studied by fixing an infra-red light source and receiver at the entrance to holes. The light source is blocked intermittently by the antennae which are periodically 'flicked' up and down when the lobster is at the entrance of the hole. Longer blocking signals of the light source occur when the lobster is leaving or entering the hole. Analysis of the data from the infra red light source was still in its infancy and there were problems with knowing what type of animal was occupying the hole. Future work is aimed at associating the light source signal with the activity patterns of lobsters (eg. do slow and fast antennae 'flicking' relate to specific types of lobster activity) and the types of animals entering and leaving a hole.

In a boulder area, the use of exposed and sheltered boulder faces was studied. Lobsters emerged from holes when light intensity decreased. Night foraging was observed only on boulders and associated algae with no lobsters observed on surrounding sand.

5.1.5 **A review of the research undertaken as part of a Ph.D. dissertation on early benthic phase *Jasus edwardsii* in Tasmania.;** Matt Edmunds (Australia)

Growth rates of early benthic phase juveniles were studied in a reserve in the Derwent estuary. Growth rates were higher during summer months.

As for *P. japonicus*, there was a high correlation between the size of the lobster and the size of the hole it occupied on mudstone rock substrate. The pattern of hole selection was not the same on dolerite rock substrates where uniformity of holes is low.

Prey availability amongst kelp holdfasts was studied in detail. Gut contents from early benthic phase animals were studied and showed that they were selectively feeding on the prey. No manipulations were performed to determine if prey selectivity changes in response to prey abundance.

5.2 SARDI, Adelaide

5.2.1 **Studies of post-larval southern rock lobster in New Zealand;** John Booth, New Zealand

The impression is that natural mortality is high. Some post-larvae may make poor choices about where they settle. If they move to find better shelter they expose themselves to predation.

If natural mortality is high, what factors may be responsible? Among others, the following were discussed:

1. Food;
2. Shelter;
3. Water quality (noted here that many animals are exposed to low salinities at one study site and that there was no indication that they died as a result suggesting that there may be a relatively high tolerance for low salinities amongst post-larval *J. edwardsii*).

At most study sites in New Zealand there are proportionately fewer 2 and 3 year old juveniles. It is assumed that this is due to natural mortality, but it may also be due to emigration from the discrete areas that are surveyed. There is a close relationship between the settlement indices and 1 to 3 year old year classes at Stewart Island and Wellington. At some sites, shelters are continuously occupied, while at other sites shelter occupation declines following periods of lower recruitment (larval/post-larval).

There are some curious situations. On the north-east coast of the North Island settlement is high, but 1–3 year old juveniles are typically hard to find. However, at Stewart Island, where settlement is low, there are higher numbers of juveniles observed by divers. This might be that the measure of settlement is poor, or there is higher predation (lower survival) or other factors, eg. poor visibility, that make the juveniles more difficult to find in the north-east.

Settlement levels are now being detected as changes in commercial catch rates in some areas of New Zealand. Density dependency may erode peaks and troughs in the population and the commercial catch figures. Migrations of juveniles may also confound any potential relationship, e.g. the contra natant migration known from the south of the South Island.

New Zealand is maintaining studies of settlement levels, settlement cues, juvenile abundance, and recruitment to the fishery.

6. Results and Discussion

6.1 Workshop issues and outcomes

The workshop identified possible mechanisms for population bottlenecks (post-settlement processes) at various life history stages following that of the puerulus. These were discussed with respect to their potential industry significance and the potential to be able to effectively research them.

The workshop brought to light what was known of these processes from other species, and for this species, elsewhere. Methods that could be used to research the processes were investigated. Finally, sites on the coasts of Tasmania, Victoria, and South Australia were appraised for their suitability with respect to accessibility, habitat, lobster abundance and any unique habitat characteristics that facilitate surveys such as natural holes suitable for puerulus.

The outcome was enhanced appreciation and knowledge of the biological processes and research methods needed to progress studies of post-settlement processes in southern Australia. The culmination of the workshop was a joint research proposal drafted by the three States involved and ancillary studies that are already under way in each State.

6.2 Biological and Fisheries Issues

The southern rock lobster, is an important resource for South Australia, Victoria and Tasmania. The combined catch is approximately 4,500 tonnes with a beach price of nearly $150 million. Over 650 fishers operate out of mainly rural coastal towns and the industry makes an important contribution to the socio-economic fabric of these towns. Over 20,000 recreational licenses issued annually in southern Australia for the recreational harvest of lobsters by diving and potting (except Victoria).

Management systems (input and output controls) and stock assessment procedures vary between, and even within States. Regardless of the methods of assessment and system of management, knowledge of the processes affecting recruitment to the legal sized biomass is of fundamental importance to the management of the resource in all States.

Nearly a decade ago, Tasmania, South Australia and Victoria commenced projects to monitor puerulus settlement as a first step towards a better understanding of lobster recruitment dynamics. These projects demonstrated consistent seasonal patterns of settlement within sites but varying seasonal patterns between some sites. Further, there was inter-annual consistency between many sites, although the magnitude of the annual settlement indices varied between sites. Variation in settlement rates between settlement sites is also significantly different between years (Anon, 1997; Gardner et al., 1997). With the exception of these projects, our knowledge of the processes affecting recruitment to the commercial fishery is restricted to the catch from pots during catch sampling surveys. This leaves a minimum of five years, and in some regions a substantially greater period in time, in the lobster's life history about which little is known.

Linking settlement indices to future commercial catches has had a profound impact on the management and marketing of the western rock lobster (Caputi *et al*., 1994). A cost benefit analysis of the puerulus-monitoring project in Tasmania (Gardner and Vanputten, 1998) demonstrated that early prediction of catches could provide enormous economic benefits. In Florida, studies in the nursery habitat utilised by *Panulirus argus* have demonstrated the effect of habitat loss, due to environmental and anthropogenic perturbations, on recruitment to the commercial fishery (Butler et al., 1995).

Southern rock lobsters are fully exploited across their entire geographic distribution. Current catches are primarily dependent on recent recruits to the fishery. As such, variation in recruitment impacts on the way the resource is managed and harvested. The latest models used in fisheries stock assessment (including the Tasmanian rock lobster model) have risk assessment capabilities based on forward simulations. Such projections rely on 'predicting' recruitment. In the Tasmanian model, future recruitment is based on hindcast recruitment estimates. Future projections incorporate all possible recruitment scenarios and are thus conservative. Linking projections to 'real' estimates of recruitment would minimise the uncertainty and risk, and potentially allow less conservative harvests. Recent advances in individually based spatially explicit models for rock lobster (Butler, 1997) could further improve forecasts.

Knowledge of post-settlement processes will enable improved evaluation of several potentially valuable enhancement opportunities. These include seeding pueruli or early benthic juveniles into areas with surplus carrying capacity; enhancing habitat; and increasing egg supply (and hopefully post-larvae).

Throughout the world there is increasing interest in the mariculture of lobsters. Improved survival rates in culture, particularly during the early benthic life history when mortality in the wild is expected to be high, raises the possibility of enhancement of wild stock through re-seeding of on-grown post-larvae. Re-seeding may enable multiple use of the resource by wild fisheries and aquaculture without increased impacts on the resource.

Habitat enhancement, as practiced in Cuba (Cruz and Phillips, 1994) and Mexico (Briones et al., 1994) has improved catches in both these countries although the mechanism (enhancement or concentration of existing lobsters) by which this has occurred is still being investigated. Where natural lobster habitat is absent in areas that receive postlarval recruitment it is reasonable to assume that survival and increased production might occur if shelter was provided.

Declines in spawning stock have corresponded with substantial reductions in egg production as the fisheries for southern rock lobster developed. Anecdotal reports from past divers indicate that there were greater numbers of juvenile rock lobsters in coastal waters than currently occur. The workshop highlighted the need to progress past these anecdotal reports and provide a scientific basis to the issue of changes in recruitment as an effect of decreasing egg production.

This issue is critical for current stock assessments as the S.A. model assumes hyperstability from density-dependent bottlenecks and no effect of egg production on recruitment. The Tasmanian model calculates virgin biomass and egg production levels on the basis of recruitment seen since 1970, again ignoring the potential effect of reduced recruitment. This conflict between model approaches and anecdotal reports can only be resolved by research.

As part of the post-settlement workshop a site east of Queenscliff, Victoria was visited. During a total of eight diver hours, no juvenile southern rock lobsters were observed and only five adults in what appeared to be ideal habitat. In the past this region had yielded high catches of rock lobsters. Despite anecdotal evidence of lower numbers of juvenile lobsters there is uncertainty whether there are bottlenecks which limit fishery production, or if larval supply is more critical.

The high value of rock lobster fisheries in southern Australia means that even small increases in the catch may have substantial benefits. A 5% improvement might result in a $10 million increase in landed value with flow-on benefits to southeastern Australian rural coastal communities. Concern has been voiced that increases in production may be offset by lower prices due to supply outstripping demand. However, price increases during the past decade suggest that demand is growing more rapidly than supply. It seems reasonable to conclude that higher production (without increased effort) in southern Australia will have a positive impact on the economy.

There is a common strategic need for the proposed research to improve assessment of the stocks, improve advice on management alternatives, and provide forecasts of stock size (and by implication potential catches), across all southern states.

Population bottlenecks, by definition, limit population growth or size. Bottlenecks in lobster populations may occur at the point of larval production, during the pelagic larval phase, during the early benthic (solitary) phase, or during the social phase of benthic life.

To capture the maximum benefit from the lobster resource it is necessary to identify where the particular population's bottleneck(s) is. Where habitat is limiting there may be potential to harvest some of the population before it is lost through natural mortality. Abalone populations have been found in some places to face bottlenecks resulting in slow growing, "stunted", populations. Harvests of small abalone from these populations have been used to increase production immediately by capturing that part of the population, which would never reach legal length, and improving growth rates and production of those that remain. Where post-larvae are limiting there is potential for increasing recruitment by increasing larval supply.

Of the potential bottlenecks the lobster population may face, only the pelagic larval phase is beyond our ability to make changes that may enhance the populations' productivity. While a bottleneck at this life stage can not be ruled out, were it to occur it only has implications for the stage which precedes it.

There is an unquestionable need to identify where opportunities occur for making more of the lobster resource, if more is desired of it, as it cannot produce more through current (conventional) management practice.

7. Conclusions

7.1 Future research recommendations

The outcome of the workshop was to focus research into post-settlement processes and determine the most achievable and cost-effective way of targeting our research effort.

Although it was recognised that to answer most of the questions on post-settlement processes would take a large team an even larger period of time, a project aimed at identifying ecological bottlenecks that constrain lobster population size was proposed. Knowledge of these bottlenecks is crucial for:

1. prediction of future catches from puerulus/ juvenile abundances;

2. prediction of the value which greater natural larval recruitment, re-seeding, or enhancement would have on the resource; and

3. prediction of the effects which puerulus removal (for aquaculture) would have.

The project would establish sites in each of the three states (SA, Vic. and Tas.) to cover spatial variation in such factors as habitat type, food availability, predator type and abundance, temperature range, growth etc. This baseline experiment, which involves 2 weeks intensive sampling twice per year, would provide the framework for additional secondary experiments to take into account specific needs of each State, logistics etc. Some of these studies could be undertaken concurrently with existing puerulus collecting programs.

The objectives of the work would be to:

1. identify critical/preferred habitat;

2. estimate growth rates of pre-recruit lobsters;

3. estimate mortality rates of pre-recruit lobsters;

4. determine patterns of shelter use and movement; and

5. document principal predators and competitors.

7.1.1 Habitat requirements, post-puerulus and juvenile density and size distributions

Two study areas would be established in each State. These areas should represent the various known near-shore habitat types of *Jasus edwardsii*. Multiple areas would enable comparisons to be undertaken between different habitat types and geographic position (which is likely to be important in terms of recruitment dynamics, growth and survival). The areas would be established near regions of known high settlement from puerulus collectors. Within each area there should be a shallow (1–8m) and a deep (>8m) site.

Each site would be intensively sampled biannually, during winter and summer to include periods of primary and secondary puerulus settlement.

At each site 5 transects of 2 m x 200 m lengths would be surveyed.

At each site a 3-D computer image of the transect area (with supporting video footage) would be produced and transect co-ordinates superimposed on this to map lobster abundances and size aggregations. The video footage, 3-D image and description of the site (bottom type, macro algae etc) would serve as a baseline for future comparative surveys. These surveys would potentially eliminate the non-quantitative basis (anecdote) for comparisons of juvenile abundance through time and have substantial value in this regard alone.

7.1.2 Growth Rates

Extra puerulus from collectors at each monitoring site could be microwire-tagged and released at night into an artificial structure on adjacent reef. The artificial structures, as used by Edmunds (1995), would act as short-term accommodation while the puerulus recuperates from tagging.

These reefs should be intensively surveyed for tagged individuals at yearly intervals.

Growth rates of medium juveniles (35–55 mm Cl) could be obtained from PIT tagging juveniles in areas where juveniles are known to be common. Several areas were identified during the workshop inspection of possible sites. Larger juveniles (55+ mm CL) could be tagged with mini T-bar tags (HallPrint).

7.1.3 Mortality Estimates (post-puerulus and juveniles)

With traditional tag–recapture methods it is impossible to isolate the three factors that affect apparent mortality: tag loss, natural mortality and migration (in and out). A method known as the Jackson square method enables migration to be estimated separately from other mortality causes. This method has been further trialed and is currently being used by Butler for *Panulirus argus*. The spatial scale of the experiment would depend on the distance lobsters are likely to move during the period of the experiment. After initial tagging, where individuals will be tagged and returned to their place of capture, observations will be taken after 24 hours (to enable post-puerulus and juveniles to recuperate after tagging), 48 hours, 96 hours and one week. Juveniles of >35 mm CL will be PIT tagged, whereas smaller juveniles could be antennae banded.

An alternative method of estimating survival could be investigated if the Jackson square method is compromised by patterns of movement. This method involves identifying “islands” of habitat surrounded by sand – a substrate over which sub-adults are unlikely to traverse – and following individual lobsters.

Tag loss and tag induced mortality could be obtained from aquaria trials and caging experiments in one State as there is no need for duplication of this research.

Lobster tethering experiments could be conducted at times of intensive sampling for comparisons between relative rates of mortality in each area as a means of validating spatial comparisons derived by other means.

7.1.4 Mortality Estimates (puerulus)

Estimates can be made through observations on artificial reefs. Yoshimura has been able to observe the settlement and movement of puerulus using artificial habitat designed to mimic the holes used by puerulus. Short-term observations of individuals can be made by antennae marking (clipping or tying silk threads) of individuals. Discussions noted that recent advances in tagging models would enable mortality estimates to be obtained with lower sample intensity than thought necessary previously - this has the effect of increasing the probability of successfully obtaining of useful mortality estimates.

Artificial reefs would be located adjacent to puerulus collection sites and could be monitored monthly during routine puerulus monitoring. Three replicate reefs will be established at two puerulus monitoring sites in each State.

In addition three artificial reefs will be established at one puerulus sampling site and these would be seeded with microwire-tagged puerulus caught in the monitoring collectors.

The post-settlement workshop made an important discovery of pueruli and post-pueruli on natural rock substrates in Port Campbell, Victoria. The finding was significant as it provided researchers with the opportunity to observe pueruli in-situ and “get their eye in”. It also indicated that short, intensive surveys in similar areas might provide a strong possibility of estimating natural mortality of early benthic lobsters in-situ.

7.1.5 Predators and competitors

In addition to counts and location of lobsters, other invertebrates and their use of lobster shelter would be enumerated and documented. Vertebrates would be estimated from video and set nets in regions adjacent to the survey sites but not so close as to interfere with territorial or residential predators.

8. Workshop participants

AUSTRALIA

Dr Bruce Phillips	Edith Cowan University
Dr Barry Bruce	CSIRO
Dr Colin Buxton	TAFI
Dr Caleb Gardner	TAFI
Mr Stuart Frusher	TAFI
Mr Sam Ibbott	TAFI
Dr Brad Crear	TAFI
Mr Dave Hobday	MAFRI
Ms Rhonda Flint	MAFRI
Mr Dave Reilly	MAFRI
Dr Matt Edmunds	CEEPL
Dr Rob Day	University of Melbourne
Dr Roy Melville-Smith	WA Fisheries
Dr Norm Hall	WA Fisheries
Dr Richard Musgrove	SARDI
Mr Jim Prescott	SARDI
Mr Tim Karlov	SARDI
Mr Alan Jones	SARDI
Mr Daniel Casement	SARDI

JAPAN

Dr Taku Yoshimura	Sekai National Fisheries Reseach Institute
Dr Chris Norman	Chiba University

NEW ZEALAND

Dr John Booth	NIWA
Dr Alistair MacDiarmid	NIWA

USA

Dr Mark Butler Old Dominion University

SA COMMERCIAL FISHING INDUSTRY

Mr Ian Regnier

Mr Glen LeCornu

Mr Mark Rothall

Mr Rod McIntyre

Mr Kevin Slaughter

Mr Neil Lisk

Mr Steven Kennett

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10. Appendix 1 - Intellectual Property

Intellectual property does not need to be protected.

11. Appendix 2 - Workshop program

Workshop Programme

Monday 1 February 1999

Tasmanian Aquaculture and Fisheries Institute

Welcome	Dr Colin Buxton
Background	Mr Stewart Frusher
Papers:	Dr Mark Butler
	Dr Alistair MacDiarmid
	Dr Taku Yoshimura

Afternoon

Field site visits: Iron Pot

Pigeon Holes

Tuesday 2 February

Morning TAFI

Papers:	Dr Chris Norman
	Dr Matt Edmunds

Afternoon

Travel to Melbourne

Wednesday 3 February

Morning MAFRI

Travel from Melbourne to Queenscliff then dive at Sorrento field site

Afternoon

Travel to Apollo Bay and dive at Apollo Bay harbour site. Observe puerulus collection site.

Thursday 4 February

Morning

Drive to Port Campbell viewing earlier puerulus collection sites en route. Dive in Port Campbell harbour field site. Observe pueruli in natural habitat and inspect puerulus collection site.

Afternoon

Drive to Mount Gambier

Friday 5 February

Morning

Dive at Blackfellows Caves, Livingstons Bay and Lighthouse Bay field sites.

Afternoon

Drive to Robe and meet with commercial fishers for an informal information session.

Saturday 6 February

Morning

Dive at Margaret Brock lobster reserve field site.

Afternoon

Drive to Adelaide

Monday 8 February

Morning and Afternoon

Workshop at South Australian Research and Development Office

Papers: John Booth

General discussion and review by all participants

Tuesday 9 February

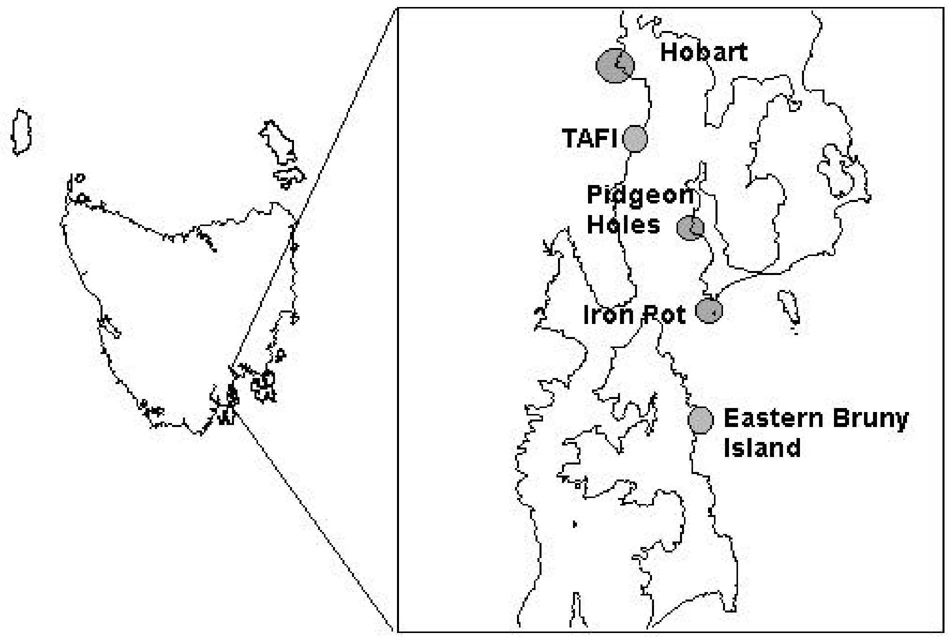
Morning and Afternoon

Workshop Review presented by Mark Butler and Alistair MacDiarmid.

Drafting research objectives and methods by workshop participants.

12. Appendix 3 - Review of field sites

12.1 Tasmania



12.1.1 Iron Pot

This site provides complex habitat consisting of large dolerite boulders overlaying a flat dolerite platform. The substrate is covered by sponges and ascidians in deeper areas, while a large variety of macroalgae flourishes in the shallow areas. *Macrocystis pyrifera*, *Phyllospora comosa* and *Lessonia corrugata* dominate the shallow reef, while *Ecklonia radiata* is prominent below about 5m depth. The substrate also has a covering of turfing brown and red algal species.
There was a high abundance of potential prey organisms including bi-valve and gastropod molluscs, echinoderms and other crustaceans, all of which have been shown to be important foods for juvenile lobsters (Edmunds 1995). A concerns about this area was that it is atypical of fishing areas due to the seasonal influence of fresh water. This area is, however, fished by commercial fisherman and heavily targeted by amateurs.
Mark Butler suggested post-larvae settle in relation to depth and structural properties of the substrate. He felt that the Iron Pot could be valuable for research in this direction due to the range of depth and substrate types within close proximity of each other. Similarly, this site provides both sheltered and exposed habitats due to a fringing reef on the northern side of the island. Additionally, the site is adjacent to a long-term puerulus settlement monitoring site so temporal data is available for this area.

A discussion about the potential of experimenting in one site such as Iron Pot, or any other, and using results elsewhere ensued. The discussion suggested that it would be sensible to experiment in a variety of areas. If the results show similarities then they may be applied widely.

12.1.2 Pigeon Holes

The behavioural activity of lobsters at this site was followed over the previous 12 months. The move by small juveniles (<35mm) from a solitary behaviour to aggregation could be marking an ontogenetic shift. It was suggested that the number of adult animals present in the area could influence the size of the shift. The possibility of a density dependent ontogenetic shift was suggested. It appears that very small *Jasus* are not attracted to larger ones, however there may be an attraction between juveniles of around 35 mm CL and larger sized animals.

The substrate here has minimal macroalgae present, with the exception of *Ecklonia radiata* which grows on top of several boulders. The bottom is silt covered with a large range of boulders and rubble resulting in abundant hides of varying sizes. The relatively flat topography of the area allows tracking of lobsters and relatively easy construction of grids on the bottom. The naturally high density of juvenile lobsters lends itself to an investigation of density dependence in this area.

John Booth catches more puerulus at 10–20 m depth than at 0–10 m so juveniles are occurring at least to 20 m. This could be due to rough surface conditions leading to better settlement and/or better survival at depth.

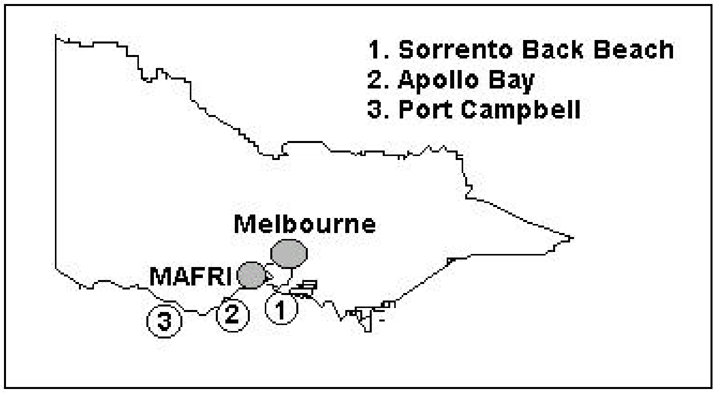
Mark Butler advocates studies in shallow water for a variety of reasons, including easier fieldwork. The biological differences between deep (eg 20 m) and shallow sites (eg 7 m) may only be small therefore he believes future research should concentrate on shallow sites. The type of work conducted should depend on the question and be very focused thereby eliminating the need for depth, except if depth is of particular interest.

Ali MacDiarmid thought that describing differences in juvenile and post-puerulus habitat and distribution is required, along with an experiment on the survival of early benthic stage lobsters, especially as there are areas of high juvenile density in the estuary.

12.1.3 Eastern Bruny Island

This dive was abandoned due to large swell.

12.2 Victoria



12.2.1 Sorrento Back Beach

The complex structure of the reef made juveniles very hard to find. The sedimentary substrate has eroded unevenly providing many ledges and holes suitable for lobsters. In the area surveyed lobsters of all sizes were scarce. During eight hours of diving only five lobsters were seen, all of which were adults. This area appeared to have low settlement and very few juveniles despite being a productive area in the past for commercial fishers. The depth of the area investigated was such that macroalgae was scarce, and sponges proliferated on most available surfaces.

There were also plenty of reef associated predators in this area including many wrasse species, cephalopods and other crustaceans. This area is very exposed and although it offers a very different habitat to other areas is unlikely to be suitable for a regular monitoring program. It would be better suited to opportunistic sampling when the weather permits.

12.2.2 Apollo Bay harbour

This was a good area to work in, with protection making it accessible most of the time, however the breakwater is artificial habitat. The primary substrate was large bluemetal boulders and cement on the breakwater, while the adjacent pier offered the addition of wooden structures. Juveniles were located upon wooden pier pylons adjacent to the collector sites. It was thought the breakwater may cause localised enhancement of settlement rates which could be utilised further.

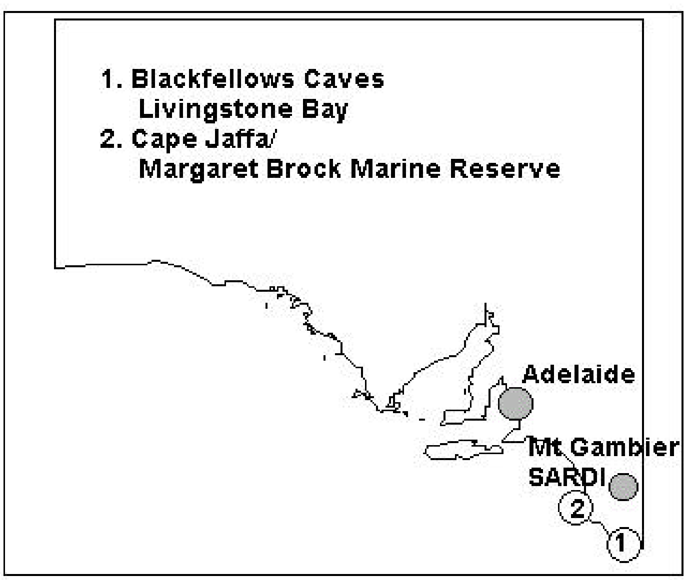
One advantage of this site is the sheltered nature of the bay behind the breakwater compared with the exposed nature of the southern side. The area allows work in all conditions behind the breakwater, and opportunistic sampling on the exposed side. There was little evidence of predatory animals here, although only a small amount of reef was sampled.

12.2.3 Port Campbell harbour

This area was considered very good for juvenile research. The limestone substrate provided plenty of natural shelters suitable for habitation by all benthic stages of lobsters. Expertise from the Japanese participants was instrumental in locating numerous puerulus settled in holes at the base of macroalgae (*Macrocystis angustifolia*) present at this site. Many other species of macroalgae were present, however it was at the base of *M. angustifolia* that puerulus were consistently collected. Port Campbell offers a range of exposure in a relatively small area, and is ideal for research as there are puerulus settling in reasonable numbers. There are some concerns over accessibility of the site as it is situated on a very exposed section of coast and although the bay has protection from the ocean, swell can restrict access and some contingency allowances would be required. Discussion centred on observations that areas associated with a concentration of currents, e.g. headlands, jetties, and breakwaters, show higher levels of settlement. It was considered that Port Campbell would require more collectors.

Port Campbell was the most remote site from a research station. Despite the logistics of sampling at Port Campbell, it was considered a worthwhile site to investigate post-settlement processes. It was concluded that experimentation at this site should be restricted to intensive sampling for one or two periods each year.

12.3 South Australia



12.3.1 Blackfellows Caves

Lewis used this site for juvenile research in the 1970's. The site is often hard to work due to the surge and potential low visibility from rotting algae and seagrass but it is accessible and may be a good site for collectors to monitor this area of coast.

Livingstone Bay is the area adjacent to Blackfellows caves. It is a large shallow bay protected from ocean swells by fringing reef. Low visibility due to fog restricted the areas that could be visited here, however dives were conducted on rubble covered by turfing algae. Subsequent visits have revealed limestone knolls throughout the rubble, these knolls harbouring large numbers of juveniles in an accessible and sheltered location.

Lighthouse point has a highly structured rocky reef bounded by sand. The reef is covered with large amounts of macroalgae. This area is swell affected, and the rocks show evidence of sand scour on the fringes. During the diving here there were few juvenile lobsters sighted, despite higher numbers of larger individuals being present.

12.3.2 Cape Jaffa, Margaret Brock Marine Reserve

Few juveniles and little habitat for early benthic stage lobsters were observed, however large numbers of larger lobsters indicate to successful settlement. There were high numbers of larger predatory fish that could impact juvenile lobsters. The presence of many large lobsters could be due to high growth rates.

13. Appendix 4 - Comments of M. Butler & A. MacDiarmid

13.1 Preface

Before making more specific comments on possible studies, we first offer a few comments recognising the inherent limitations and unique opportunities associated with the spiny lobster research situation in Tasmania, Victoria, and South Australia. A very positive aspect of the proposed research is the co-operative attitude of the principal investigators. Indeed, there are great advantages in having conformity in the scientific questions and approach taken in the primary studies performed in each state. However, in conjunction with this co-operative research program, more focused, unique studies by each State that capitalise on the environmental or logistical advantages available to each party should be explored.

13.2 Bottlenecks

Identification of ecological bottlenecks that constrain lobster population (stock) size lies at the crux of both the scientific interest among States and the potential for industry-based funding. If such bottlenecks exist and can be broached, then there is the possibility of enhancement or increased productivity. So what are the bottlenecks? Three general possibilities come to mind and are evident from studies elsewhere: A) PL Supply, B) Settlement Limitations, and C) Early Post-settlement Limitations. In the paragraphs to follow, we outline a few questions associated with each topic and offer some potential avenues for research. One should recognise, however, that there is likely to be great variability among research sites or even through time at a given site in the relative importance of each of these processes. Post larval supply is notoriously variable and some features of the benthic environment that potentially affect the subsequent survival and growth of juveniles (e.g. prey availability, macroalgal abundance, predator abundance, etc.) may also differ among sites or change over time. Again, the multi-State and multi-site research approach, carried out in intense sampling periods spread over several years, is likely to yield the most promising and comprehensive results.

13.3 Post Larval Supply

This includes broodstock considerations and subsequent post larval supply.

i) Broodstock limitations: include standard egg-per-recruit considerations, but also sperm limitation issues that have been largely overlooked. Broodstock research is well underway for *J. edwardsii*, so we need not dwell on this further here.

ii) PL Supply: this too is also well underway with respect to the measurement of PL catch in collectors along the coasts in question. However, measurement of PL supply on collectors alone is insufficient to address the question of whether supply is limiting or not. That is, post larvae might arrive in large numbers in some areas, but without ample settlement habitat, those recruits are lost, as has been documented in other regions.

13.4 Settlement Limitations

At its most general, settlement is limited by postlarval behaviour and habitat structure. These are perhaps best tackled by combining very focused laboratory habitat choice experiments with field manipulations of settlement habitat, along with studies that integrate measures of PL supply, habitat structure, and the abundance of early benthic juveniles (which ties this study with those to follow under Early Postsettlement Limitations).

i) Lab Choice Experiments: these involve tests to determine the specific habitat conditions that promote settlement (e.g. vertical nature of habitat, hole size, presence of macroalgae, light levels, rock holes vs. seagrass, etc.). In absence of plankton-caught postlarvae, need to embark on an intense effort to acquire transparent, recently-settled PL from collectors sampled daily and in enough abundance at high settlement sites to yield sufficient numbers for experiments. Those PL would then be quickly transported to lab where experimental set-ups await them for simultaneous runs. Access to labs in Hobart, Adelaide, and new ones soon in Queenscliff figure prominently here. The availability of existing high settlement sites and special expertise of those accustomed to transplanting Macrocystis (e.g. Sam Ibbott) are also positive points.

ii) Field Settlement Experiments: these involve field tests of hypotheses concerning settlement preferences of PL, carried out at sites where settlement is known to occur and is measurable (e.g. Port Campbell). These studies involve manipulation of both natural and artificial structures (e.g. natural and artificial rocks with holes, natural and artificial Macrocystis) in replicated factorial designs followed by monitoring of new settlers.

C) Early Postsettlement Limitations

i) "Grand Experiment": In many ways this is the over-arching study as it integrates many aspects of the recruitment process in the three States and is potentially an enormous sink of time and effort. Therefore, it must be conducted in short bursts of intense effort within specific sampling windows.

The basic idea is to choose sites within each State where PL supply is high and then subsites where habitat is perceived to be "optimal" and others where it is less so. PL supply will of course vary among these areas, which offers a spatial comparison of PL supply. It will also have low and high seasons within a site, providing temporal variation within a site. If one also knows the subsequent abundance of juveniles at these sites, as well as habitat structure, then comparisons among time periods within and among sites will reveal patterns perhaps consistent with one type of bottleneck or another.

Although not a formal manipulative experiment, where PL supply or habitat is directly manipulated, it should nonetheless yield useful observations and is considerably more feasible given the constraints of personnel and environment.

Surveys of early benthic juveniles and habitat structure at these sites should be slated at least twice a year, timed so that they lag the period of highest and lowest settlement by a period sufficient to allow the settlers to grow to an observable size (e.g. 7–8 month for *P. argas*). Specific, demarcated areas would be methodically surveyed for all juveniles each sampling period, based on methods pioneered for *J. edwardsii* by Matt Edmunds.

Besides juvenile numbers and sizes, one could also make measurements of growth/nutrition. Growth rates might be determined from mark–recapture of resident juveniles, along with microwire-tagged outplants of juveniles from collectors. Relative measures of growth and condition might include: length/weight ratios, pleopod moult staging and circumference measures, blood serum sampling, and biochemical analyses of tissue constituents (e.g. C/N, lipids).

If growth rates are known and size–frequency data available for each site, then various cohort analyses can be used to estimate mortality. In addition, if the study area were set up in a grid fashion, and if densities are high enough, then estimates of mortality and movement might be obtained using Jackson's method or other similar grid-based mark–recapture methods. These estimates would have to be based on the results from the day-to-day recaptures in the focused sampling period, rather than among sampling periods (when tags are lost, individuals leave or die, etc.).

At the same time, habitat structure for both settlers and early juveniles would be quantified. This might include the number of PL holes per unit area, macroalgal community diversity, rugosity of bottom at a couple of spatial scales (e.g. ht of boulders, rubble etc.; fractal dimensions), Macrocystis height etc.

ii) Ancillary Studies: Tethering of various sized individuals in different habitats will yield relative comparisons of risk of predation that can be quite insightful. Outplanting of microwire-tagged juveniles at various densities and within different habitats for short durations might also yield growth and mortality estimates. This can be accomplished using cages (with and without tops) or by capitalising on isolated "islands" of selected habitats surrounded by sand.

13.5 Practical Considerations of Settlement Enhancement

A range of studies might be performed that deal with the practical aspects and potential for enhancing PL supply that all involve the release and recapture of microwire-tagged juveniles. For example, what size to release, day vs. night release, lab behavioural or foraging conditioning, densities to release, etc.