STOCK ENHANCEMENT OF LOCAL POPULATIONS OF BLACKLIP ABALONE (*HALIOTIS RUBRA* LEACH) IN NEW SOUTH WALES, AUSTRALIA.

Thesis submitted by

Rowan C. Chick BSc (Hons)

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School of Marine and Tropical Biology

James Cook University

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ABSTRACT

This thesis examines the release and long-term (>2 years) survival and growth of hatchery-reared larval and juvenile blacklip abalone (*Haliotis rubra* Leach), on natural coastal reefs in New South Wales (NSW), Australia. Abalone are demersal, relatively sedentary, marine molluscs, that support important commercial, recreational and indigenous fisheries in numerous locations around the world. This thesis was developed in response to substantial depletions of local populations of *H. rubra* along >250 km of the NSW coast and the ineffectiveness of traditional fisheries management strategies to arrest these declines. These failures stem from demographic processes, common to haliotids, that limit their ability to re-establish populations that have been subject to substantial decline. A series of laboratory and field experiments were designed and conducted to examine a range of factors, and their interactions, that can have substantial affects on the success of releasing hatchery-reared *H. rubra* to natural reefs. The principal finding was that successful stock enhancement of local populations can be achieved, and the greatest value of a stock enhancement strategy is likely to be gained where the primary management objective is rebuilding depleted natural populations. Methodology, baseline targets and other recommendations are provided that would aid implementation of a stock enhancement management strategy to complement current traditional fisheries management approaches. The objectives of the research in this thesis were to: 1) investigate factors affecting the settlement, metamorphosis and early growth of *H. rubra* larvae; 2) batch-tag larvae and juveniles to enable their identification when recaptured; 3) develop and test methods for the successful release of larvae and juveniles; 4) develop a monitoring strategy to estimate the abundance of released abalone through time; 5) quantify long-term survival and growth to provide minimum targets for stock enhancement; 6) determine the impact of releasing juveniles on wild populations; 7) provide a bio-economic analysis and; 8) provide recommendations for the implementation of a stock enhancement management strategy for *H. rubra* in NSW.

The release of larvae to natural reefs requires them to be exposed to a number of handling and transport processes. In laboratory experiments conducted in this thesis, greater proportions (commonly >75%) of larvae settled, metamorphosed and grew to larger sizes when exposed to settlement substrata for longer periods of time (>24 hours). There was a lower settlement response in the presence of water flow, although the addition of gamma-aminobutyric acid (GABA) increased the proportion of larvae that settled within short periods of time, i.e. 25 - 100% more in ≤60 sec.. Larvae were resistant to simulated handling and transport processes, indicating their utility for stock enhancement.

The tagging of larvae and juveniles is fundamental to assessing the success of an enhancement program. Hatchery-reared *H. rubra* larvae and juveniles were successfully batch-tagged. The

tagging procedures provided an indelible mark, enabling the identification of individuals once recaptured, and unambiguous differentiation from wild conspecifics. Successful batch-tagging was also critical for the assessment of subsequent field experiments undertaken in this thesis. Larvae were batch-tagged with the epi-fluorescent dye, calcein. Laboratory experiments demonstrated that the tagged larval shell was clearly visible in the spire of juvenile shells after >250 days. The recapture of tagged and released larvae from natural reefs, >500 days after release, confirmed the persistence of this tag. A reliable and cost-effective method for batch-tagging juveniles was through the use of a commercial diet that resulted in the distinctive blue-green colouration of the shell. The presence of this blue-green colouration differentiated released juveniles from those in naturally occurring populations, could be observed with the naked eye, without the need for a UV light source, and persisted on the spire of individuals for >900 days.

Methods of releasing *H. rubra* larvae and juveniles were developed and tested in a series of laboratory and field experiments. A deployment pump that included a pressurised container and hose, was used to successfully release larvae to natural reefs. The addition of GABA and refrigeration during simulated transport, and the stage of release from the deployment pump, significantly affected the number of larvae delivered through the pump. The release of larvae to physical shelters on the reef significantly increased the numbers that settled, and their survivorship. There was added complexity in the process of releasing juveniles than with that for larvae. The use of a deployment device (PVC tube, ~300 x 125 x 65 mm), that was securely placed onto the substratum, was integral to the successful release of juveniles. Use of these devices in a standard release protocol ensured the limited physical handling of juveniles and provided a simple, cost effective and efficient method for the release of large numbers to areas of natural reef.

A monitoring strategy was developed and tested to enable accurate estimates of the abundance and therefore survival of released *H. rubra* ,of a variety of life history stages, to be measured. The abundance of *H. rubra* juveniles is difficult to accurately assess on natural reef because of their cryptic distribution among complex topography in rocky habitat. As a consequence, the precision and relative accuracy of methods to sample released abalone was examined in a series of field experiments, and included the dispersal of juveniles from deployment devices. The most accurate and precise estimates of the number of *H. rubra* surviving were detected using methods that disturbed the habitat, i.e. turning over boulders, within a release location, and multiple sampling approaches were required to measure the abundance of abalone of different sizes. For larvae, the collection of boulders provided more accurate estimates of abundance than samples taken using a venturi-lift. For juveniles, thorough searching of boulder substratum and more replicates provided more accurate estimates of abundance. Further, stratified sampling among

habitats after natural disturbance revealed greater densities of *H. rubra* in 'solid habitat', and spatially stratified sampling indicated juveniles can disperse up to 10 m from their release point in <8 days.

The success of a stock enhancement strategy is determined by the net value it adds to a population. This necessitates estimates of the long-term survival and growth of released individuals, the impact released individuals have on the extant population, and the bio-economic feasibility of an enhancement strategy. Rates of survival and growth varied substantially among releases and locations. However, the long-term survival of batch-tagged and released larvae and juveniles demonstrated that local populations of abalone could be enhanced with significantly greater numbers of juveniles surviving at multiple release locations than at control locations after >2 years. The release of juveniles had no detectable affect on the mean total number of wild conspecifics or wild recruits over these time scales. Long-term survival of released larvae and juveniles was generally low (<0.03%, range: 0 - 0.03% and; <4%, range: 0 - 10%, respectively). However, at three of the twelve juvenile release locations it exceeded that expected for wild abalone (range: 4 - 10%). Growth rates of released juveniles (range: 18 - 47 $mm.yr^{-1}$) indicated that they would generally reach sexual maturity within 2 - 3 years and exceed the minimum legal length within 4.5 years. A deterministic, bio-economic model was used to analyse the net present value (NPV) of a stock enhancement strategy for *H. rubra* in NSW, against an alternate investment return of 10% p.a.. Positive NPV occurred where long-term survival was >4% and where growth rates were higher than average rates reported in this research, or beach price exceeded \$AUD $34.kg^{-1}$.

Low rates of long-term survival of larvae suggests their large-scale release is unlikely to provide a viable stand alone option to successfully enhance local populations of *H. rubra*. The survival and growth of released juveniles, to replicate locations, demonstrated that depleted local populations of *H. rubra* in NSW can be enhanced, and that a stock enhancement program can complement the NSW Abalone Fishery management strategy. The success of any large-scale stock enhancement program will be determined by the definition of its objectives. Outcomes from this thesis suggest that the greatest value of a stock enhancement strategy will be gained where its primary objective is to rebuild depleted populations, rather than optimise commercial yield through the release of individuals to overcome recruitment limitation or to harvest released individuals at a larger size. The decision to implement such a program, including explicit description of its primary objective, is required to be made among well-informed representatives of all stakeholders. Further, this decision needs to be made with a thorough understanding of the current biological structure of the populations, including the nature of population depletions, the economic status of the fishery and in light of current, complementary and alternative management arrangements that may provide comparative increases in net value.

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Life history stage definitions as used in this thesis

larvae:	post-fertilised egg through to settlement stage, developed larvae
settled larvae:	larvae attached to the substratum, having undergone metamorphoses or not, up to ~4 days after initial settlement; ~0.3 < 0.5 mm
early juvenile:	abalone ~5 - 60 days post-settlement; ~0.5 < 2 mm SL (shell length)
juvenile:	an abalone >60 days post-settlement and up to size at maturity; 2 < 90 mm SL
early adult:	a mature abalone within approximately the first year of maturity; 90 < 115 mm
adult:	a mature abalone after approximately the first year of maturity and of minimum legal length (MLL) in NSW, Australia (≥115 mm SL; prior to July 2008), unless otherwise stated (see bio-economic modelling, Chapter 6, where MLL ≥ 117 mm, as of July 2008)

General terms

Barrens habitat:	areas of reef dominated by crustose coralline algae and relatively high abundances of sea urchins (Underwood *et al.* 1991).
boulder field:	relatively loose boulders (250 - 600 mm diameter), that can be moved by a diver underwater, interspersed between areas of solid habitat within Fringe habitat, and not dominated by articulated coralline alga and other turfing alga, or containing large quantities of sediment among boulders)
deployment device:	also described in the text as a 'device'. Physical structure made of poly-vinyl-chloride (PVC) used to hold and release juvenile abalone (dimensions ~300 x 125 x 65 mm), unless otherwise stated
Fringe habitat:	the variety of subtidal reef habitats defined in (Underwood *et al.* 1991)
larval age:	age of larvae in days post-fertilisation (used in relation to hatchery-reared abalone larvae in flow through, filtered, UV sterilized seawater at 18^{o}C)
metamorphosis:	the irreversible attachment of a larvae to a substratum, identified by the presence of peristomal shell growth

peristomal shell:	shell deposited after metamorphosis
settlement:	the attachment of larvae to a substrate whether having undergone metamorphosis or not
shell length (SL):	maximum diameter of the shell (mm)
solid habitat	area of reef consisting of boulders cemented together, immovable boulders and patches of solid bedrock containing cracks and fissures
stock enhancement:	the means of adding individuals to a natural reef to augment the total number of individuals persisting through time to support a sustainable population, harvestable stock or both
survival:	the total number of abalone estimated to be within a release location (abundance) divided by the number of abalone released, expressed as a percentage, unless otherwise stated