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Periwinkle Fishery of Tasmania: Supporting Management and a Profitable Industry

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Abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
CDF	Commercial Dive Fishery
CPI	Consumer Price Index
DPIPWE	Department of Primary Industries, Parks, Water and Environment
FRDC	Fisheries Research Development Corporation
IMAS	Institute for Marine and Antarctic Studies
MSC	Melbourne Seafood Centre
PIRSA	Department of Primary Industries and Resources of South Australia
SFM	Sydney Fish Market
TAC	Total Allowable Catch
TDCA	Tasmanian Commercial Divers Association

Executive Summary

This represents the first comprehensive study of the fishery, fisheries biology and markets for the edible periwinkle, *Lunella undulata*. Commercial catch and effort data, fisher knowledge, and growth and reproductive biology of periwinkles were integrated to provide a robust foundation supporting the management of the Tasmanian fishery. In addition, an evaluation of the domestic market for periwinkles, including distributors, retail and restaurant components, identified a number of impediments that need to be addressed by suppliers (fishers) if market growth and improved economic returns are to be realised.

Periwinkles are a moderately sized marine gastropod, growing to approximately 65 mm, which are harvested commercially by hand from subtidal reefs in Tasmania and several other Australian states. The species forms large localised aggregations that are readily targeted by divers in shallow water. In Tasmania they have been fished commercially since the 1980s as a part of the Commercial Dive Fishery. A management plan introduced in 2005 included a total allowable catch (TAC) of 35.2 tonnes split evenly over two management zones (Developed Zone in the south-east and an Undeveloped Zone covering remaining waters). A general lack of information on the biology and population structure of the periwinkle necessitated that a precautionary approach be adopted when setting the catch limits and, furthermore, the minimum size limit that was implemented at the time had no scientific grounding. The aims of the present study were to provide an assessment of the status of the periwinkle resource in Tasmania, determine size at maturity and growth to provide a basis for setting biologically meaningful minimum size limits, evaluate market potential to maximise economic returns, and to produce a report card to aid in the sustainable development and management of the fishery.

Commercial catches have fluctuated throughout the history of the fishery, largely as a result of fishers entering and exiting the industry and/or switching targets to fish alternate species. Since 2006 landings have fluctuated between 13 and 35 tonnes, averaging 22 tonnes per year. Most of the catch is taken from the south-east and north-east coasts, with catch rates higher in the south-east than the north-east. Regional catch rates (kg/h) have remained relatively stable since effort data was first recorded in 2007, suggesting current catch levels in the main fishing areas are sustainable. The resource is, however, under-utilised with large sections of coastline having minimal to no catch taken, implying opportunities exist to increase production. Regional catch and effort analyses highlighted that the zoning implemented with the initial management plan was restricting the development of the fishery into under-utilised areas (north and west coasts) since the TAC for the Undeveloped Zone was effectively taken from the north-east coast. In response, the fishery was rezoned for the 2013/14 season (September to August) with the Undeveloped Zone split into three (North-east, Northern and Western Zones) and the statewide TAC increased to 52.8 tonnes to facilitate development on the north and west coasts.

A mark-recapture growth study at five locations spanning the main fishing regions along the east coast revealed that initial growth of periwinkles is rapid, with animals reaching between 35.8 and 46.2 mm, equivalent to 80-88% of the average maximum lengths, within three years. Spatial variability in growth was evident with average maximum lengths differing by as much as 32% depending on site, ranging between 47 mm at Spikey Beach (central east coast) and 62 mm at Piccaninny Point (north east coast) and Recherche Bay (southern-most site). Growth was considerably slower at the Spikey Beach site, taking over six years to reach the legal minimum size limit of 45 mm compared with other sites which took 2.8 to 3.7 years to recruit to the fishery. Growth rates and maximum sizes were negatively related to water temperature, indicating that productivity of stocks may be influenced by climate variability.

Sex and maturity status of periwinkles was confirmed using visual and histological examination of gonad development. Mature males have a creamy-white gonad while mature females have a green gonad of variable shades. The length at 50% maturity ($LM_{50\%}$) varied between 23 and 26 mm on the east coast of Tasmania (between 1.1 and 1.6 years of age), with individuals in the north maturing at smaller sizes compared with the south. Lengths after two years of growth following maturity ranged between 39 and 47 mm suggesting that the vast majority individuals have the opportunity to complete at least one spawning, and for most two, before recruiting to the fishery at the current size limit, justifying the increase in minimum size limit from 30 to 40 mm in 2009 and to 45 mm in 2013. The increase to 45 mm was in

response to findings from the present study. Seasonal variation in gonad developmental stage, gonadosomatic index and anecdotal reports from fishers indicate that periwinkles have a protracted period of spawning activity, between October and April, with peak spawning activity during January and February.

Based on beach price, the Tasmanian periwinkle fishery is currently valued approximately $110,000, well below the potential value of $340,000 should the TAC be fully harvested. Supply of product to market is highly variable, with monthly volumes fluctuating between zero and 6.6 tonnes since 2006. Feedback from markets indicates it has been difficult sometimes for mainland retailers and restaurateurs to source periwinkles, which has subsequently led to a decrease in demand by consumers. By contrast, oversupply of product has occasionally been evident and resulted in a reduction in market floor prices of up to 36%. Market modelling of data from the Sydney Fish Market showed that Tasmanian supply was negatively correlated to price, with irregular supply, including large volumes landed infrequently as well as months with no catch, a key contributing factor. A significant and real increase in price can be attributed to changing fisher behaviour to improve timing of the catch, both seasonally and through more consistent levels of catch (thereby avoiding the price penalty associated with over supply). Consistency in supply is considered one of the key aspects to develop the periwinkle fishery.

The market for periwinkles appears to have considerable potential for expansion, especially through the restaurant and retail sectors (in particular to Vietnamese communities). Restaurateurs who have used periwinkles perceive them to be a versatile product, adding an element of uniqueness and flair to menus. However, a lack of product knowledge throughout the broader marketplace coupled with inconsistency of supply have been identified as hindering market growth. In order to address this problem, there is a need for an integrated marketing campaign driven by suppliers (fishers) to increase product image and knowledge. Product branding, labelling, a product fact sheet/brochure and the provision of sample boxes to markets are considered feasible strategies to increase product demand.

In accordance with the stock status classification guidelines defined in the *Status of Key Australian Fish Stocks Reports 2012* the Tasmanian periwinkle fishery is assessed as sustainable. Rezoning of the fishery coupled with the increase in the minimum size limit, both implemented in 2013, should help facilitate the sustainable expansion of the fishery. Ongoing monitoring of commercial catch and effort data will underpin assessment of the fishery and a supplier driven integrated marketing approach represents an important strategy to facilitate market expansion and increased economic returns to industry.

Keywords

Periwinkles, *Lunella undulata*, age and growth, size at maturity, periwinkle markets, Tasmanian Commercial Dive Fishery.

Introduction

Tasmanian Commercial Dive Fishery

The Commercial Dive Fishery (CDF) is a dive capture fishery that has operated in Tasmanian waters since the 1980's. The fishery targets numerous minor species comprising of:

- periwinkles – *Lunella undulate*;
- native sea urchin - *Heliocidaris erythrogramma*;
- long spined sea urchin – *Centrostephanus rogersii*;
- Japanese seaweed, wakame – *Undaria pinnatifida*;
- whelks – *Pleuroploca australasia* (removed from the fishery in 2009).

Additional species that are harvested under special permit or licences include:

- wild pacific oysters – *Crassostrea gigas*;
- native flat oysters – *Ostrea angasi*; and
- clams – *Venerupis largillierti*;

Most target species are harvested by divers using surface supply compressed air (hookah) operated mainly out of small boats (<10 m in length). Species are collected by hand, a single pronged hook or tongs, placed in a catch bag and then emptied into bins on board the fishing vessel for transport to a purge site or processing factory. Historically the most valuable species harvested has been the native sea urchin. However, in the past decade catches of periwinkles, clams and cockles have become increasingly valuable. Effort in the fishery is concentrated on the south and east costs of Tasmania, especially by fishers operating out of the ports of Hobart, Bicheno and St Helens. Not all of the 55 commercial dive licence holders are active in the fishery.

The periwinkle

Scientific name: *Lunella undulata*
Family: Turbinidae
Synonyms: *Turbo undulatus*, *Subninella undulates*. Genetic revision by Williams (2007) demonstrated that the genus *Turbo* was not monophyletic since some taxa, including the Australian species *Turbo torquatus* and *Turbo undulatus*, did not form a clade with the other *Turbo* species. As such nomenclature for *Turbo torquatus* and *Turbo undulatus* was changed to *Lunella torquata* and *Lunella undulata*, respectively, and are referenced as such throughout.
Common names: periwinkles, turban shells or snails, turbos, wavy turbo, warrener
Standard fish name: PERIWINKLES

The periwinkle, *L. undulata*, is a moderately sized marine gastropod found on exposed sand-scoured reef and boulder habitat in shallow temperate waters (0-20 m) of southern Australia (Figure 1). They grow to a maximum length of ca. 65 mm and are distributed from Hopetoun, Western Australia (33°57′ S, 120° 53′ E) to Coolangatta, Queensland (28°10′ S 153°32′ E), and around Tasmania (Edgar 2012). Periwinkles are generalist herbivores consuming a wide variety of macroalgae (seaweed) and articulated coralline algae (Clarkson and Shepherd 1985; Wernberg *et al.* 2008).

Periwinkles form large aggregations in shallow coastal waters which allow them to be targeted by commercial fishing operations. They are harvested by hand from subtidal reefs around the coast of Tasmania, New South Wales, Victoria and South Australia. The majority of commercial catch consists of *L. undulata* and originates predominantly from Tasmania and South Australia. Small volumes are also harvested in other states along with the closely related, but larger, *Lunella torquata* and *Turbo militaris.* A small recreational harvest for all species, predominantly from intertidal collecting, is also sustained.

Figure 1. Periwinkles, *Lunella undulata*, aggregating on a shallow rocky reef in NE Tasmania.

Previous research

Biological information on *L. undulata* is scarce with few studies focusing on this highly abundant, commercially harvested gastropod. Previous studies have considered some aspects of diet (Clarkson and Shepherd, 1985; Worthington and Fairweather 1989), reproduction (Underwood, 1974) and habitat (Worthington and Fairweather 1989; Smoothey 2008), while periwinkle ecology has been incorporated as a component of major studies focusing on broader community ecology (Edgar *et al.* 2004; Currie and Sorokin, 2009). Limited but detailed studies on the closely related *L. torquata* are available and have examined reproductive biology and ecology (Joll 1975; Joll 1980; Ettinger-Epstein and Kingsford 2008).

Ecology

Lunella undulata and closely related species have highly varied patchy distributions within their distributional ranges forming large localised aggregations (Keough *et al.* 1993; Vanderklift and Kendrick 2004; Currie and Sorokin 2009). In 1993, very dense intertidal aggregations of the species were observed off Falmouth, eastern Tasmania, with up to 430 individuals counted in a single 25 cm quadrat (Griffith *et al.* 1995). However, these aggregations fluctuated hugely and none of similar size have been observed since (T.J. McManus, Falmouth. *pers. comm.*).

Past research suggests that larval settlement and aggregating behaviour of periwinkle species is strongly influenced by habitat type. Controlled experimental studies on the Japanese species *L. cornuta* found that the settlement of larvae and post-settlement aggregating behaviour of juveniles was strongly linked to the presence of articulated coralline algae (Hayakawa *et al.* 2007; Hayakawa *et al.* 2008). Biogenic habitat features (i.e. presence of canopy-forming and turfing coralline algae) have been shown to be an important determinant for the movement and distribution patterns of *L. undulata* in NSW (Smoothey 2008). Body size also plays a major role in post-settlement dispersal patterns. Two studies investigating *L. undulata* and *L. torquata* both found that larger snails moved significantly larger distances and among patches of habitat than smaller individuals, which tended to remain within protective kelp habitat (Ettinger-Epstein and Kingsford 2008, Smoothey 2008).

Periwinkles are generalist herbivores consuming a wide variety of algae (Wernberg *et al.* 2008). A dietary study found that *L. undulata* predominantly consumed brown and green macroalgae and articulated coralline algae (Clarkson and Shepherd 1985). Brown macroalgae is also an important source of habitat, providing protection from waves, desiccation and predators (Worthington and Fairweather 1989). There seems sufficient evidence to suggest that the presence of macroalgae and coralline algae provide a vital source of food and shelter, and has some influence on aggregating behaviour.

Populations of *L. undulata* may be effected by declines in kelp forest, due to natural or anthropogenically-induced climate change and the poleward range expansion of the barren-forming long-spine sea urchin *Centrostephanus rodgersii*. In eastern Tasmania, *L. undulata* numbers halved within a month following experimental removal of canopy-forming kelp; with such declines probably due to increased predation (Edgar *et al.* 2004). Furthermore, experimental removal of kelp cover in NSW caused a dramatic decrease in *L. torquata* even though food algae were plentiful (Ettinger-Epstein and Kingsford 2008). This strong link between the abundance of *L. torquata* and kelp cover, explains the considerable decline in numbers after the 1997/98 El Niño event, which severely affected kelp density in the region (Ettinger-Epstein and Kingsford 2008).

Life History

In NSW *L. undulata* has a protracted spawning period from October to May, and may undergo incomplete spawning (retain unshed eggs until the next spawning event) (Underwood 1974). The timing of spawning in other waters is unknown. They have short-term lecithotrophic larvae (planktonic larvae which live off the yolk supplied by the egg) (Underwood 1974), and it is assumed that the larval duration is about five days, similar to other species within the taxon (Shepherd *pers. comm.* within Sullivan and Mavrakis 2006).

The related *L. torquata* spawns twice a year, in autumn/winter and in spring/summer, however, spawning events have been found to be non-synchronous between populations separated by relatively small distances (10s of kms) (Ward and Davis 2002). Another study on *L. torquata* in Western Australia found that spawning occurred several times per year, with a peak of activity in summer (Joll 1980). Environmental conditions, such as water temperatures are probably important in regulating reproductive cycles and triggering spawning events (Underwood 1974; Joll 1980).

There have been no previous studies of age and growth in *L. undulata*. The larger *L. torquata* (maximum size 98 mm) and *T. intercostalis* (maximum size 80 mm) have been shown to grow quickly in the first few years of life, reaching 46 and 59 mm after two years, respectively (Joll 1975). Comparisons of growth of *T. intercostalis* at two sites in Western Australia suggested growth was significantly slower at the cooler site which also had reduced food supply (Joll 1975). Bruton *et al.* (1991) found that *T. sarmaticus*, a South African species, grew more rapidly in the smaller size classes, then slowed and reaching the maximum size at about 10 – 11 years of age. Foster *et al.* (1999) showed growth rates of *T. sarmaticus*, varied significantly depending on diet.

Fisheries

No fisheries based studies have been completed on *L. undulata* though there has been some research on the effects of harvesting populations in the intertidal zone. Correlations between human collection and size composition of several gastropod populations found that, with the exception of *L. undulata*, individuals were significantly larger in the areas protected from collection (Keough *et al.* 1993). Of the gastropod species examined, *L. undulata* was the only subtidal species, suggesting that populations may be replenished from subtidal recruits (Keough *et al.* 1993).

The South African turbo shell *T. sarmaticus,* which constitutes a localised subsistence fishery, was found to be regionally sustainable due to adjacent subtidal and intertidal refuge populations which maintained the larger mature individuals (Proudfoot 2006). In another study on this species mature individuals were found in subtidal habitats, which were preferred over intertidal habitats (Bruton *et al.* 1991). Density and size structure of *T. sarmaticus* has been found to be similar between marine reserves and exploited sites, such resilience may again be due to replenishment from subtidal populations (Foster and Hodgson 2000).

Need

Periwinkles exhibit patchy distributions, forming large localised aggregations that are easily harvested by commercial fishers. The fishery in Tasmania has been operating for over 30 years with catches reaching as high as 35 tonnes per annum. Despite this there is a lack of information on the biology, population structure and behavioural characteristics of the periwinkle that hinders prospects to maximise the fishery potential for the species in Tasmania.

The Department of Primary Industries, Parks, Water and Environment (DPIPWE) is bound by the *Living Marine Resources Management Act 1995* to ensure that fisheries are managed in a sustainable manner. However, with the lack of information about the periwinkle stock DPIPWE has adopted an ostensibly precautionary approach to guide it in setting catch limits for the species. Furthermore, the minimum size limit that applies for the species has no scientific grounding and thus there is no surety that it provides adequate protection to enable individuals to breed prior to being recruited into the fishery.

There is strong support from managers and industry for research into the population structure and fisheries biology of periwinkles required to guide the future development of the fishery. Commercial Dive Fishery operators have also identified the need for an assessment of market supply and demand relationships in order to improve economic returns. Periwinkles are harvested in several states with Melbourne and Sydney the main domestic markets, meaning that the Tasmanian fishery competes in a national context. Understanding ways to better market and promote periwinkles is required to achieve strong market growth and maximise returns. The lack of market understanding is likely to have limited the development of the fishery, which in all likelihood has failed to reach its full potential both in terms of sustainable harvest and economic returns.

Objectives

The objectives of this project are to:

1. Assess diver perceptions on periwinkle resource status and factors that influence aggregating behaviour and variability in abundance.

2. Assess regional and habitat variability in size at maturity and growth in periwinkles and the appropriateness of current size limits.

3. Evaluate the relationship between supply and demand for periwinkles and options to maximise economic returns to the Tasmanian industry.

4. Develop a fishery report card to aid in the sustainable development and management of the periwinkle fishery.

Methodology

Commercial fishery data

Commercial fishery information and data was sourced from fisheries logbook data, observations of commercial operations and surveys of key fishers.

Logbook data

Prior to the implementation of the Commercial Dive Fishery Management Plan in December 2005, the only data available about the fishery was catch volumes, with no data recorded on fishing areas or effort during this period. Furthermore there were no data available for 1999 and the period between January 2005 and the start of the 2006/07 fishing season (September 2006).

The implementation of the management plan included a requirement for fishers to report fishing location/fishing block/fishing zone and daily catch data (Figure 2). From the start of the 2007/08 fishing season (September 2007) effort information (dive hours) was also incorporated in the logbook.

Logbook data were grouped spatially for regional analysis with regions based on the zoning arrangements that were implemented for the 2013/14 season; namely Northern (N), North Eastern (NE), South Eastern, (SE) and Western (W) Zones (refer Figure 5). Reporting of catch and effort at this regional scale has been limited to those years (fishing seasons) in which ten or more days fishing for periwinkles was reported.

Geostatistical catch curves (catch verses fished area) by region and fishing year are presented following the methods of Petitgas (1998), with fished area within a region based on the number of reporting blocks fished.

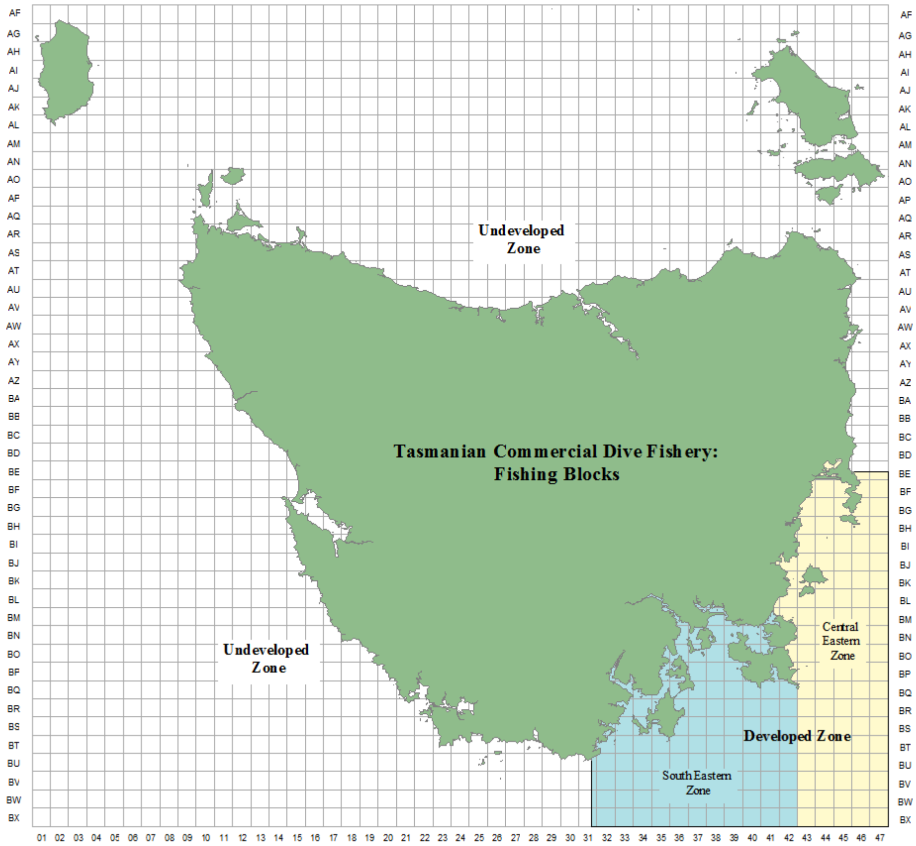


Figure 2. Map showing reporting blocks and Developed and Undeveloped Zone boundaries used in the Tasmanian Commercial Dive Fishery from 2005.
The subdivision of the Developed Zone into Central Eastern and South Eastern Zones was predominantly for the management of the urchin fishery.

On-board catch sampling

Researchers joined fishers on eight commercial fishing trips in both the NE and SE regions to observe operations and gain insights into harvesting, handling and processing procedures. Observed operations were undertaken as single day trips.

Fisher survey

Semi-structured face-to-face interviews were conducted with key fishers covering a range of issues relating to the periwinkle fishery, including fishing operations, periwinkle ecology (habitat; aggregations), resource dynamics (stock status; recovery from fishing), market (current and future development) and management. The seven interviewed fishers accounted for 84% of the total production reported over the last three fishing seasons.

Key objectives of fisher surveys were to:

- describe fishing operations, processing methods and supply chains to markets;
- record diver observations on periwinkle aggregating behaviour and recovery from fishing;
- assess fisher perceptions about the current status of stocks and how this has changed over the history of the fishery;
- determine the socio/economic/environmental drivers of fisher behaviour; and
- gain insights into the markets for periwinkles and assess avenues for future market development.

Fisheries biology

Sites

Five sites along Tasmania's east coast were selected for a 12 month study of periwinkle growth and size at maturity (Figure 3). Sites were selected after discussions with key commercial fishers in each region, and are considered representative of the broader east coast region. Since 2006, 85% of the total commercial catch has been taken from the area covered by these sites. Additional samples of periwinkles for size at maturity analyses were collected from the north-west coast (Hunter Island), west coast (Low Rocky Point) as well as five other sites along the east coast (Figure 3) by research divers and commercial fishers under permit.

At each of the growth and size at maturity sites a HOBO Water Temperature Pro v2 data logger was installed at ca. 2-3 m depth to measure temperature over the study period. These data are presented along with temperature data from long-term temperature monitoring sites from various locations around Tasmania (Figure 3). Temperature loggers used at the long-term monitoring sites are located in ca. 8-12 m water depth and have been in place for various periods of time since ca. 2005.

Annual heating degree days were calculated by adding the difference between the daily mean temperature and a base temperature of 16°C for all days where 16°C was exceeded. Cooling degree days were calculated by adding the difference between a base temperature of 13°C and the daily mean temperature for all days colder than 13°C. The base temperatures were selected based on other similar species where growth is substantially reduced above 16°C and below 13°C.

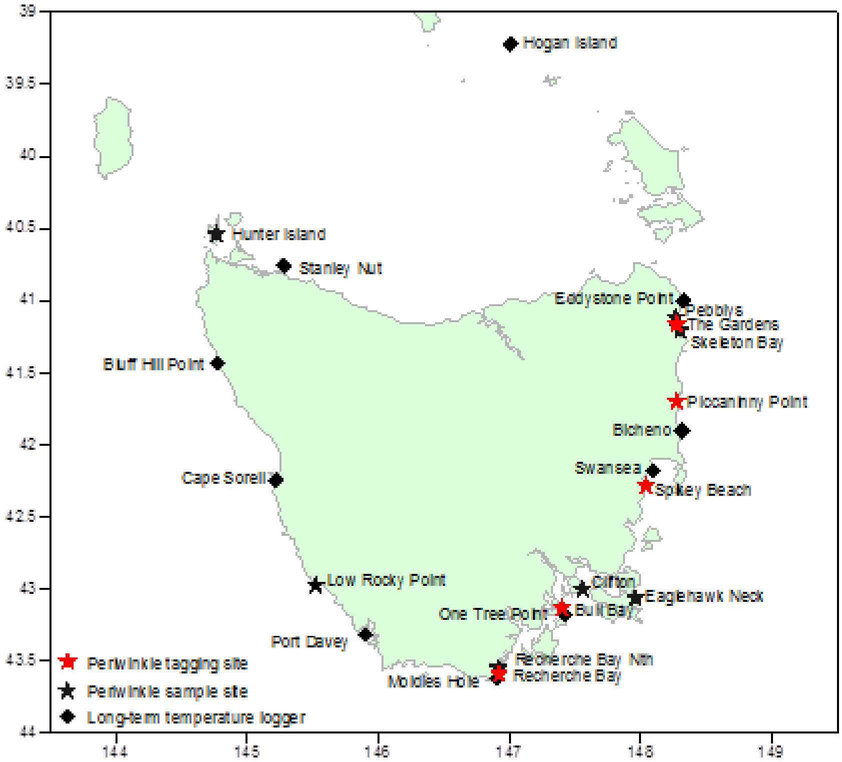


Figure 3. Map of Tasmania showing the five tagging sites to assess periwinkle growth and locations of long-term temperature loggers referenced in this study.

Biological measurements

Maximum shell length was used to describe periwinkle size and to match the standard used to describe the size limit in the commercial fishery. The maximum shell length and operculum lengths were measured to the nearest 0.1 mm and whole weights to the nearest 0.1 g to determine shell length-weight and operculum length- shell length relationships. The latter was determined due to advice that it would be valuable for archaeologists and historians researching aboriginal middens.

Growth

A minimum of 600 periwinkles were collected and measured by divers along shore-normal dive transects to obtain representative length-frequency distributions of populations at the five tagging sites in February/March 2012. Collections were conducted again 12 months later to assess changes in the population size structure and determine if cohorts could be used to assess growth.

A total of 600 periwinkles from each of the five sites (3000 in total) were tagged with Hallprint FPN glue-on shellfish tags. Individuals to be tagged were selected to ensure a broad size range was obtained to facilitate accurate estimation of growth parameters. The thin (150 um), flexible polyethylene tags were attached firmly with cyanoacrylate glue and covered with clear marine epoxy resin. Periwinkles were collected by divers, tagged and then released by divers at the same site of capture. All tagged animals were released within a 5 m radius. In addition to the glue-on tags, periwinkles were marked with a paint mark to aid detection. At two sites (Bull Bay and Spikey Beach) the tag number was also written on the operculum with graphite (2B pencil) as anecdotal reports suggested this may be sufficient to re-identify individuals through time. Recapture surveys were conducted February/March 2013, approximately 12 months after tagging.

Recaptured periwinkles were measured to the nearest 0.1 mm. Growth increments were analysed using a non-linear regression of Fabens (1965) re-parameterisation of the von Bertalanffy growth function

$$\Delta L_i = (L_\infty - L_i)(1 - e^{-Kt_i}) \qquad \text{Equation 1}$$

where ΔL_i is the growth increment, L_∞ is asymptotic or average maximum length, L_i the release length, K the coefficient of growth and t_i the time at liberty of the i-th periwinkle. The relationship between L_∞ and degree-days was determined by linear regression and tested for significance (P<0.05).

Seasonal growth was determined by monitoring 100 individuals held in flow-through sea-water tank facilities at the Institute for Marine and Antarctic Studies, Taroona. The tagged periwinkles were maintained in ambient water temperature and light conditions and were fed on brown and green macroalgae which was added to the tank on a regular basis. The periwinkles ranged in size between 9.4 mm and 32.2 mm at the start of the experiment and were measured every three months. Three mortalities were recorded over the 12 month tank study.

Gonad maturation and size at maturity

Sexual maturation and the reproductive cycle were assessed thru macroscopic and microscopic examination of the gonad. At 1-2 month intervals approximately 50 periwinkles were dissected from each tagging site and gonads fixed in FAACC (10% formalin, 5% glacial acetic acid and 3% calcium chloride). A portion of gonad tissue was dissected from just posterior to the spiral caecum and processed using standard histological techniques to yield 6 µm sections which were stained with haematoxylin and eosin dyes. In addition, some specimens were sectioned longitudinally along the visceral coil to determine if there was variation in maturation and spawning in different areas of the gonad. Gonad maturation and oocyte developmental stages were described and categorised based on descriptions of the closely related

L. torquata (Table 1; Joll 1975). While microscopic staging could distinguish all stages of gonadal development, macroscopic staging could only differentiate the boarder stages of non-sexual juvenile, maturating juvenile (male and female) and adults (male and female). Macroscopic and microscopic staging was compared at this broader level to assess the accuracy of macroscopic staging. Additional periwinkles were staged macroscopically during the main period of maturation to provide a minimum of ten individuals per 1 mm bin where possible; these data provided the basis for the length at maturity analyses.

In this study, length at maturity refers to the length class at which 50% of individuals were classed as mature ($LM_{50\%}$). Preliminary analysis showed that there was no difference in $LM_{50\%}$ values between male and female periwinkles, and as such data for the two sexes were combined for all analysis. Rates of maturation by size were determined by logistic regression of the maturation data (maturity status, size to 0.1 mm) to the logistic equation using the statistical package *STATISTICA*:

$$p = \frac{e^{c+dx}}{1+e^{c+dx}} \qquad \text{Equation 2}$$

where *p* is proportion mature, *x* is length (or age), and *c* and *d* are parameters of the logistic function.

The gonad sections of adult females were also used to assess the timing of spawning by monitoring changes in oocyte development and measuring changes in the gonadosomatic index (GSI). GSI was calculated as:

GSI = (area of gonad section / total area of section) x 100. Equation 3

The use of total section area in the calculation standardises the gonad size with respect to the animal size. The areas were determined using the image analysis software ImageJ (Image analysis and processing in Java).

In addition to samples collected in the present study, histological sections from periwinkle gonads collected from three sites - Bicheno, North Bruny Island and Recherche Bay - between November 1991 and May 1993 were re-examined. These sections were prepared in the same manner as the present study, with each location sampled more or less on a monthly basis (R. Green, *pers. comm*.). Approximately thirty adult female gonads were staged and GSI calculated for each monthly sample at each locality.

Table 1. Description of gonad stages in periwinkles (adapted from Joll 1975)

Stage	**Description**	
Juvenile	**Non-sexual**	
Undeveloped juvenile	No germ cells present. Gonad lumen not developed.	
Juvenile	**Male**	**Female**
Maturation Stage 1	Spermatogonia, spermatocytes and spermatids present, but sparsely scattered along the tubules. A few spermatozoa; no amaebocytes. Lumen small.	Only oogonia and early stage oocytes present No fully developed oocytes. Lumen of ovary still small.
Maturation Stage 2	Testis moderately full with spermatozoa. Thick layers of spermatogenic cells present. No empty areas	Oogonia and a full range of developmental stages of oocytes, including fully developed oocytes, present. No empty areas of signs of collapsed ovary.
Adult	**Male**	**Female**
Ripe	Testis lumen full of spermatozoa. Few spermatocytes or spermatids. A narrow space between the tubules and the mass of spermatozoa.	Ovary packed with fully developed oocytes, Oogonia and early stage oocytes present. Stalked, vitellogenic oocytes infrequent.
Spawned - fully	Lumen of testes empty of spermatozoa except for occasional relics. Few spermatocytes or spermatids around tubules. Testis may be partially collapsed. Amaebocytes present in Lumen	Ovary fully devoid of fully developed oocytes, except for a few relics which show signs of degeneration. Oogonia and early stage oocytes present. Ovary somewhat collapsed and trabeculae folded. Amaebocytes present.
Spawned - partially	Some areas of the testis devoid of spermatozoa except for relics; other areas full of spermatocytes or spermatids around tubules. Empty areas contain amaebocytes.	Part of the ovary, usually an area near the inner wall, devoid of developed oocytes Outer ovary contains fully developed oocytes. Oogonia and early stage oocytes present. Trabeculae intact but usually somewhat folded.
Regeneration Stage 1	Tubule walls covered with a thick layer of spermatogenic cells. Moderate quantities of spermatozoa present. Spawned areas containing amaebocytes present.	A wide range of Oocyte developmental stages present. From oogonia to fully developed oocytes. Spawned areas may still be present. And ovary may still show signs of collapse.
Regeneration Stage 2	Lumen moderately full with spermatozoa. A few small spawned areas containing amaebocytes may occur. Spermatogenic cells form a layer of varying thickness around the tubules. In early R2 stage the layer may be very thick, but as the testis approaches the ripe condition the numbers of spermatogenic cells (and the thickness of the layer) diminish.	Ovary moderately full with fully developed oocytes. Oogonia and a range of developmental stages still present.

Markets and economics

Market survey

Fish markets, wholesalers, distributors, retailers and restaurateurs that had processed, utilised or consumed periwinkles in both Sydney and Melbourne were visited in February 2013. Semi-structured, face to face interviews were conducted to gain insights on supply and demand, product utilisation, market structure and potential avenues for market development. Both the Sydney Fish Market (SFM) and Melbourne Seafood Centre (MSC) were visited and interviews with six wholesalers and distributors were conducted, along with supply managers at the SFM and the CEO of the MSC. Regional seafood retailers were interviewed (five persons) in the Vietnamese communities of Cabramatta (Sydney) and Footscray (Melbourne) where periwinkles are traded. Furthermore, seven chefs who had used periwinkles on their menus were interviewed.

Market data and modelling: Sydney Fish Market

Monthly sales data, comprising volume, minimum, mean and maximum prices, were obtained from the SFM between September 2001 and May 2013. Price data were adjusted to i) the overall Australian consumer price index (CPI) and ii) the Sydney Seafood CPI relative to June 2013 to determine if the long term increase in price represents a real increase in the value / profitability of the fishery or an increase solely due to inflation. All CPI data were obtained from the Australian Bureau of Statistics (ABS). The Australian CPI gives an indication of relative prices that a periwinkle fisher would be paying for commodities, including business expenses such as fuel and personal expenses such as food and housing. In contrast adjusting by the Sydney Seafood CPI gives an indication of the value of periwinkles relative to other seafood products in Sydney. A linear regression was used to explore the changes in CPI adjusted data through time.

A generalised linear model was used to explore the relationship between volume marketed, year, time of year and price. Time of year was based on four three-month periods (quarters) beginning at the start of the quota season, the first quarter being September to November. Coincidently, these coincided with the four seasons. Two models were run, one with each of the CPI indices listed above.

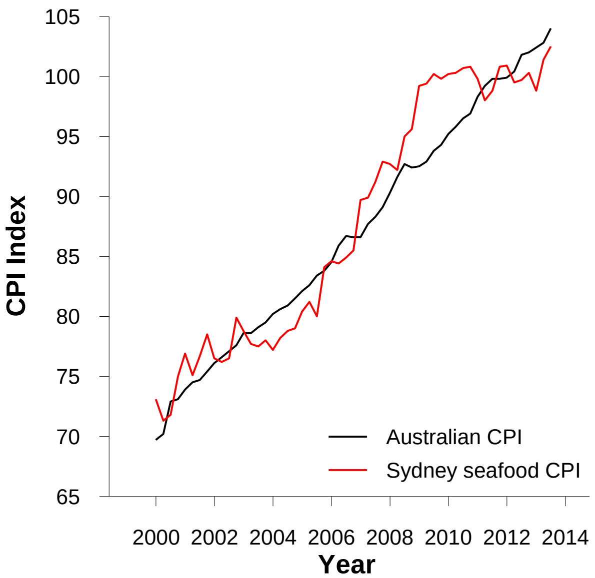


Figure 4. Australian and Sydney seafood Consumer Price Index (CPI)

Fishery value

Total fishery value was calculated using beach price estimates and fishery logbook catch data. Beach price estimates were based on market floor prices collected from the SFM, which included market commission and transport costs. The market floor prices were adjusted to account for these costs, consistent with the methodology used by ABARES to determine Commonwealth fishery prices. The adjusted prices reflect beach prices consistent with the definition provided in Australian Fisheries Statistics (Skirtun *et al.* 2013). Feedback from fishers and retailers indicated that SFM floor prices are comparable to those obtained in other markets in Sydney and Melbourne.

Report card

Fishery and biological data, combined with fishers' perceptions and market information were synthesised to produce a fishery report card and provide recommendations to improve management regimes and develop strategies to maximise catch, market growth and economic returns.

Results

Management overview

The commercial periwinkle fishery in Tasmania forms part of the CDF which also includes the commercial harvest of sea urchins and several other invertebrate species. The fishery commenced in the 1980s and since that time there have been large fluctuations in catch and levels of activity. Initially the fishery was unregulated however, concerns over latent effort and localised overfishing led to proposals to limit access to the fishery. A moratorium on the issue of new licences was introduced in 1994 and from 1999 any licences that had lapsed could not be renewed or replaced. These initiatives resulted in a considerable reduction in the number of licence holders, dropping from 127 in 1993 to 55 in 2005. Despite the large number of licence holders in the fishery relatively few have targeted periwinkles in any given year.

Prior to the implementation of the Commercial Dive Fishery management plan (DPIPWE 2005), operators had unrestricted access to each of the main commercial dive species (urchins and periwinkles). The management plan was developed to facilitate the sustainable management of the target species and to assist the further development of the fishery while adhering to principles of ecologically sustainable development. Management strategies involved establishing zones for specific species to allow greater management flexibility, area closures during critical periods, minimum size limits, and the introduction of Total Allowable Catches (TACs) to address concerns relating to stock status and latent capacity in the fishery.

The management plan divided the fishery for periwinkles (and urchins) into two zones based on catch history; a 'Developed' Zone off the south-east coast where the majority of the catch had been taken and an 'Undeveloped' Zone that included the south, west, north and north-east coasts (Table 2, Figure 5). TACs were introduced for both zones as a precautionary measure to limit the exploitation of periwinkles. Within the Developed Zone the TAC was set at 17.6 tonnes; 75% of the total average annual catch for the five years prior to the implementation of the plan. The same catch limit was applied to the larger Undeveloped Zone, resulting in a state-wide TAC of 35.2 tonnes. The management plan and associated rules commenced in December 2005; fishing seasons run between September and August in the following year.

A minimum size limit of 30 mm was introduced in 2005 but was not set on a scientific basis. Observations that periwinkle populations were recovering very slowly after harvesting led to a size limit increase to 40 mm as a precautionary measure for the start of the 2009/10 fishing season.

A review of the Commercial Dive Fishery Management Plan and policies was undertaken in 2010 and resulted in a number of changes relating to the harvest of periwinkles (DPIPWE 2011). These included:

- dual abalone and commercial dive licence holders being permitted to take commercial dive species while on an abalone fishing trip;
- flexibility regarding the incidental take of small quantities of undersize periwinkles; up to 10% of the catch by number; and
- rules to accommodate the placement, removal and transport of periwinkles to and from cauf sites.

The most recent review of the periwinkle fishery completed in 2013 incorporated key findings from the present study. The fishery was rezoned with the Undeveloped Zone split into three, namely North East Zone, Northern Zone and Western Zone (Table 2, Figure 5). The Developed Zone boundaries remained unchanged although that zone has been renamed as the South East Zone. The state-wide TAC was increased to 52.8 tonnes under the new structure and the size limit increased to 45 mm, taking effect in September 2013.

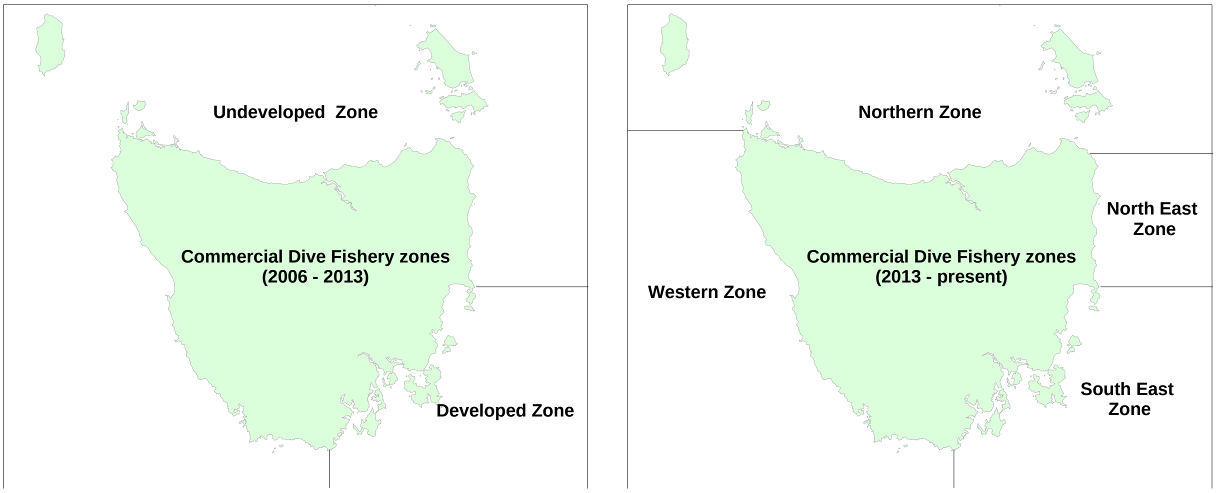


Figure 5. Fishing zones for the Tasmanian commercial periwinkle fishery applied between the 2006/07 and 2012/13 fishing seasons (September – August; left) and new zoning arrangements applied from the start of the 2013/14 fishing season (right).

Table 2. Zones and total allowable catch (TAC) in the Tasmanian commercial periwinkle fishery.

Fishing season	Zone	Area	TAC (tonnes)
Pre 2005	No zones		No TAC
2006/07 – 2012/13	Developed	Whale Head and north to a line running west to east through Cape Sonnerat	17.6
	Undeveloped	All other waters	17.6
	Total		**35.2**
2013/14-on	South East Zone	Whale Head and north to a line running west to east through Cape Sonnerat	17.6
	North East Zone	North of Cape Sonnerat to a line running west to east through Cod Bay	17.6
	Northern Zone	Cod Bay, west to Woolnorth	7.6
	Western Zone	Woolnorth, south to Whale Head	10.0
	Total		**52.8**

Fishery operations

Periwinkles are harvested by divers using surface supply compressed air (hookah) equipment operating predominately out of small boats (<10 m in length). The animals are gathered by hand or hook and are placed into catch bags before being emptied into bins/caufs on board the fishing vessel. Selection of sized animals (currently ≥ 45 mm) is achieved by a combination of the divers actively searching/sorting underwater, large-meshed catch bags which allow smaller animals to fall through, and on-board sorting. Reported dive times averaged 3.2 h/day and most ranged between 1-5 h/day (refer Figure 14). Dive times of up to 9 h/day have been reported; dive durations of this order are achievable due to the shallow coastal waters that periwinkles inhabit, typically less than 5 m.

Catches are initially transferred to purge sites where the periwinkles are allowed to purge for a minimum of 48 h. Purging is necessary to allow the expulsion of sand and detritus from within the shell and typically occurs at coastal cauf (purge) sites under permit for a minimum of two days before shipping to market. Purging within holding tanks at processing facilities, although possible, is uncommon due to the large quantity of waste excreted. Failure to purge periwinkles results in sub-standard product that can result in consumer dissatisfaction. After purging periwinkles are packed into 10-20 kg polystyrene boxes and shipped live by road freight to Sydney and Melbourne fish markets, wholesalers and distributors.

Catch and effort

State-wide trends

Catches of periwinkles increased steadily in the early years of the fishery and reached 32.1 tonnes by 1997 (Figure **6**). Since then catches have fluctuated between 13.0 and 35.2 tonnes p.a., averaging 23.3 tonnes p.a. Recent landings have been taken by between 8 and 15 divers in any given season.

Initially, most interest was centred on the Developed Zone with the catch limit of 17.6 tonnes reached in the first fishing season (2006/07; Table 3, Figure 14). By contrast, the Undeveloped Zone was left largely unfished. In 2007/08 the strategy of separate catch limits in the two management zones coupled with market demand, saw effort extend into the Undeveloped Zone. There was a more even spread of effort and the catch limit was attained in both management zones. Catches in the Developed Zone then fell substantially and since 2008/09 catches from the Undeveloped Zone have consistently exceeded those for the Developed Zone, reversing the pattern that existed earlier in the fishery (Figure **7**). State-wide landings fell to a 16-year low of 13.0 tonnes in 2009/10 before recovering to range between 17.9 and 20.5 tonnes in the last three seasons. The total annual catch of periwinkles has been well below the TAC in most fishing seasons with an average only 62% of the TAC being caught.

Monthly catches have varied significantly, ranging between zero and 6.6 tonnes (Figure 8). A nil catch was reported in May 2007 when the Developed Zone was closed because its TAC had been attained and there was no fishing activity at that time in the Undeveloped Zone. By comparison, at the opening of the 2007/08 season in September 2007 the highest monthly catch was reported, derived entirely from the Developed Zone following the five month closure of that zone.

Since the start of the 2006/07 fishing season, periwinkles have been harvested predominately along the south and east coasts of Tasmania (Figure 9), particularly in regions close to the ports of Hobart in the south and St Helens in the north-east. In the past seven seasons catches have averaged over one tonne in five fishing blocks[1], with the heaviest fished block yielding a total of 27.6 tonnes for the period (Figure 10). A further five blocks averaged between 0.5-1 tonne while 14 blocks averaged 0.2-0.5 tonnes p.a. In total, catches have been reported from 80 individual fishing blocks since 2006/07.

[1] Fishing blocks are defined by the geographic coordinate system with borders 10 minutes latitude and 10 minutes longitude in length (c.a. 6 nm × 6 nm).

Patterns of annual effort in terms of days fished and dive hours mirror that of the total catch, with the maximum fishing effort (121 days and 395 dive hours) coinciding with the catch peak recorded in the 2007/08 season (Figure 7). Fishery-wide catch rates declined steadily from 290 kg/day in 2006/07 to 164 kg/day in 2011/12 before increasing to 199 kg/day in 2012/13. Catch per hour dropped from a peak of 99 kg/h in 2007/08 to 56 kg/h in 2009/10 before increasing to 72 kg/h in 2012/13.

Cumulative catch curves highlight the change in catch distribution over the past seven seasons (Figure 11). Both total catch and area fished contracted between 2007/08 and 2009/10, before increasing again in the subsequent three seasons. The 2012/13 catch was greater than that of the preceding four seasons, but was taken from fewer fishing blocks in all but one of those seasons; that being 2009/10 when landings were 37% lower. Proportional catch curves indicate that 20% of the blocks fished have produced 58-73% of the catches in each season (Figure 11).

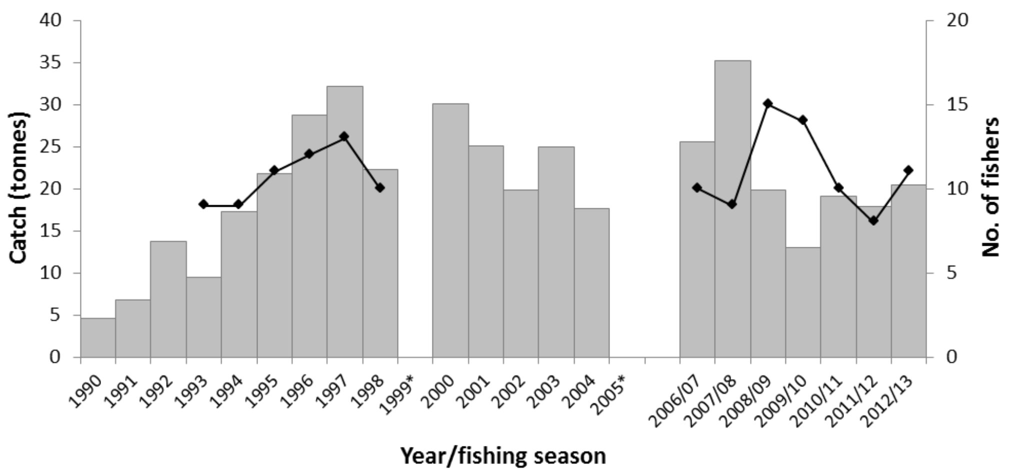


Figure 6. Annual catch (bars) of periwinkles taken since 1990. Pre-2005 data refers to calendar year while post 2006/07 data is represented by fishing season (September-August).
No data are available for 1999 and 2005.

Table 3. Commercial catch (tonnes) of periwinkles by fishing season (1 September to 31 August) since the introduction of the Tasmanian Commercial Dive fishery Management Plan in 2005.

	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13
Developed Zone	18.906	17.607	8.543	3.275	6.954	5.450	3.290
Undeveloped Zone	6.629	17.616	11.303	9.684	12.186	12.410	17.186
Total Catch	25.535	35.223	19.846	12.959	19.140	17.860	20.476

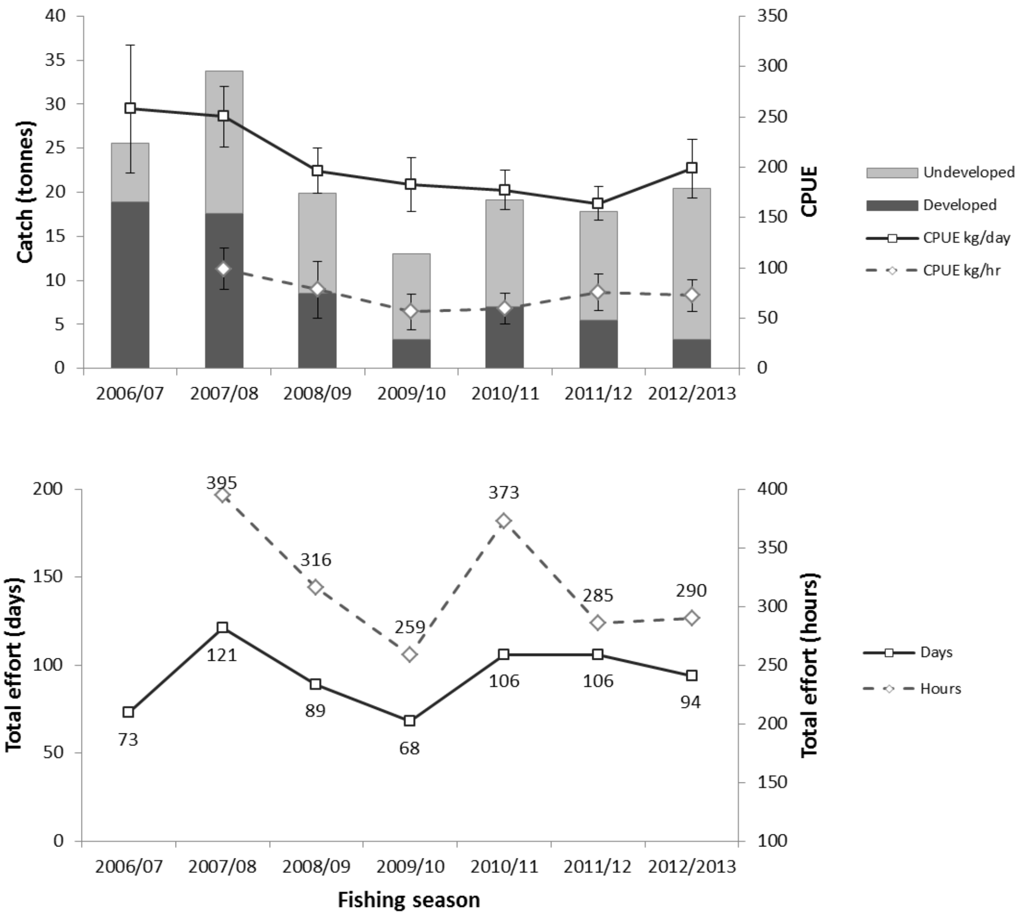


Figure 7. State-wide commercial catch and average catch per unit effort (CPUE) (± 95% CI) of periwinkles in each fishing season (September to August) since the introduction of the fishery management plan. Total catch reported for Developed and Undeveloped management zones.

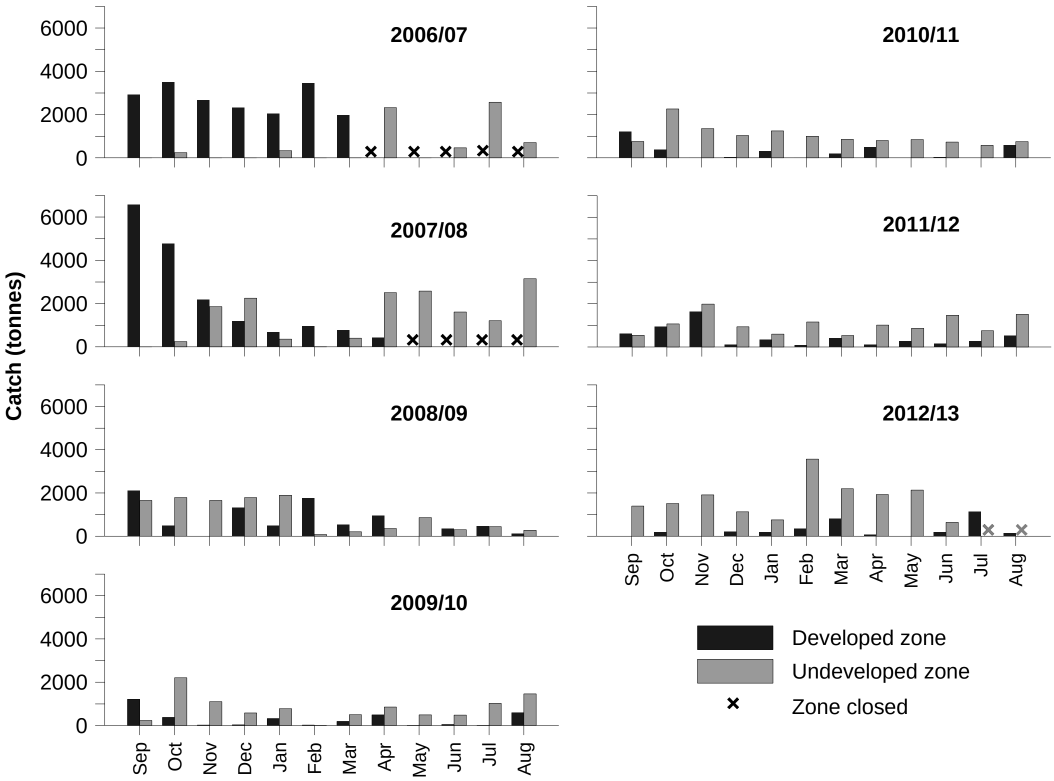


Figure 8. Monthly periwinkle catch originating from the Developed and Undeveloped management zones between the 2006/07 and 2012/13 fishing seasons.

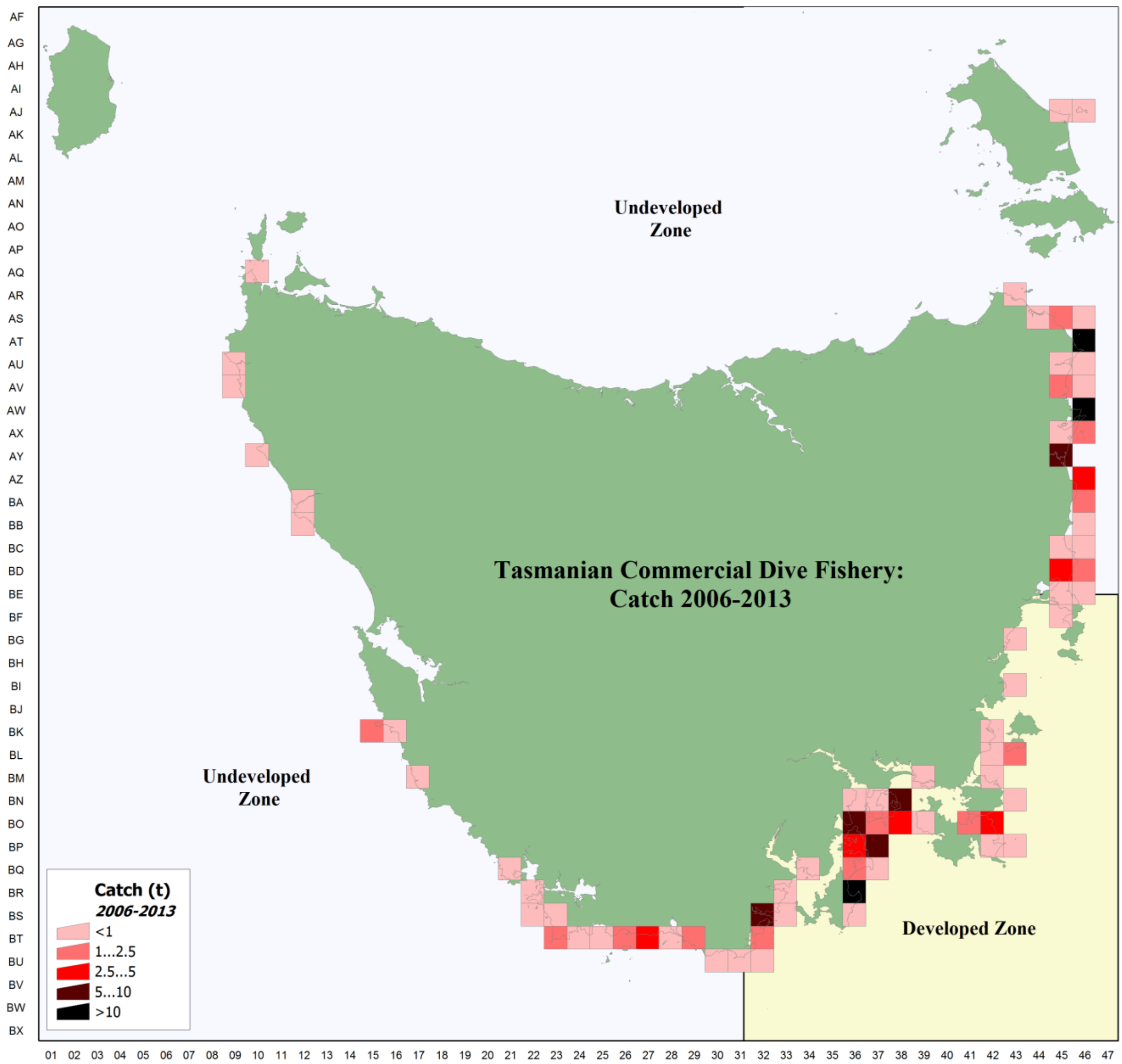


Figure 9. Combined periwinkle catch by fishing block for the seven fishing seasons between 2006/07 and 2012/13.

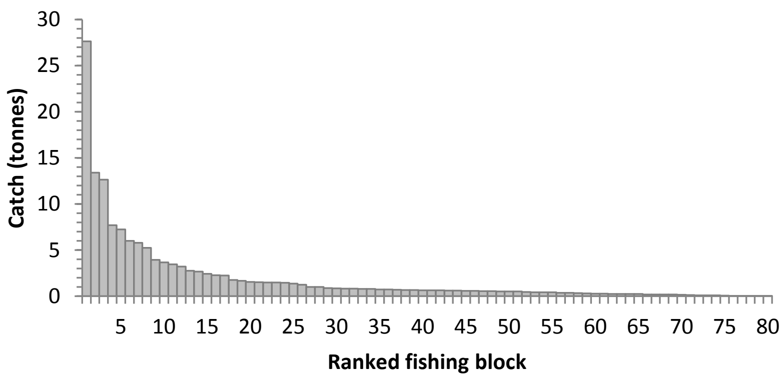


Figure 10. Combined total catch of periwinkles by fishing block for the period 2006/07 to 2012/13 ranked in decreasing order of catch.

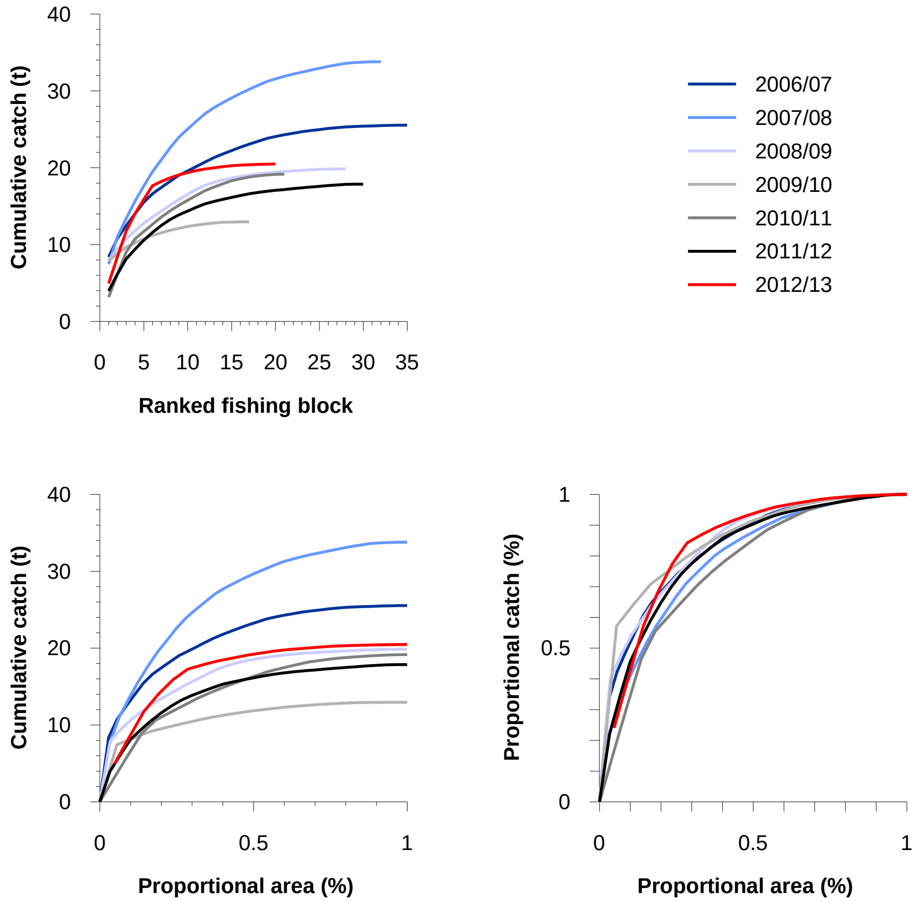


Figure 11. State-wide cumulative catch curves of periwinkles by fishing season since 2006/07.

Regional catch and effort

Regionally catches have varied significantly since 2006/07. South East (SE) catches reached the TAC (17.2 t) in 2006/07 and 2007/08 but trended downwards in subsequent years (Figure 12). Moderate catches were also taken in the West (W) in the first two fishing seasons but have remained at low levels since that time. By contrast, catches in the North East (NE) have steadily risen since 2006/07 to a peak of 14.7 t in 2012/13. Trends in regional effort mirrored that of catches.

Average daily catches tended to decline between 2006/07 and 2009/10 but have stabilised over the last 3-4 years in all regions (Figure 12). Daily catch in the SE declined from 305 to 156 kg/day between 2006/07 and 2009/10 and have ranged between 160-253 kg/day since that time. NE catch rates declined from 242 kg/day in 2007/08 to 167 kg/day in 2010/11 and have remained just above this level for the last two seasons. Fishers explain this pattern as a reflection of a general shift away from catching large quantities in a single fishing trip (prevalent amongst some operators early in the fishery) to a greater focus on matching catches to market demand.

An alternative measure of catch rate, catch per hour has also varied markedly between regions, being significantly higher in the W and SE than in the NE. Catch rates in the W ranged between 137-150 kg/h, in the SE between 60-103 kg/h and in the NE between 44-74 kg/h since 2007/08 (Figure 12). Limited data are available for the N (no more than five fishing days in any season) but suggest that catch rates are comparable to those for the NE (35-42 kg/h). NE catch rates declined slightly between 2007/08 and 2010/11 before increasing to a peak in 2012/13. After an initial decline, catch rates in the SE stabilised and even increased slightly before falling in the most recent season. It is significant that during 2012/13 the NE was closed after the Undeveloped Zone reached its TAC forcing some fishers to redirect effort to the SE. Catch rates achieved by these 'relocated' fishers were substantially lower for more regular fishers in the SE and this contributed to the observed fall in catch rates for that region. Management changes, including the increase in size limit in from 30 to 40 mm that occurred in 2009 may have had some impact on fishing practices but did not appear to have influenced catch rates in an obvious manner, at least at the regional scale.

Regional catch curves depict the dynamic nature of the Tasmanian periwinkle fishery, highlighting substantial changes in the spatial distribution of catches (

Figure **13**). Within the SE zone, catch curves from 2006/07 and 2007/08 are substantially different to those for subsequent seasons and indicate a considerable contraction in the area fished and catch yield over time. For the NE zone, catch curves indicate that large catches were taken from a small number of fishing blocks between 2007/08 to 2009/10, with over 7 tonnes landed from a single block. By comparison, higher catches from 2010/11 and 2011/12 were spread over a larger area whereas in 2012/13 the fishery was again concentrated in a small number of blocks. Fishing activity in the N and W zones has been too limited in recent years to make inferences about the fishery in those zones.

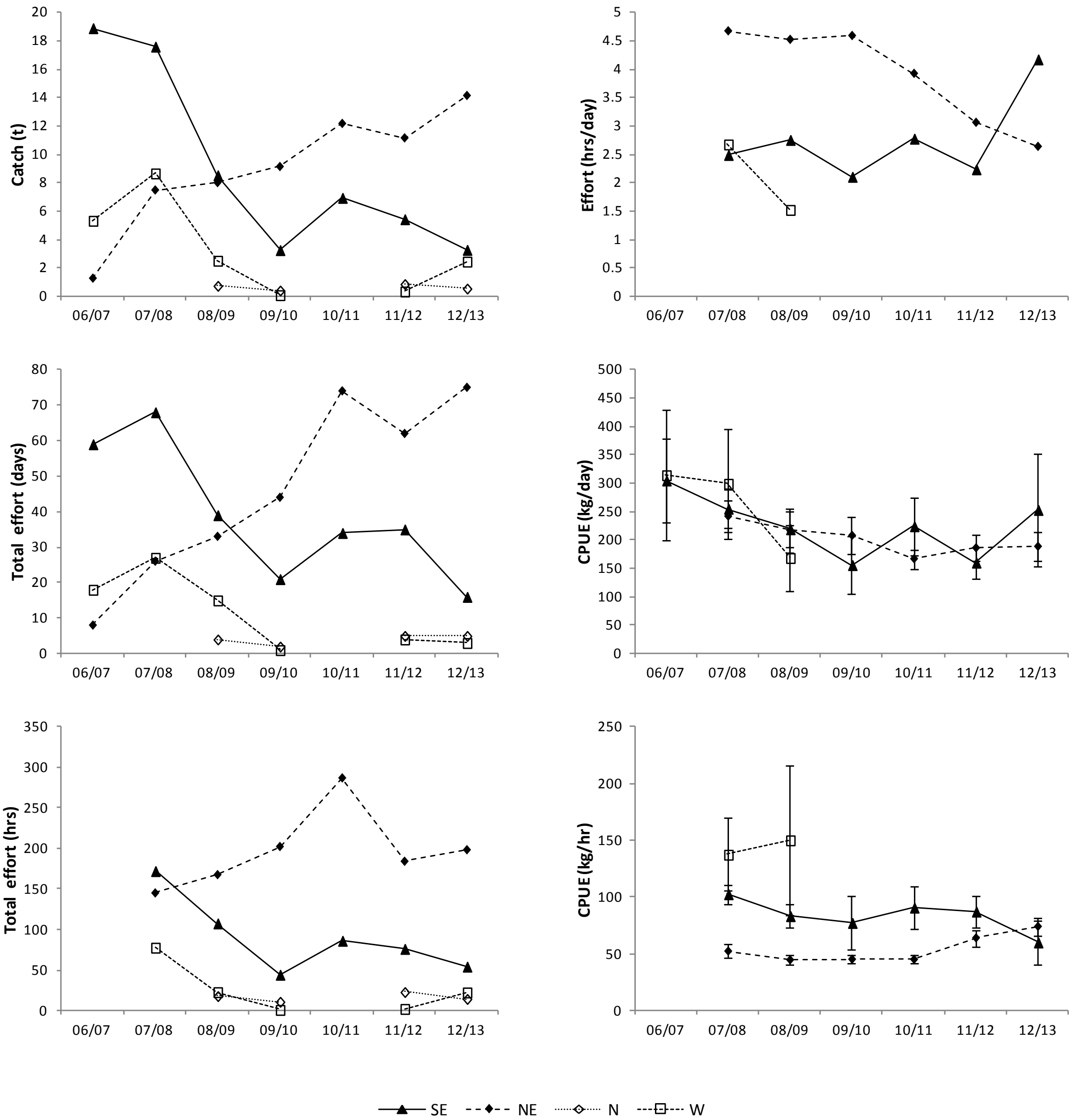


Figure 12. Regional catch, effort and catch rates for periwinkles by fishing season. Regions: SE, south eastern; NE, north eastern; N, northern, W, western. Effort data (hours fished) was not reported in the 2006/07 fishing season. Effort (h/day) and CPUE are not shown when there were fewer than 10 days fished in a given region and season.

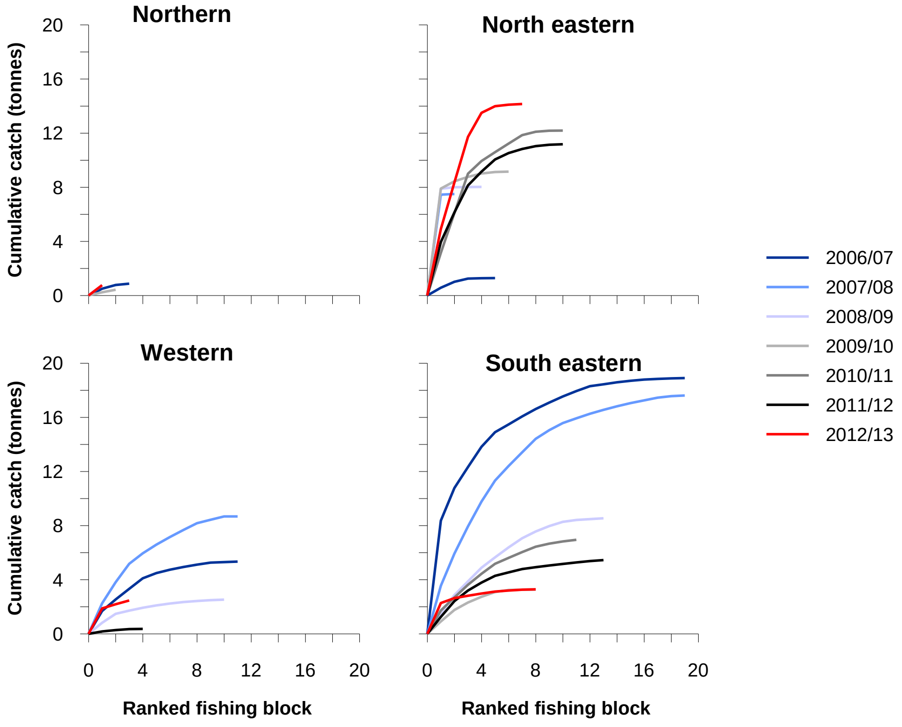


Figure 13. Regional cumulative catch curves of periwinkles.

Daily catches

Fishers typically catch 100-300 kg of periwinkles per day, with daily catches since the start of the 2006/07 fishing season averaging 220 kg (Figure 14). These catches are typically taken in up to 5 hours of fishing (dive) time. Catches of up to 1200 kg and dive durations of up to 9 hours in a single fishing day have been reported.

The daily catch taken by individual fishers is mainly regulated by one of two harvest strategies. Most commonly fishers seek to harvest quantities requested by the market (wholesalers/distributors or retailers). Generally these are regular fishers who have established supply chains and set markets and catches are typically supplied for a fixed unit price. By comparison, catches taken by more opportunistic fishers or new entrants to the fishery tend to more variable, being less driven by market requirements, and are supplied to the open market for a variable price.

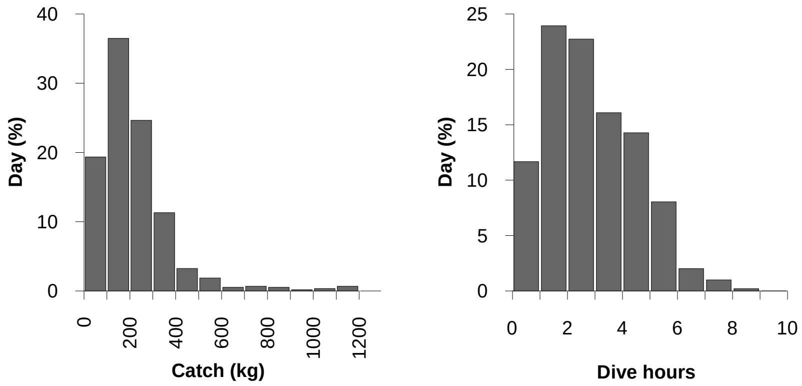


Figure 14. Reported daily catches (left) and hours dive per day (right) expressed as a percentage of total days fished since the start of the 2007/08 fishing season.

Fisher dynamics

Fisher characterisation and behaviour

Fishers currently active in the industry have been harvesting periwinkles for between six months and almost 30 years and typically also fish for other species including, urchins, cockles and abalone. Periwinkle fishing generally comprises 5-40% of individual fisher's effort; the level of involvement being dependent on whether operators view periwinkles as a key source of income or a subsidiary/opportunistic catch. Effort directed toward periwinkles from individual fishers may vary seasonally as effort shifts toward other more valuable target species during their peak harvest times or when seeking to fill catch quotas towards the end of quota years (e.g. abalone).

Fishers who have both abalone quota and a commercial dive licence typically give lower priority to fishing for periwinkles and will cease harvesting periwinkles if abalone prices increase or quota needs to be filled. Similarly, if beach prices are high for other commercial dive species, such as urchin and cockles, effort will often be diverted from periwinkles towards these species. A shift in focus away from periwinkles to harvesting the long-spined sea urchin (*Centrostephanus rodgersii*) has been reported by some operators since the development of the latter fishery in 2009. The low priority afforded to periwinkles by many fishers has significant implications in providing regular supply to markets.

Fisher participation / licensing

There have been 55 CDF licences since the introduction of the management plan in 2005. During the first five years under the plan there were 32 licence transfers which introduced new operators into the fishery.

A total of 30 individual licence holders have reported catching periwinkles since 2005, with range of 8-15 and an average of 11 fishers actively fishing for periwinkles in any given year. Only one operator has fished in all seven seasons, another has fished in five seasons and a further six have fished in four seasons (Figure 15). One third of all operators who have fished for periwinkles have fished in just one season since the management plan was introduced. Within any given fishing season the catch has been dominated by one to three fishers (Figure 16); the top three catches accounting for 68-87% of the total product landed in each season.

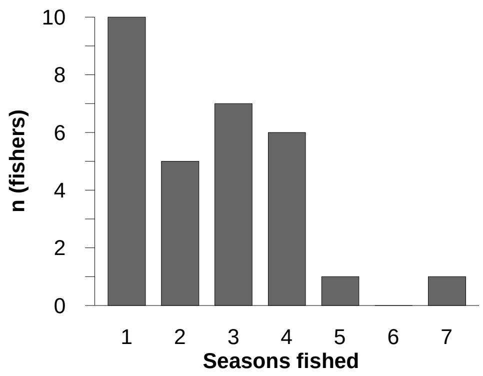


Figure 15. Fisher participation in the periwinkle fishery since the start of the 2006/07 fishing season. Fishers are classed to have participated if they reported landing catch at any stage within a season.

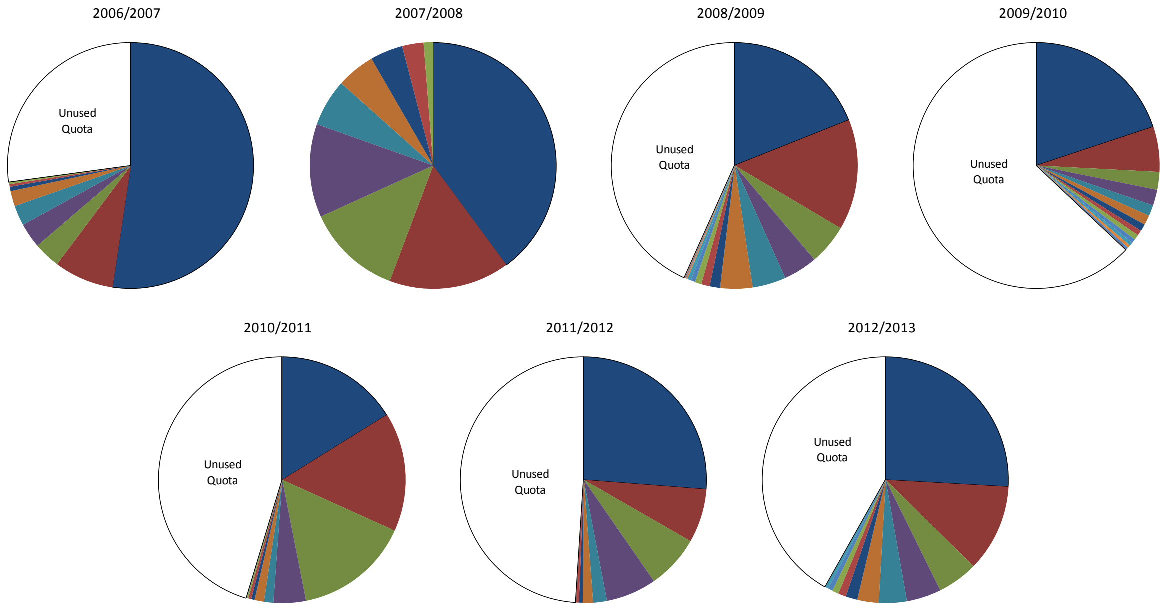


Figure 16. Catch distribution amongst fishers as a proportion of the total allowable catch (35.2 tonnes). Note: colours are not consistent between years for fisher confidentiality.

Management changes and current concerns

Zoning and TAC

Industry, both fishers and processors, expressed concerns that the two zone management arrangement was inappropriate for the fishery and was impeding its development. In 2005, when the management plan was first developed, zones were established in line with historical fishing patterns and half of the available TAC assigned to the south east (Developed Zone) where much of the catch had originated. The much larger remaining area of State waters (Undeveloped Zone) was allocated the same catch limit.

Since the implementation of the management plan, fishing effort and catches have expanded considerably along the north eastern coast and this has resulted in the TAC for the Undeveloped Zone being almost fully attained from this relatively small area, with little fishing occurring along the north and west coasts. It was considered highly likely that under this arrangement the Undeveloped Zone TAC could be reached entirely from the north east, thereby inhibiting further exploration and development in other areas of the fishery.

Consultation with resource managers and industry throughout the present study has contributed to a recent decision to restructure the management zones in an effort to facilitate further development in previously unfished areas. The Undeveloped Zone was subdivided into a North East Zone, where the majority of the catch is currently taken, and two other zones, namely a Northern Zone and Western Zone, these changes taking effect for the 2013/14 season (Table 2, Figure 5). The TAC of 17.6 tonnes from the Undeveloped Zone was maintained in the North East Zone. A TAC of 10 tonnes was applied to the Western Zone coast and 7.6 tonnes to the Northern Zone, increasing the state-wide TAC to 52.8 tonnes. The rezoning of the fishery is seen as an important strategy to support development by allowing the underutilized areas of the west and north coast to remain open to fishing should the North East Zone TAC be reached.

Flexibility regarding the incidental take of a small amount of undersize periwinkles

The introduction of a rule in 2011 that allows catches to contain up to 10% of undersize periwinkles has been widely welcomed by fishers. The rule recognises that undersized periwinkles may be taken unavoidably when harvesting and has resulted in greater operational efficiency and relieved concerns over prosecution for inadvertent catches of undersize periwinkles. The issue was particularly problematic for periwinkles as divers may sweep both size and undersize periwinkles into catch bags and individually handling and measuring large numbers of individuals underwater or on board vessels is not feasible. Observation of fishing practices and catch sampling indicate that the proportion of undersized individuals in catches is likely to be far less than 10%.

Fisher observations and feedback: fishery limitations, threats and management concerns.

Periwinkle habitat and aggregations

Periwinkles are broadly distributed through an array of habitat types, however a specific habitat preference is considered to be a key reason for the formation of high density aggregations. Periwinkles typically aggregate in exposed crevices on sand scoured reefs and at sand-rock interfaces bordering reef edges. There is also a belief amongst the divers surveyed that periwinkles associate with low density *Phyllospora* coverage and gutters with accumulated detritus which provide both shelter and food. Apart from habitat preference for food and shelter, fishers were unsure of any behavioural or physiological reasons for the aggregating behaviour.

Replenishment of fished aggregations is assumed to occur as a result of the movement of animals into this preferred habitat from surrounding areas where they are present in relatively low densities. High density aggregations are evident throughout the year.

Fishers observed that smaller individuals/juveniles are more commonly present in shallower water <1 m, while larger adults aggregated in marginally deeper depths of 1-5 m. Small-scale movement of some populations has been observed with animals moving inshore into shallow waters during periods of calm weather and offshore to marginally deeper water during periods of heavy swell.

Catch and effort

Effort, and associated catch, is frequently concentrated close to the fishers' home ports due to the low value that periwinkles attract at market. Fishers seek to keep expenses down to make the operation viable and thus favour sites close to home over potentially more productive sites further afield. The low beach price of periwinkles and thus the profitability of the industry was cited as the main reason the TAC is not reached in most years, with fishers tending to target more valuable species or deciding not to fish at all for periwinkles.

Localised overfishing

Localised overfishing of stocks has been observed throughout the history of the fishery, with some heavily fished areas reportedly taking several years to recover to harvestable levels. However, since the introduction of a size limit in 2005, and the subsequent increase to 40 mm in 2009, fishers report that heavily fished areas have tended to recover at a much faster rate.

Localised overfishing has been observed to result in substantial decreases in both mean size and biomass of periwinkles. Localised overfishing is typically the result of multiple fishers targeting sites close to key ports or access points. While concentration of fishing effort in localised areas may be unavoidable due to low profit margins in the fishery, an appropriate minimum size limit is expected to ensure that stocks (sub-legal adult biomass) remain healthy. In areas where depletions have occurred fishers report that a consistent supply of juveniles is still present and these are expected to recruit to the fishery.

Fishers noted that relatively large quantities of periwinkles need to be harvested for operations to be profitable, and as such fishing only occurs where densities are high. As a consequence, low density areas remain unfished thereby ensuring that large adults persist within the exploited areas and may contribute to the sustainability of the population either through immigration or spawning.

Fisher perceptions of stocks status and recovery after fishing

At a regional scale fishers were unanimous in their belief that periwinkle stocks are healthy and the current catch levels are sustainable. The few operators who have participated in the fishery over an extended period suggested that they had observed no long-term changes in size structure.

Prior to 2009 many sites subjected to heavy fishing for periwinkles were slow to rebuild to harvestable levels. However, following the increase in the minimum size limit to 40 mm fishers have reported substantially quicker rates of recovery, with many suggesting that even heavily fished areas can probably be fished again within 6-12 months.

Operators who fish the same areas regularly indicated that they tend not to take all sized periwinkles in a fishing session but seek to leave a proportion of the stock to provide at least some harvestable biomass for when they next visit the site. This represents a form of rotational harvest strategy. Fishers did express concern that this strategy may have to change should more fishers enter the fishery and competition increase.

Purging

The purging of periwinkles is essential to supplying quality product to market. The process of physically purging periwinkles by fishers can be time consuming and it has been considered by some as a 'hindrance' and an 'impediment' in the whole operation. This perception is amplified as operations are typically low-volume and low-value. At present the product value is insufficient to justify purging animals at processing facilities; the cost associated with purging at processing facilities is estimated at ~$3/kg. Additionally, processors are reluctant to take on periwinkles due to the amount of sand and waste excreted, especially if they are operating recirculating systems.

Established fishers have developed procedures and routines for purging periwinkles. Education of all fishers, particularly those new to harvesting of periwinkles, of the damaging impact unpurged product can have on the market is seen as essential to the future of the industry.

Latent effort

There are 55 licence holders in the CDF who are all able to harvest periwinkles, although far fewer (8 - 15) tend to be active in any given year, and thus there is concern amongst some current fishers about the substantial latent capacity within this niche fishery. An influx of fishers targeting periwinkles resulting from market development or decline in other sectors (e.g. urchins) could affect the stability of markets, increase localised fishing pressure and influence the long-term viability of individual operations. As the quota is not individually allocated, this could also lead to a race to fish with most of the product landed early in each quota season. In other fisheries this has resulted in inefficient and costly fishing and contributes to market oversupply.

Any change to licensing arrangements to allow licence-holders to nominate supervisors to fish their licences was identified by some fishers as an issue that could see activation of this latent capacity (see below).

Supervisors

The licence framework of the CDF when first introduced in 2005 was structured as an owner operated licence only, with no provisions for supervisors to be nominated to fish the licence. Recently some industry members have indicated that they believe the fishery has developed to a point where it would benefit from licence owners having the option to appoint supervisors on the licence, particularly when fishing for the long-spined urchin. Adopting such a change would allow a supervisor to be placed on a commercial dive licence, remove the restriction on a person owning only one commercial dive licence and allow licences to be owned by other than a natural person (for example a proprietary company or partnership). While freeing restrictions on operators, this option does provide opportunity for increased fishing capacity as inactive licences could be leased out.

Feasibility and logistics of fishing the west coast

There is a widely held view that a substantial biomass of periwinkles exists on the west coast of Tasmania. The remote location of these stocks coupled with typically unfavourable sea conditions for shallow water diving substantially limits the harvest of these fish. To profitably harvest periwinkles from this area individual catches need to be considerably larger than for less remote areas or, alternatively, be taken as part of a trip that included targeting of other species. At the present time the market does not appear to be able to handle large catches without resulting in oversupply, as storing of catches or post-processing of product appear problematic.

Prior to 2011 divers fishing under the authority of a commercial dive licence could not be in possession of abalone or rock lobster, thus multispecies fishing trips were not an option. However, the policy was changed in 2011 to allow commercial dive species and abalone on board a vessel providing that all divers on the vessel own (or supervise) an abalone dive licence and a commercial dive licence. That is, all divers are dual licensed. The relaxation of the ruling has somewhat freed up the ability of divers to harvest the lower-value periwinkle while on abalone fishing trips and subsequently made catches of periwinkles from the west coast a more feasible option. In 2012/13 approximately 2.5 t of catch was taken from the west coast.

Market 'flooding'

Throughout the history of the fishery there have been reports of large volumes (in excess of one tonne) of periwinkles being captured and placed onto the market. Such large volumes have flooded the market and resulted in a considerable reduction in the market floor price. Subsequent to these occurrences it has taken a considerable period of time for prices to recover to previous levels. Market oversupply has typically been due to the actions of occasional or opportunist operators who have not had long-term involvement in the fishery and did not have prior arrangements with buyers.

Fisheries biology – age, growth and reproduction

Temperature

Water temperatures recorded at each site over the study period were assessed along with long-term recordings at nearby monitoring sites (Table 4, Table 5, Figure 17). The logger at Recherche Bay was lost in heavy swell and was replaced in June 2012, while the Piccaninny Point logger failed after 2 days. The logger at The Gardens site was buried under sand and may underestimate the water temperature in the latter part of the study.

Temperatures generally followed seasonal and latitudinal gradients, with mean monthly temperatures varying between 11.0-18.4 °C. The warmest temperatures were recorded in the January-March period across all sites, peaking at 18.4°C at Spikey Beach, 18.0 °C at The Gardens, 17.9 °C at Bull Bay and 16.7 °C at Recherche Bay. Temperatures at the southernmost site, Recherche Bay, had warmer winter temperatures than the more northern sites of Bull Bay and Spikey Beach. The temperature profile at Spikey Beach site was unique, with cooler winter temperatures and warmer summer temperatures recorded compared to all other sites.

Assessment of 10 long-term temperature monitoring sites showed that sites in the south and south-west had both the lowest summer temperatures and heating degree days, while those in the north and north east recorded the highest (Table 5). Variation in mean temperatures between sites was greater in summer (3.4°C) than winter (2.4°C). Temperatures at Swansea (nearby Spikey Beach) off eastern Tasmania were warmer in summer and cooler in winter than at all other sites. In addition, both the highest annual heating and cooling degree days were recorded at Swansea.

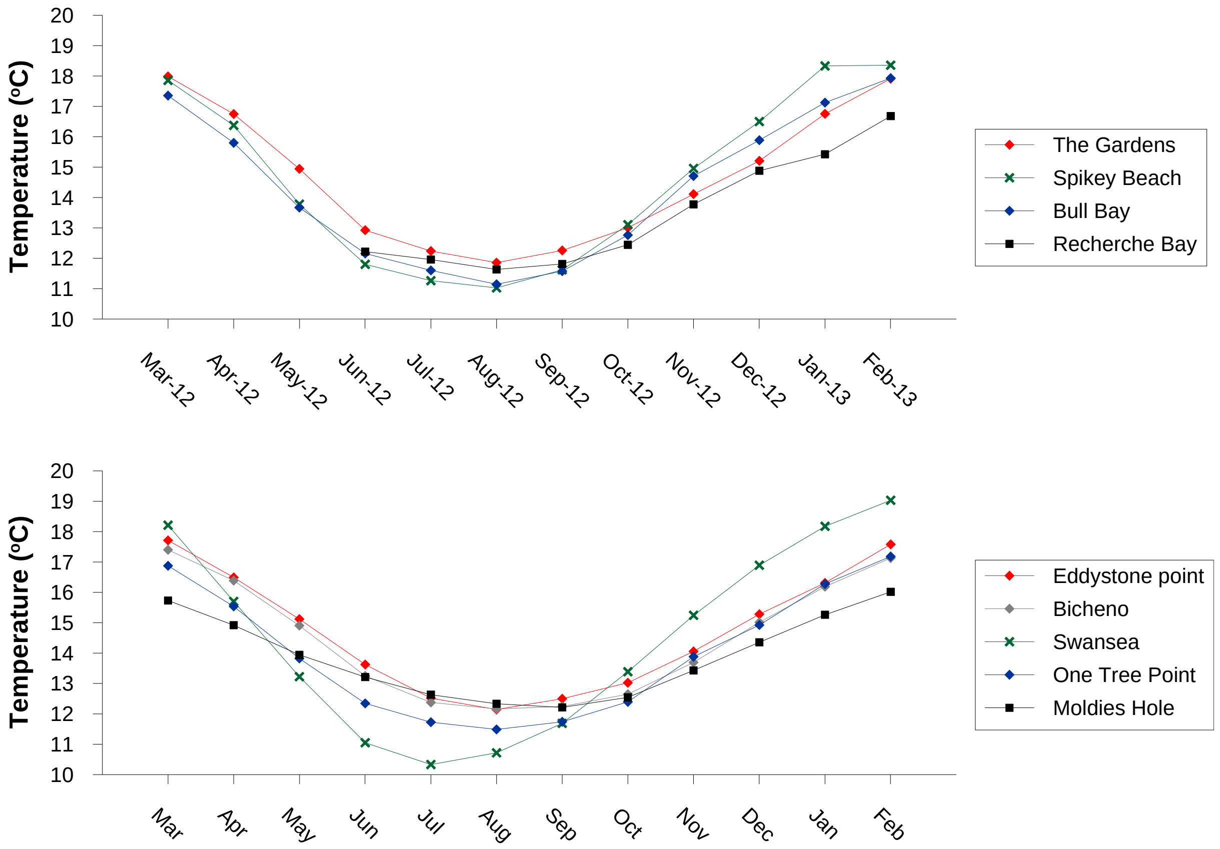


Figure 17. Mean monthly water temperatures (°C) at the tagging sites (top) and long-term mean monthly water temperatures (°C) at locations near to the study sites (bottom). Note: the Piccaninny Point logger failed, while Recherche Bay logger was lost in heavy swell and was replaced in June 2012.

Table 4. Mean monthly water temperatures from periwinkle research sites between March 2012 and February 2013.

Periwinkle sites	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Gardens	18.0	16.7	14.9	12.9	12.2	11.9	12.3	13.0	14.1	15.2	16.8	17.9
Spikey	17.9	16.4	13.8	11.8	11.3	11.0	11.6	13.1	15.0	16.5	18.3	18.4
Bull Bay	17.4	15.8	13.7	12.2	11.6	11.1	11.6	12.8	14.7	15.9	17.1	17.9
Recherche				12.2	12.0	11.6	11.8	12.4	13.8	14.9	15.4	16.7

Table 5. Mean (x̅) seasonal water temperatures and standard deviation (σ), as well as average annual heating (>16°C) and cooling (<13°C) degree-days from long-term temperature monitoring sites at various sites around Tasmania.
Temperature data spans varying periods of length between 2004 and 2013. The periwinkle tagging sites are listed alongside the closest long term temperature monitoring sites.

Zone	**Site**		**Logger depth**	**Data span**	**Temperature**								**Degree days**	
					Spring		**Summer**		**Autumn**		**Winter**			
	Logger site	Nearby tagging site	(m)	(years)	x̅	σ	x̅	σ	x̅	σ	x̅	σ	Heating >16°C	Cooling <13°C
North East														
	Eddystone Point	The Gardens	11	4.7	13.5	0.7	16.3	1.1	16.4	1.4	12.7	0.9	123	59
	Bicheno	Piccaninny Point	13	7.7	13.2	0.8	16.1	1.1	16.2	1.4	12.5	0.7	95	81
South East														
	Swansea	Spikey Beach	8	4.1	14.3	1.2	18.0	1.2	15.6	2.4	10.9	0.8	240	263
	One Tree Point	Bull Bay	8	8.2	13.1	1.0	16.1	1.3	15.4	1.5	11.8	0.5	72	163
	Mouldies Hole	Recherche Bay	6	6.5	13.0	0.7	15.2	1.0	14.9	1.0	12.6	0.5	2	71
Western														
	Port Davey	n/a	12	1.0	12.6	0.4	14.6	1.2	14.8	0.6	12.5	0.7	1	108
	Cape Sorell	n/a	11	5.5	13.3	0.8	15.5	1.0	15.2	1.0	12.9	0.6	6	32
	Bluff Hill Point	n/a	10	2.4	13.7	0.9	16.4	1.2	15.8	1.3	13.2	0.5	86	7
Northern														
	Stanley Nut	n/a	8	2.9	14.0	1.1	17.6	1.2	16.3	2.1	11.7	0.8	219	167
	Hogan Island	n/a	10	4.2	14.0	0.8	17.3	1.1	16.8	0.8	13.5	0.9	197	9

Morphometrics

The length-weight relationship for periwinkles is defined by the equation:

$$Wt = 0.000275 \times L^{3.018} \ (R^2 = 0.99, n=545)$$

where *Wt* is weight in grams and *L* is shell length in mm (Figure 18). There was a ten-fold increase in periwinkle weight over the size range 30 to 65 mm, with the number of individuals per kilogram decreasing from 127 to 12 over this same size range (Table 6). Based on the previous size limit of 40 mm this equates to an average of 53 periwinkles per kilogram whereas at 45 mm the number drops to 37 individuals.

The maximum operculum length of periwinkles is linearly related to the shell length and is defined by the equation:

$$Op = 0.403 + 0.395L \ (R^2 = 0.99, n=565)$$

where *Op* is the operculum length in mm.

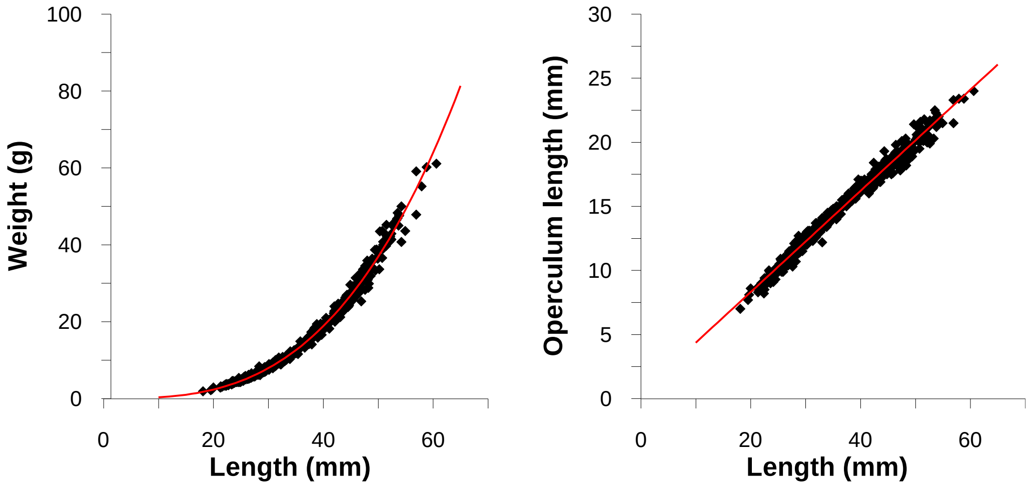


Figure 18. Total (shell) length-weight (left) and (shell) length-operculum length (right) relationships of periwinkles from Tasmania.

Table 6. Predicted weights and numbers per kg of periwinkles at various lengths based on length-weight relationship.

Length (mm)	Weight (g)	No./kg
30	8	127
35	13	80
40	19	53
45	27	37
50	37	27
55	49	20
60	64	16
65	81	12

Population structure

Periwinkle populations at the study sites were comprised predominantly of individuals between 15 and 60 mm (Figure 19). Clear modal progression of size classes was apparent at most sites over a 12 month period. This growth of cohorts was most evident at Bull Bay, with modes increasing from 19 to 34 mm and 42 to 50 mm, suggesting growth of approximately 15 mm in the smaller cohort and 8 mm in the larger cohort, respectively. Similarly, a mode at The Gardens progressed from 26 to 36 mm suggesting growth of approximately 10 mm over 12 months.

Small periwinkles < 20mm were seldom found within the high abundance areas of larger individuals, but were aggregated in shallower cryptic habitats and amongst the holdfasts of dense microalgae. By comparison larger individuals were often aggregated around sand-scoured reefs, sand-rock interfaces bordering reef edges, exposed crevices and accumulated detritus.

All sites other than Spikey Beach had been subjected to some fishing activity during the two years prior to the study. Previous fishing is likely to have influenced size frequency distributions, reducing the relative abundance of larger individuals (> 40 mm), particularly obvious at Piccaninny Point (Figure 19). The population at Spikey Beach was considerably smaller than all other populations, with the maximum length recorded being 53 mm. The largest individual of 66 mm was recorded at Bull Bay.

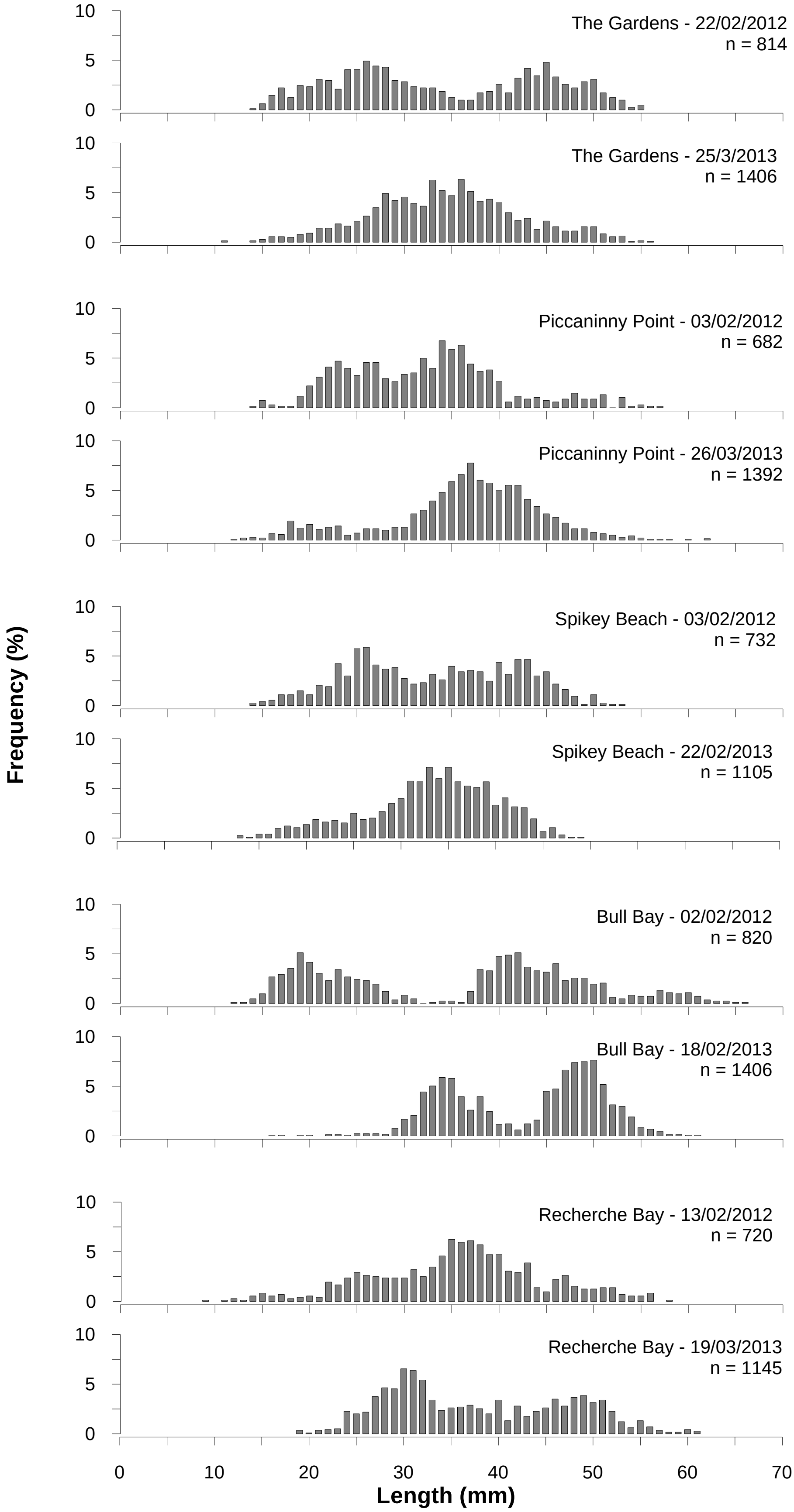


Figure 19. Length-frequency distributions of Periwinkle populations at the five research sites.

Growth

Relatively high tag recapture rates (>10%) were obtained at four of the five sites (Table 7). The low recapture rate at the Piccaninny Point site can be attributed to the high exposure of the site, dispersal amongst a large and dense population, macroalgae coverage hindering searching and potential tag loss due to sand abrasion. Furthermore, growth of coralline algae and tubeworms on periwinkle shells (Figure 20) may have reduced detection rates. In addition, it is suspected at least two sites (The Gardens and Bull Bay) were subjected to fishing throughout the project.

Dives undertaken at the tagging sites at approximately 1-2 month intervals enabled some observations to be made about the tagged animals. Paint markings on shells mostly vanished after 3-9 months depending on the exposure of the site. Piccaninny Point appeared to be the most exposed site to sea swell based on physical characteristics and observations over the study period and paint markings were abraded away quickly. In addition, a large proportion shells at the site were highly abraded from sand scouring. By comparison, Bull Bay appeared to be the most protected site from the influence of sea swell and partial paint markings were still evident on a small proportion of shells at the end of the study. Operculum markings survived the 12 month study; however operculum growth covering the graphite marks made some of the numbering illegible (Figure 21). Two individuals (1.3%) were recaptured at Bull Bay with operculum markings but no tags, indicating that some degree of tag loss may have occurred.

Tagged individuals were observed to be highly abundant within the close proximity of their release points for the first six months post release, after which wider dispersal became more evident, coinciding with spring/summer period. While most recaptures at the end of the study period were located in close proximity to the release point, some individuals were found on nearby patches of reef up to 150 m away and separated by sand. It is unclear whether these individuals actively crossed sand or were displaced during heavy swells to resettle on the nearby reefs.

Growth in periwinkles was linearly related to length, with smaller individuals growing at a quicker rate (Figure 22). The maximum growth increment for an individual periwinkle was 19.0 mm and was recorded at The Gardens. This individual increased from 19.0 to 38.0 mm in 12 months. By comparison some of the largest individuals recorded zero growth. Growth increments at Spikey Beach were less than those observed at all other sites, with no individual recaptured growing more than 10.3 mm.

Table 7. Summary of periwinkle tagging and recapture numbers

Site	Date of tagging	Date of recapture	Number tagged	Number recaptured
The Gardens	22/02/2012	25/03/2013	600	60
Piccaninny Point	3/02/2012	26/03/2013	600	8
Spikey Beach	3/02/2012	22/02/2013	600	67
Bull Bay	2/02/2012	18/02/2013	600	145
Recherche Bay	13/03/2012	19/03/2013	600	89

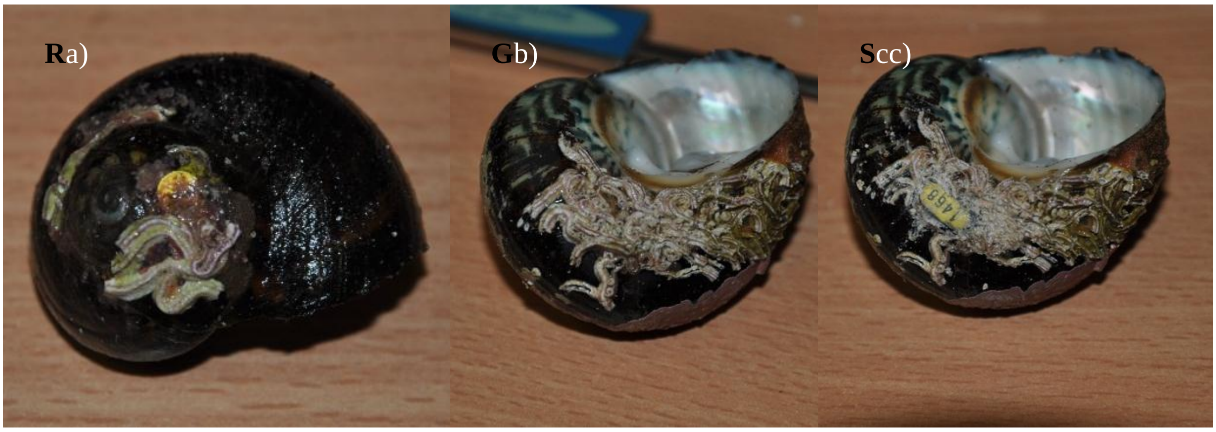


Figure 20. Tube worm and coralline algae growth on periwinkle shells. a) A tag partially obscured by tubeworms and coralline algae. b) A tagged periwinkle with tubeworm growth obscuring the tag. c) The same animal in a) with growth scraped away to reveal tag.

Figure 21. Labels scribed on operculum with a graphite marker proved moderately successful, with some marks still clearly visible after 12 months (left). However operculum growth often covered marks making them illegible.

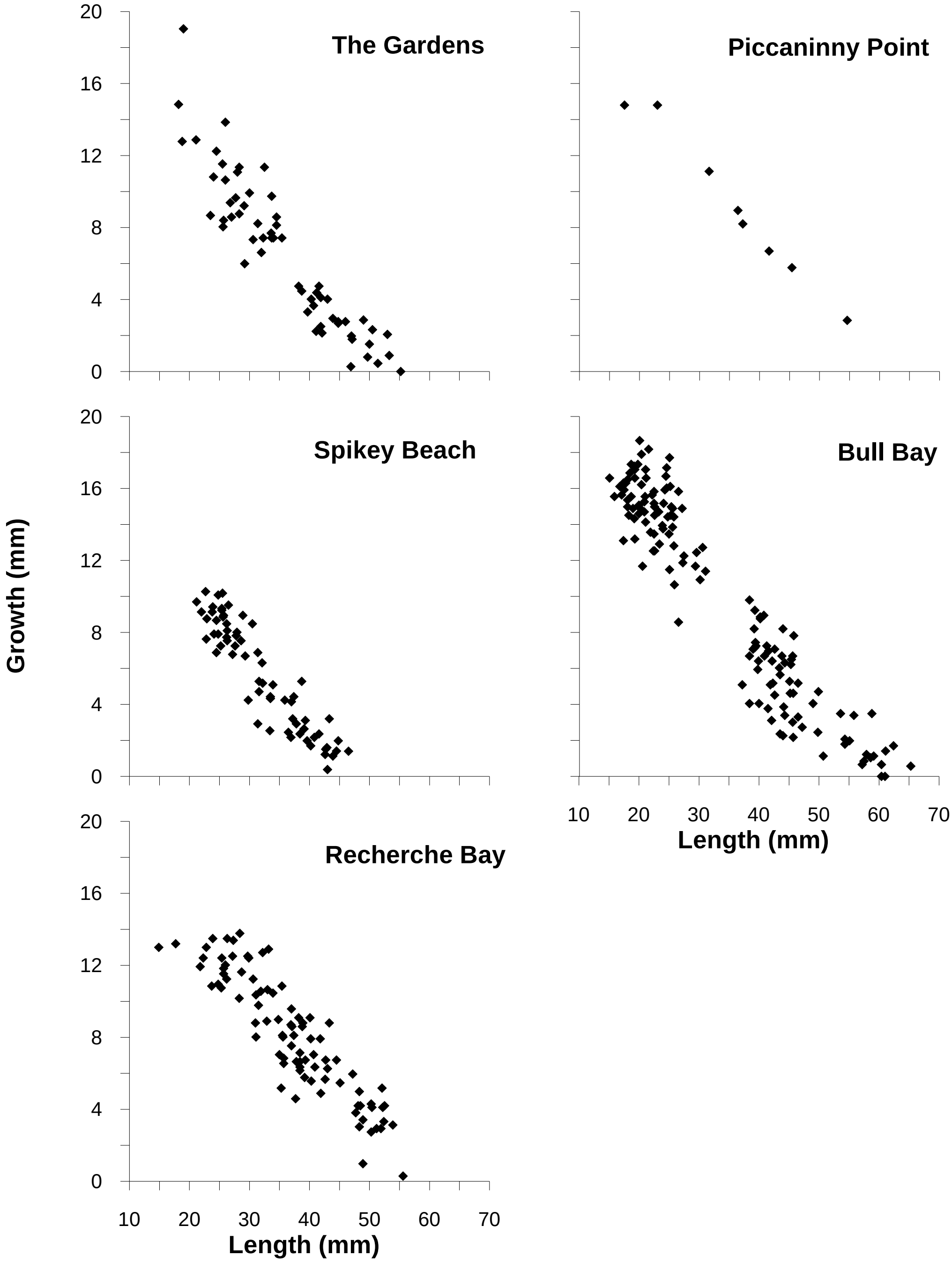


Figure 22. Annual growth increments of periwinkles from the five tagging sites off eastern Tasmania.

Von Bertalanffy growth curves produced from tag recapture data suggest growth of periwinkles is rapid within the first few years of life (Table 8, Figure 23). Depending on the site, animals reach between 35.8 and 46.2 mm within three years, equivalent to 80-88% of the average maximum length (L_∞). Spatially, average maximum lengths varied by as much as 32%, ranging between 46.9 mm at Spikey Beach and 61.9 mm at Piccaninny Point. Due to the low number of recaptures at Piccaninny Point (n=8), growth modelling at this site should be treated with caution.

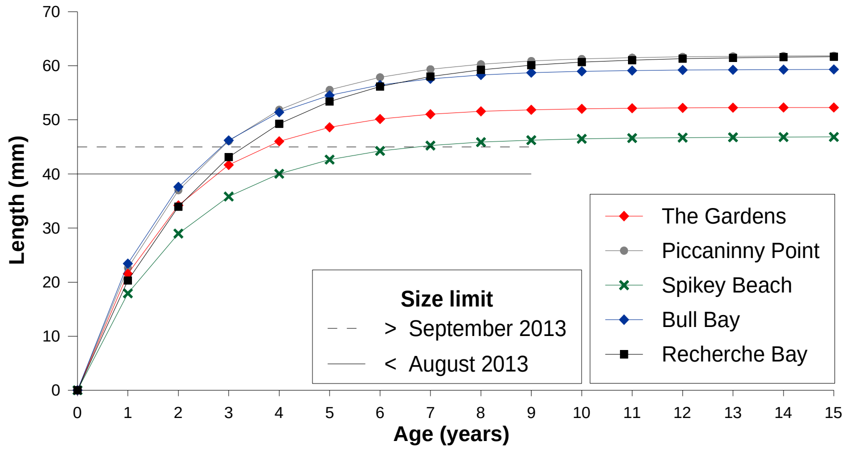


Figure 23. Von Bertalanffy growth curves of periwinkles at five sites off the east coast of Tasmania. Note: low numbers of recaptures at the Piccaninny Point site may result in poor model accuracy. The Tasmanian commercial size limits are also shown.

Table 8. Estimated shell lengths of periwinkles at each year of age derived from von Bertalanffy growth modelling of mark-recapture data at five locations off eastern Tasmania. The estimated age at the current size limit (40 mm), the von Bertalanffy growth parameters K, and L_∞, and the goodness of fit (R^2) are also given. Note: low numbers of recaptures at the Piccaninny Point site may result in poor model accuracy.

Site	von Bertalanffy growth parameters			Age at 45 mm	Estimated length at 1 to 10 years of age									
	L_∞	K	R^2	Years	1	2	3	4	5	6	7	8	9	10
The Gardens	52.32	0.53	0.90	3.7	21.5	34.2	41.7	46.1	48.6	50.2	51.0	51.6	51.9	52.1
Piccaninny Point	61.93	0.45	0.99	2.9	22.6	37.0	46.1	51.9	55.6	57.9	59.4	60.3	60.9	61.3
Spikey Beach	46.87	0.48	0.93	6.7	17.9	29.0	35.8	40.0	42.7	44.3	45.3	45.9	46.3	46.5
Bull Bay	59.36	0.50	0.95	2.8	23.4	37.6	46.2	51.4	54.5	56.4	57.6	58.3	58.7	59.0
Recherche Bay	61.83	0.40	0.95	3.3	20.3	34.0	43.1	49.3	53.4	56.2	58.0	59.3	60.1	60.7

Aquaria trials indicated seasonality in growth, with proportionally higher growth occurring in autumn, accounting for 34.5% of the annual growth, when temperatures averaged 14.9 °C (Figure 24). The percentage of annual growth was slightly lower in summer when mean temperature was higher (17.2 °C), and was lowest in winter and spring when temperatures were reduced (11.4 °C and 13.1 °C, respectively).

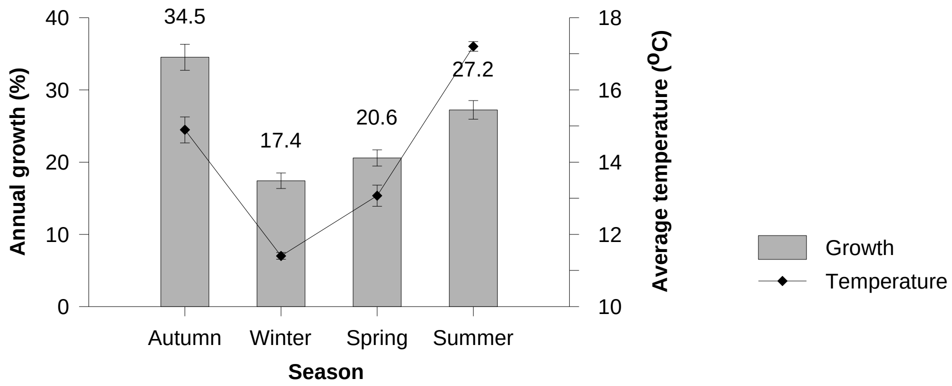


Figure 24. Percentage of annual growth (± 95% CI) and corresponding average temperatures (°C ± 95% C.I.) in laboratory held periwinkles. Values relate to growth.

Mean maximum length was significantly related to heating degree-days (>16°C) with increasing degree-days resulting in a decrease in maximum size (*P*<0.05; Figure 25, Table 9). While there was also a trend of mean maximum length decreasing with the increasing number of cooling degree-days (<13°C) the relationship was not as strong. The trend of higher temperatures resulting in decreased size is most evident at Spikey Beach with periwinkles taking 6.7 years to reach the commercial fishery size limit of 45 mm compared to other sites which take between 2.8 and 3.7 years (Table 8).

Table 9. Linear regression of annual heating (>16°C) and cooling (<13°C) degree-days against mean maximum length.

Degree-days	Intercept	Coefficient	Adjusted R^2	P-value
Heating >16°C	63.744	-0.068	0.738	0.039
Cooling <13°C	62.790	-0.050	0.219	0.241

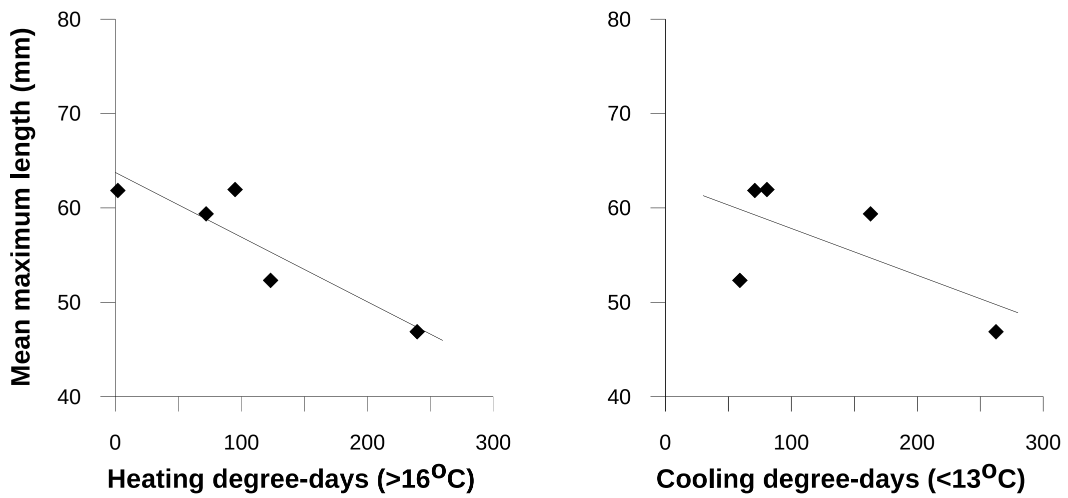


Figure 25. Relationship between heating (>16°C) and cooling (<13°C) degree-days and mean maximum length of periwinkles derived from von Bertalanffy growth curves at five sites off the east coast of Tasmania.

Sexual maturation

Gametogenesis in both male and female periwinkles was determined from sectioned gonads (Table 1) with developmental stages compared with macroscopic development to create a key to assess the onset of sexual maturity (Table 10). The key was adapted from one developed for *L. torquata* by Joll (1975) as the two species exhibited similar maturational development.

Oogenesis: In developing females the formation of oogonia occurs throughout the ovary, covering the surfaces of the trabeculae and the ovary walls. Oocytes develop from oogonia primarily by nuclear growth and pass through generative and vegetative phases before entering vitellogenesis. During vitellogenesis the nucleolus disperses and by the time the oocytes are fully developed it is no longer visible. A jelly layer also forms around the oocyte during vitellogenesis. Oocytes part from the surface of the trabeculae during the early stages of development, and by the latter stages of development are only attached by a thin stalk. Oocytes at this stage are referred to as stalked oocytes. Fully developed oocytes detach from the trabeculae and lie free within the ovary until spawning. Gametogenetic cell types in female periwinkles are shown in Figure 27.

Spermatogenesis: Spermatogonia develop from germ cells lining the testis and give rise to spermatocytes by nuclear growth. Meiotic division of spermatocytes form spermatids before developing into spermatozoa. Spermatoza form a tightly packed mass within the testis and are retained until spawning. The duration of spermatogenesis is suspected to be quite rapid (Joll 1975).

Macroscopically, non-sexual juveniles were distinguishable from maturating males and females, and maturating individuals were distinguishable from adults. Maturation stages 1 and 2 were unable to be differentiated macroscopically, nor were the adult stages of ripe, spawned and regeneration. The clear differentiation between juveniles and adults, however, allowed for macroscopic staging to assess size at maturity. In order to validate the accuracy of macroscopic staging, a subsample of individuals within each of the macroscopic stages was also examined histologically and maturity status assessed. All of the individuals macroscopically staged as juvenile were confirmed to be maturating juveniles based on histological examination. By contrast, 20.1% of individuals classified macroscopically as adults were staged as juveniles histologically (Figure 26). The vast majority of these misclassified juveniles (93.2 %) were Maturation Stage 2. This finding, while largely supporting the macroscopic classification of immature and mature individuals, does suggest that the maturity ogives may include a small bias that will result in a slight underestimation of size at maturity.

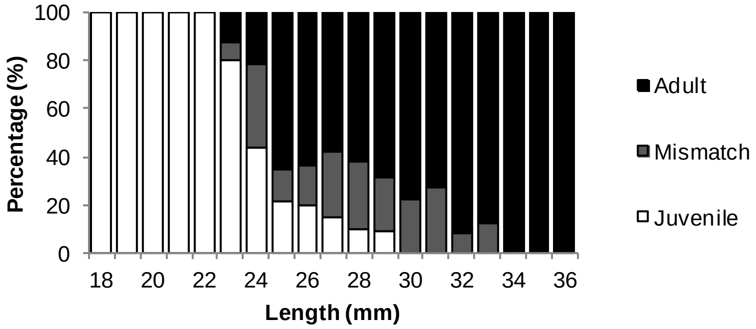


Figure 26. Classification mismatch between macroscopic and histological staging of periwinkle maturation. Mismatched individuals were classified as adults based on macroscopic staging but were classified as juvenile based on histology.

Figure 27. Gametogenetic cell types in female periwinkles.

Table 10. Images of periwinkle gonads with macroscopic descriptions at different stages of sexual maturation. Histological sections are from same individual are shown and were used to validate macroscopic staging. Section 1: Non-sexual; Section 2: Female maturation; Section 3: Male maturation.

Section 1: Non-sexual

Developmental stage	Image	Histological section
Undeveloped juvenile **Non-sexual** No detectible signs of gonad development. Gut only visible, dark brown/black in colour. *Size: 18.4 mm* *Piccaninny Point, 23/11/2012*		

Table 10, Section 2: Female maturation

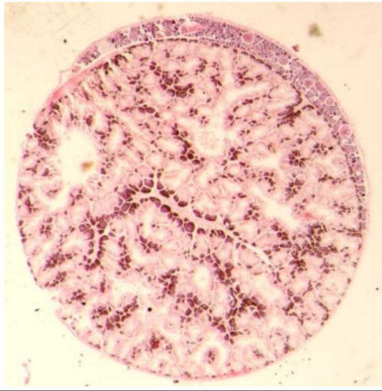
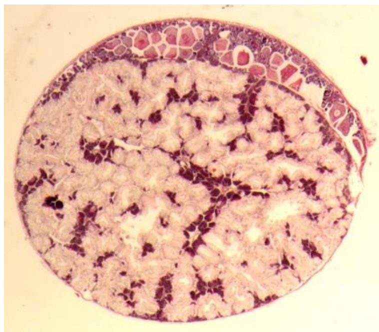
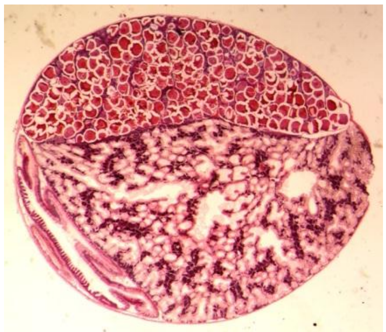
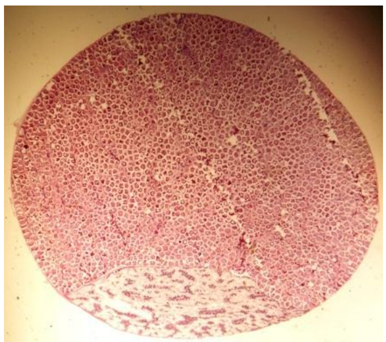
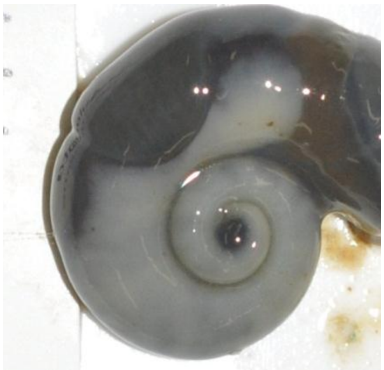
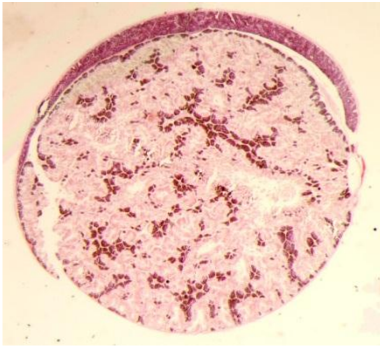
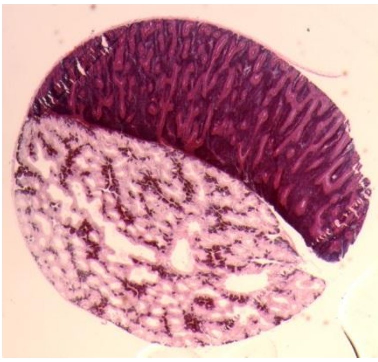
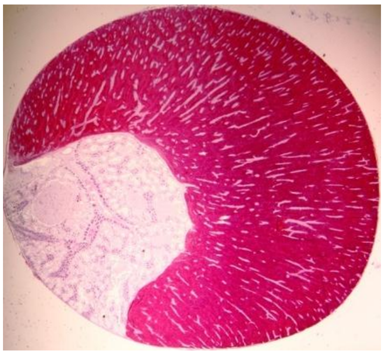
Developmental stage	Image	Histological section
Juvenile Female Maturation Stage 1 Gonad green and thin. Gut still visible through gonad. *Size: 25.6 mm* *Bull Bay, 21/08/2012*		
Juvenile female Maturation stage 2 Gonad green. Some large oocytes detectible Thin at extremities. *Size: 21.2 mm* *Piccaninny Point, 23/11/2012*		
Adult female **Ripe** *(small specimen)* Gonad green. Oocytes visible and dense. Depth to gonad cross section. Colour variants, light to olive green, brown, brown/purple *Size: 27.5 mm* *Piccaninny Point, 23/11/2012*		
Adult female **Ripe** *(large specimen)* Gonad green. Oocytes visible and dense. Depth to gonad cross section. Colour variants, light to olive green, brown, brown/purple *Size: 46.6 mm* *Piccaninny Point, 23/11/2012*		

Table 10, Section 3: Male maturation

Developmental stage	Image	Histological section
Juvenile male **Maturation stage 1** Gonad white/grey and thin. Gut still visible through gonad. *Size: 20.3 mm* *Piccaninny Point, 23/11/2012*		
Juvenile male **Maturation stage 2** Gonad white/grey. Gut not visible through gonad. Thin at extremities. *Size: 26.8 mm* *Bull Bay, 21/08/2012*		
Adult Male **Ripe***(small specimen)* Gonad cream. Depth to gonad cross section. *Size: 29.5 mm* *Bull Bay, 19/11/2012*		
Adult Male **Ripe** *(large specimen)* Gonad cream. Depth to gonad cross section. *Size: 44.0 mm* *Piccaninny Point, 27/07/2012*		

Size at maturity

The length at 50% maturity ($LM_{50\%}$) in periwinkles varied spatially around Tasmania and also temporally at individual sites (Table 11). $LM_{50\%}$ varied between 22.9 mm at The Gardens to 32.0 mm at Low Rocky Point. These sites are located in the north-east and south-west of Tasmania, respectively, and represent a general trend of lower $LM_{50\%}$ values in the warmer northern waters and larger in cooler southern waters.

Estimated $LM_{50\%}$ varied through time at each of the main sampling sites, with the maximum variation being 5.8 mm at the Recherche Bay site, equivalent to 9.4% of the mean maximum length (L_∞) for that area (Figure 28). The lowest $LM_{50\%}$ values occurred during summer, while the highest values were recorded during the autumn-winter period. This fluctuation in $LM_{50\%}$ appears to be linked to the seasonal reproductive cycle and values obtained in the period immediately preceding the peak spawning activity should be considered.

At the five key study sites, length at maturity was obtained by averaging values based on sampling between November and February (Table 12). The $LM_{50\%}$ showed a clear latitudinal gradient, with size at maturity increasing with latitude, for instance, $LM_{50\%}$ ranged from 23.2 mm at The Gardens to 26.2 mm at Recherche Bay.

Based on the growth functions, periwinkles were estimated to reach $LM_{50\%}$ at between 1.1 and 1.6 years of age and enter the fishery (45 mm) 1.7 to 5.1 years later depending on location. These results suggest that all individuals have the opportunity to spawn at least once before being susceptible to fishing at the current size limit, justifying the increase in the size limit from 30 to 40 mm in 2009 and subsequently to 45 mm in 2013.

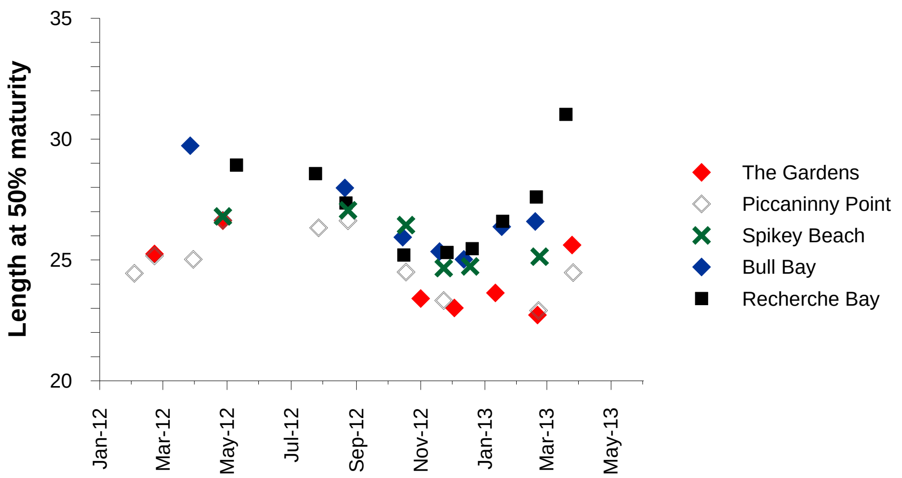


Figure 28. Seasonal changes in the length of 50% maturity of periwinkles at the five research sites off eastern Tasmania.

Table 11. Predicted length at 25%, 50% and 75% sexual maturity ($LM_{25\%}$, $LM_{50\%}$, $LM_{75\%}$) of periwinkles at various research sites off eastern Tasmania. logistic regression parameters *c* and *d* are shown.

Site	Date	Length at % sexual maturity (mm)			Logistic curve parameters	
		$LM_{25\%}$	$LM_{50\%}$	$LM_{75\%}$	*c*	*d*
North east						
Pebblys	06/12/2012	22.5	23.7	24.8	-23.05	0.97
Skeleton Bay	06/12/2012	23.1	23.9	24.8	-30.83	1.29
The Gardens	22/02/2012	24.1	25.3	26.4	-24.19	0.96
	27/04/2012	25.9	26.6	27.4	-38.92	1.46
	01/11/2012	22.5	23.4	24.3	-27.97	1.19
	03/12/2012	22.2	23.0	23.8	-32.19	1.40
	11/01/2013	22.6	23.6	24.7	-24.65	1.04
	20/02/2013	21.9	22.7	23.6	-28.96	1.27
	25/03/2013	24.6	25.6	26.6	-27.64	1.08
Piccaninny Point	03/02/2012	23.6	24.4	25.3	-32.37	1.32
	22/02/2012	24.3	25.2	26.0	-32.89	1.31
	30/03/2012	24.1	25.0	26.0	-29.50	1.18
	27/04/2012	25.7	26.6	27.6	-31.53	1.18
	27/07/2012	25.1	26.3	27.5	-24.07	0.91
	24/08/2012	25.7	26.6	27.5	-32.41	1.22
	18/10/2012	23.4	24.5	25.6	-24.59	1.00
	23/11/2012	22.2	23.3	24.4	-23.75	1.02
	21/02/2013	22.1	22.9	23.8	-29.69	1.30
	26/03/2013	23.7	24.5	25.3	-34.03	1.39
South east						
Spikey Beach	27/04/2012	25.4	26.8	28.2	-21.59	0.81
	24/08/2012	25.5	27.1	28.7	-18.54	0.69
	18/10/2012	24.9	26.4	28.0	-18.82	0.71
	23/11/2012	23.9	24.7	25.4	-35.39	1.43
	18/12/2012	23.7	24.7	25.8	-26.01	1.05
	22/02/2013	23.7	25.1	26.5	-19.68	0.78
Eaglehawk	02/02/2013	24.7	26.0	26.4	-22.56	0.87
Clifton	20/11/2012	24.1	25.2	26.2	-27.11	1.08
Bull Bay	27/03/2012	28.3	29.7	31.2	-22.82	0.77
	21/08/2012	26.8	28.0	29.2	-25.86	0.92
	15/10/2012	24.5	25.9	27.4	-20.05	0.77
	19/11/2012	23.7	25.3	27.0	-17.21	0.68
	12/12/2012	23.8	25.0	26.2	-23.27	0.93
	17/01/2013	25.0	26.4	27.7	-21.64	0.82
	18/02/2013	25.4	26.6	27.8	-24.20	0.91
Southport	26/11/2012	25.2	26.5	27.8	-22.47	0.85
Recherche Bay	10/05/2012	27.9	28.9	30.0	-30.24	1.05
	24/07/2012	27.5	28.6	29.7	-28.97	1.01
	22/08/2012	26.2	27.4	28.5	-26.51	0.97
	16/10/2012	24.1	25.2	26.3	-25.21	1.00
	26/11/2012	23.7	25.3	26.9	-17.03	0.67
	20/12/2012	24.5	25.5	26.4	-29.71	1.17
	18/01/2013	25.6	26.6	27.6	-28.36	1.07
	19/02/2013	26.5	27.6	28.7	-28.32	1.03
	19/03/2013	29.5	31.0	32.6	-22.12	0.71
South west						
Low Rocky Point	21/03/2013	32.0	32.5	33.0	-72.91	2.24
North west						
Hunter Island	19/03/2013	29.2	31.4	33.5	-16.24	0.52

Table 12. Estimated shell length of periwinkles at 25%, 50% and 75% sexual maturity ($LM_{25\%}$, $LM_{50\%}$, $LM_{75\%}$) based on estimates during primary maturation and spawning period (November-February), and shell length at each year for 5 years following onset of sexual maturity ($LM_{50\%}$) at five locations off eastern Tasmania. Length at maturity is derived from logistic curve analysis; L_{∞}: mean maximum length from Von Bertalanffy growth modelling. Note: low numbers of recaptures at the Piccaninny Point site may result in poor model accuracy.

Site	Mean length at % sexual maturity (mm)			Age at LM50%	Age at 45 mm	Estimated length 1 to 5 years following sexual maturation (LM50% - mm)				
	$LM_{25\%}$	$LM_{50\%}$	$LM_{75\%}$	(years)	(years)	1 yr	2 yr	3 yr	4 yr	5 yr
The Gardens	22.3	23.2	24.1	1.1	3.7	35.2	42.2	46.4	48.8	50.3
Piccaninny Point	22.7	23.6	24.5	1.1	2.9	37.6	46.5	52.1	55.7	58.0
Spikey Beach	23.8	24.8	25.9	1.6	6.7	33.3	38.5	41.7	43.7	44.9
Bull Bay	24.5	25.8	27.2	1.1	2.8	39.1	47.1	51.9	54.9	56.6
Recherche Bay	25.1	26.2	27.4	1.4	3.3	37.9	45.8	51.1	54.6	57.0

Spawning

Staging of gonads in spawning condition could not be determined reliably using macroscopic examination so histology was used to assess spawning status. In fully spawned individuals the ovary was almost entirely devoid of developed oocytes and showed signs of collapse (Figure 29). Histology also revealed partial spawning is prevalent in the species, with separate regions of spawned and ripe gonad present. Longitudinal sections of partially spawned gonad revealed spawned regions to be located posteriorly along the visceral coil, and unspawned (ripe) sections located anteriorly (Figure 29-d). Cross-sections of gonad from partially spawned individuals highlighted considerable variation in levels of spawned area detected (Figure 29-c, e, f). It is assumed that slight variation in the position of posterior spiral caecum cross-sections will influence the partial spawned area detected. Potentially, spawned gonad may not always be detected from such cross-sections, especially after commencement of the regeneration phase.

Fishers have observed spawning activity in periwinkles based on the detection of spawn product through its slimy texture and its sweet pungent aroma. They report that spawning typically occurs during summer, between December and February; however there are anecdotal reports of spawning occurring as early as October and as late as May. Spawned product is sometimes detected on-board the dive vessel after capture, but more commonly in purge sites. It is thought that the stress of handling may induce periwinkles to spawn, hence higher prevalence of spawning periwinkles at purge sites.

Full or partially spawned periwinkles were detected in histological sections over an extended period between the months of November and April (Figure 30, Figure 31). At individual sites mature periwinkles at various developmental stages were detected in any given month indicating spawning is not synchronous within a population. For example, fully and partially spawned, as well as Regeneration Stage 1 and 2 individuals were detected at Bicheno in April 1993, whereas ripe and partially spawned, as well as Regeneration Stage 1 and 2 individuals were detected at The Gardens in April 2012. The proportions of spawned and Regeneration Stage 1 individuals was low across all sites, and Regeneration Stage 1 individuals were not present in the month following spawning, indicating gonad recovery after spawning is rapid.

Large fluctuations in GSI were evident between sampling periods, with values varying between 38 and 88% (Figure 30, Figure 31). These extreme values were recorded at Piccaninny Point, the peak occurred in January 2013 when the periwinkles were in ripe condition while the lowest GSI occurred in February 2012 when all of the individuals had either spawned or gonads were regenerating. Periwinkles in spawning condition or Regeneration Stage 1 were present between January and March at most of the sites surveyed during 2012-13, with spawning activity extending into April at The Gardens site (Figure 31). Sampling during the 1990s indicated spawning activity at Bicheno between November and January as well as during April (1993), each of these events being accompanied by a marked decline in GSI. Partial spawning activity recorded at The Gardens, Spikey Beach and Bull Bay in February 2013 did not, however, result in obvious declines in GSIs.

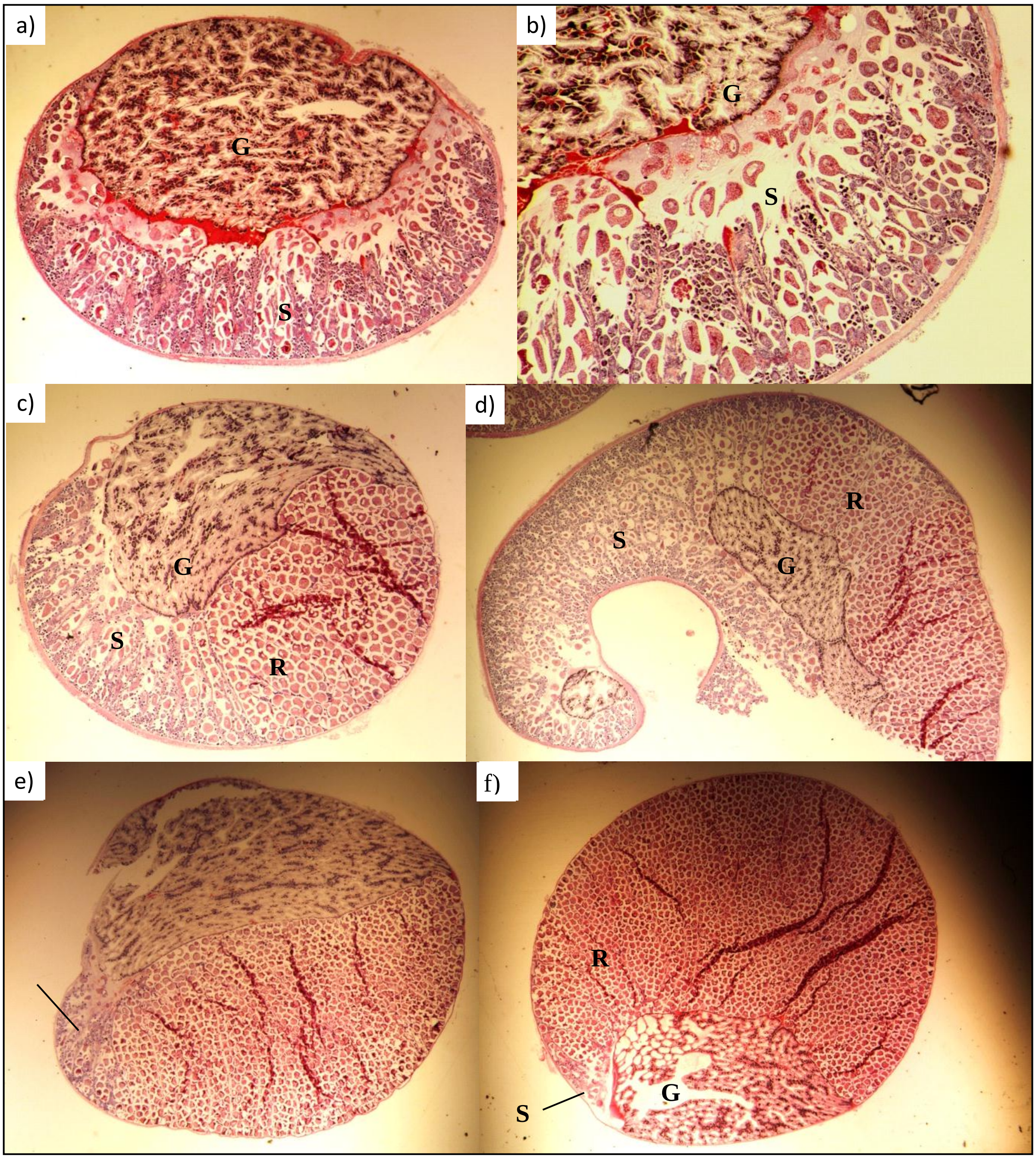


Figure 29. Varying levels of spawning in periwinkles: a-b) fully spawned; c-f) partially spawned. S: spawned region; R: Un-spawned region containing ripe oocytes; G: Gut. Images a and b are from the same individual, as are c and d.

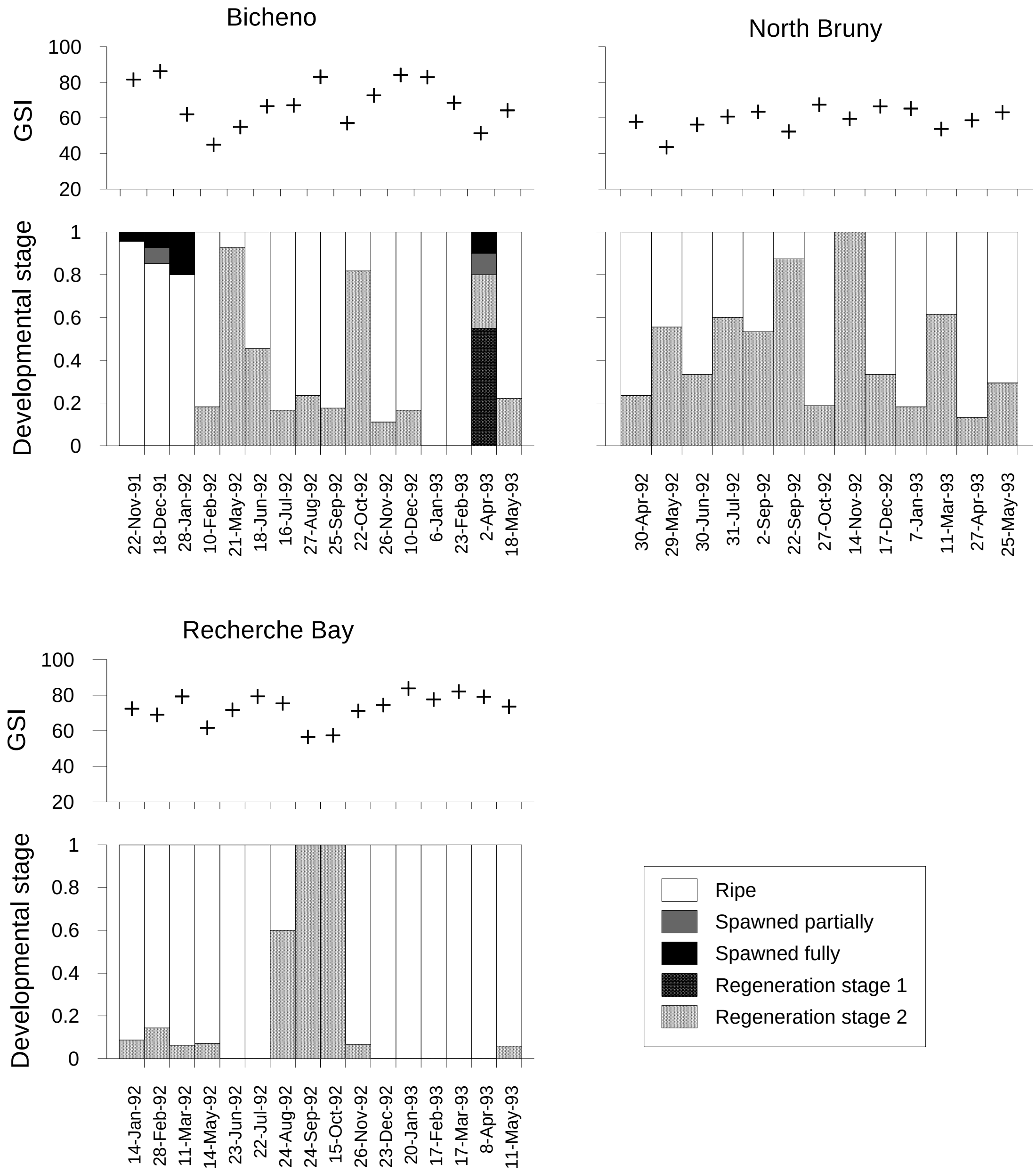


Figure 30. Female gonadosomatic index and proportion of gonadal developmental stages in periwinkles sampled from three sites off eastern Tasmania between 1991 and 1993.

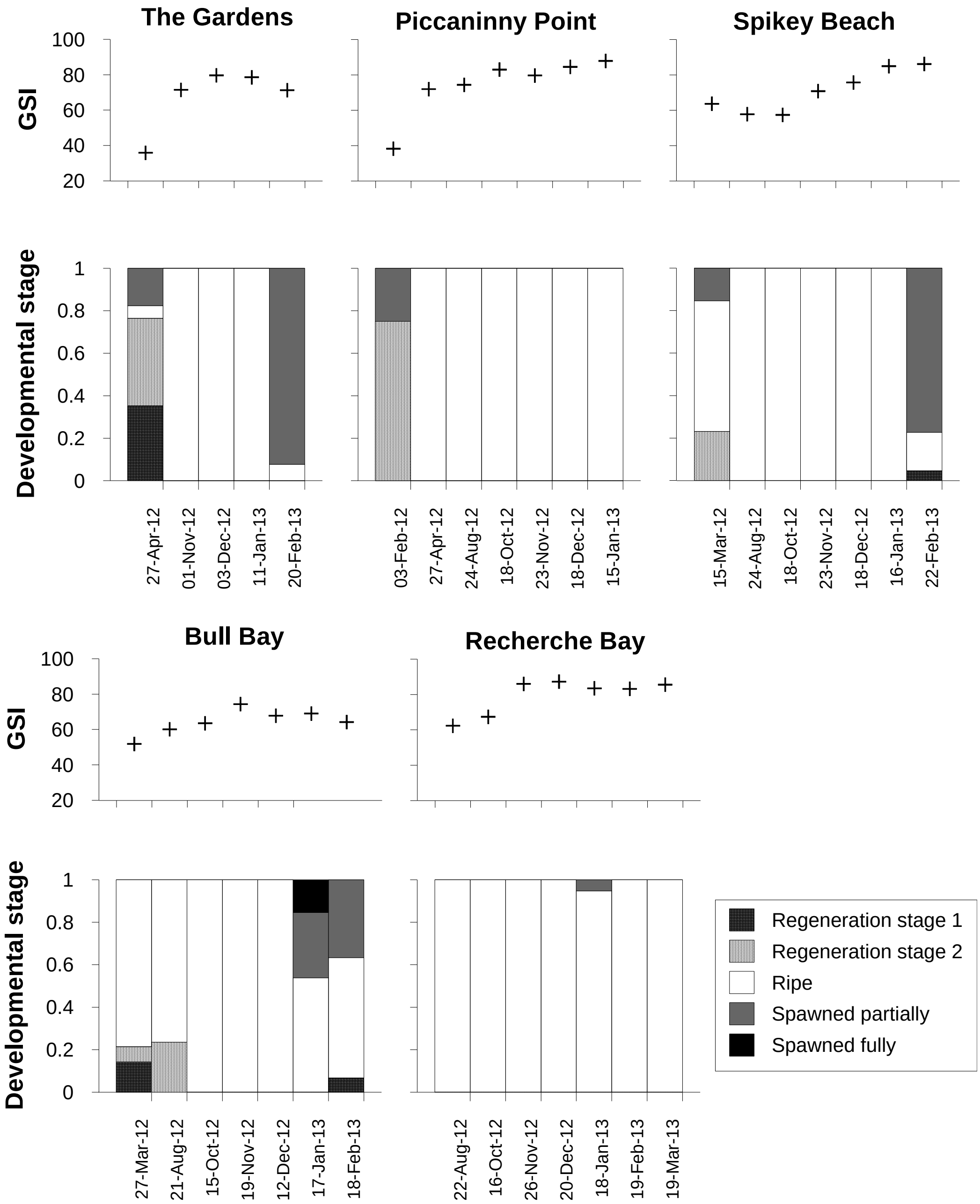


Figure 31. Female gonadosomatic index and proportion of gonadal developmental stages in periwinkles from histological sections from five sites off eastern Tasmania between 2012 and 2013.

Periwinkle markets

Market value

The annual value (beach price) of the periwinkle fishery to the Tasmanian economy averaged approximately $120,000 (CPI adjusted) between 2007 and 2012 (Figure 32). However, decreasing catch has resulted in the value falling from $185,000 to $80,000 during this period. The value of the fishery had the total TAC been harvested and assuming no price drop with increased volumes, would be approximately $220,000. With the 2013 TAC increase, this value increases to approximately $340,000.

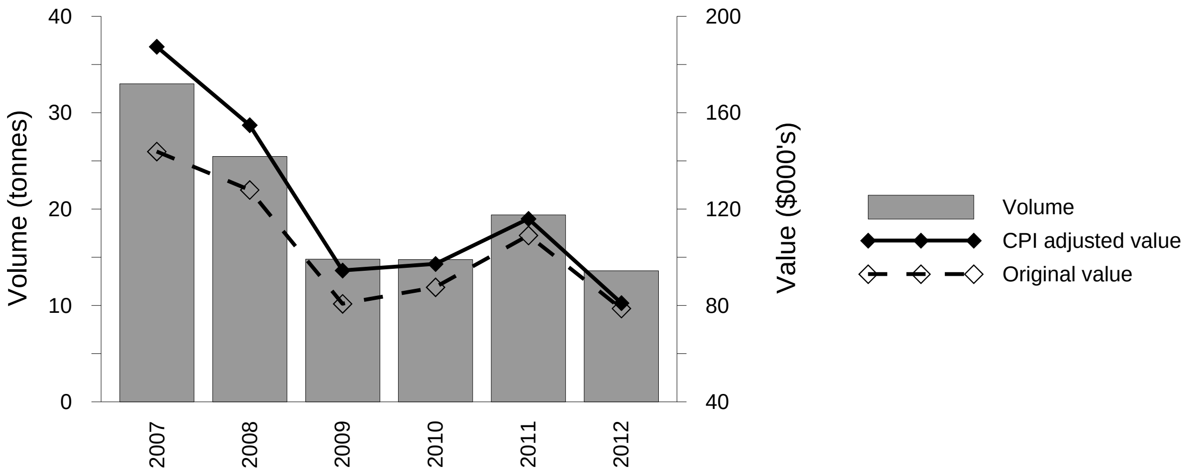


Figure 32. Value (beach price) of the Tasmanian periwinkle fishery since 2007

Market structure

In Tasmania between three and six fishers have typically supplied over 90% of the product in any given year (Figure 16). These ‘suppliers’ sell through a variety of channels, including mainland based-seafood distributors, direct to retailers, or through the open market (e.g. SFM). Most commonly, the more regular fishers sell product direct to distributors, retailers and in small quantities to restaurants, while the more irregular fishers tend to sell through distributors and the market floor.

The final destination for periwinkles is divided roughly evenly between the restaurant and retail sectors, with the majority of product being sold in the metropolitan areas of Sydney and Melbourne. Smaller volumes are occasionally on-shipped from distributors in Sydney and Melbourne to other locations such as Brisbane and Perth, with small quantities even shipped back to Melbourne from Sydney.

Retail sector

The retail sector for periwinkles is predominantly comprised of sales through seafood retailers in the Vietnamese communities of Sydney and Melbourne (Figure 33). Smaller volumes sometimes enter Greek and Chinese markets. The periwinkles are kept alive at seafood retailers in systems ranging from aerated tubs to recirculated seawater aquariums. Periwinkles are marketed to the general public to be consumed in family meals and as a snack food. In the latter case the periwinkles are steamed, removed from the shell with a pick, and consumed with a dipping sauce (Ken Nguyen, 2013, *pers. comm.*). Live periwinkles retailed for $12/kg (February 2013) in both Sydney and Melbourne.

Figure 33. Periwinkle retailers in the Vietnamese communities of Sydney and Melbourne.

Restaurant sector

Restaurants offering periwinkles include top-end restaurants looking for unique and edgy products as well as ethnic restaurants in cultural hubs, in particular in Vietnamese communities. Periwinkles tend to feature predominantly on entrée menus of high-class restaurants and both as entrée and main components in ethnic restaurants. They have featured on the menus of some of Australia's best dining establishments including the 2013 Australian restaurant of the year 'Quay', as well as 'Momofuku Seiobo' and 'Gowings' in Sydney and 'MoVida' in Melbourne.

High profile Australian chefs including Peter Gilmore (Quay) and Paul Easson (Gowings, Rockpool) endorse periwinkles as an excellent food product with high potential. Periwinkles uniqueness and versatility are seen as adding excitement to a menu. By comparison, factors relating to availability and preparation time are seen as negative aspects for a food source.

Figure 34. Entrée at Gowings Bar and Grill, Sydney. *Raw live clams/Mussels/Vongole/Steamed Periwinkles: A light dressing of parsley, coriander stalks, rice wine vinegar, lemon* (left). Periwinkle noodle soup at a Cabramatta restaurant (right).

Supply and demand

The current market for periwinkles is primarily demand driven with wholesalers and retailers in Sydney and Melbourne requesting set quantities from key fishers. Demand is not always met and supply shortages periodically occur. Volumes supplied to the open market, such as the SFM, are often sporadic.

Tasmanian supply (catch)

Supply of Tasmanian caught product has averaged 1.8 tonnes/month since the start of the 2006/07 season. However, during this period volumes have fluctuated substantially, frequently varying by more than 50% between months (Figure 35, Figure 36). Monthly catches have ranged between zero and 6.6 tonnes; these extremes occurred within a five month period in 2007 and were due to the closure and reopening of the Developed Zone related to TAC status (Figure 8). Supply during the 2010/11 to 2012/13 seasons has been more stable than in previous years and has averaged 1.6 tonnes/month.

Weekly catches are generally less than one tonne, but have been as high as 2.8 tonnes (Figure 35, Figure 36). A high variation in weekly catch is apparent and is highlighted by nil catches in about a quarter of all weeks, including 16 periods of two or more weeks when no product was landed (Figure 36). Some fishers are able to hold product at the purge sites for short periods, making it is possible to regulate quantities put onto the market thereby avoiding short-term oversupply and reducing the impact of periods of undersupply that may be due to weather or are dictated by variation in market demand.

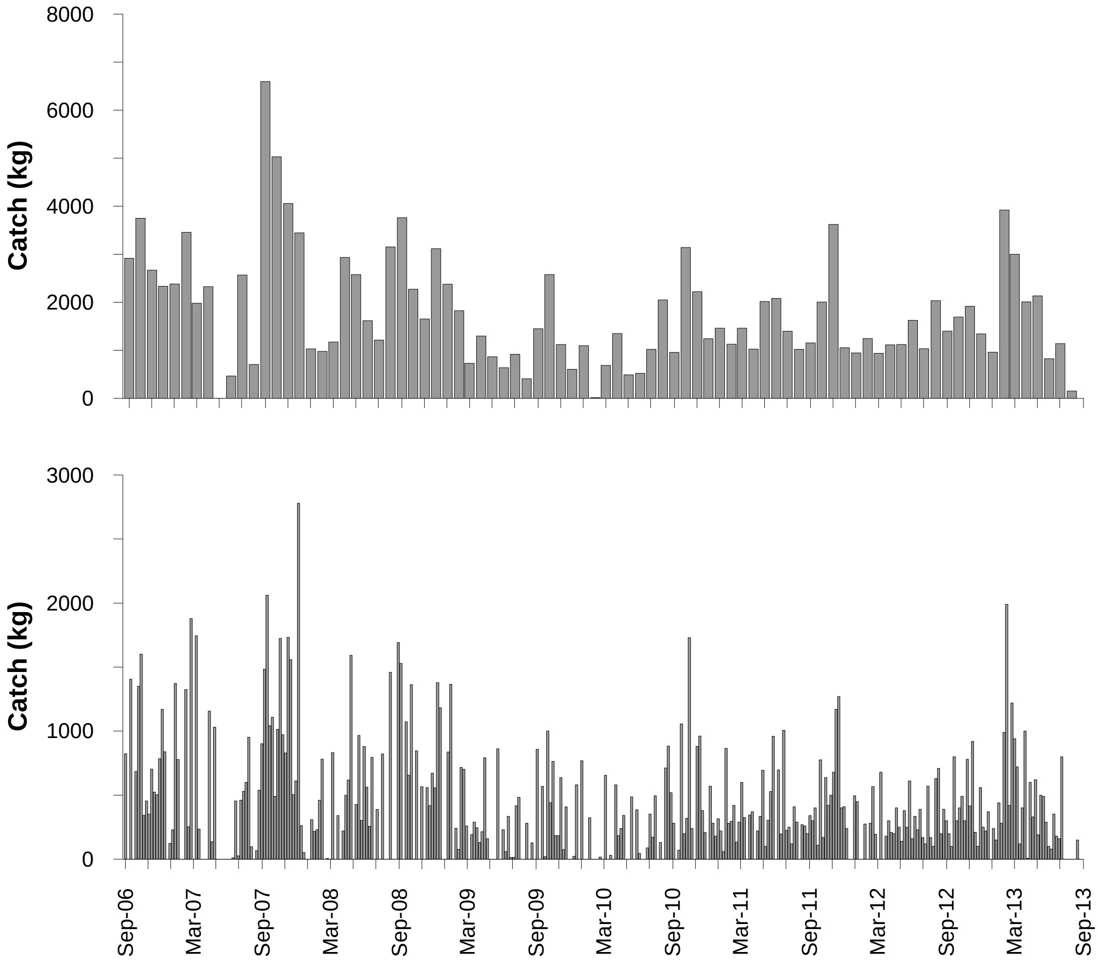


Figure 35. Monthly (top) and weekly (bottom) catch volumes as a proxy for market supply of periwinkles from Tasmania.

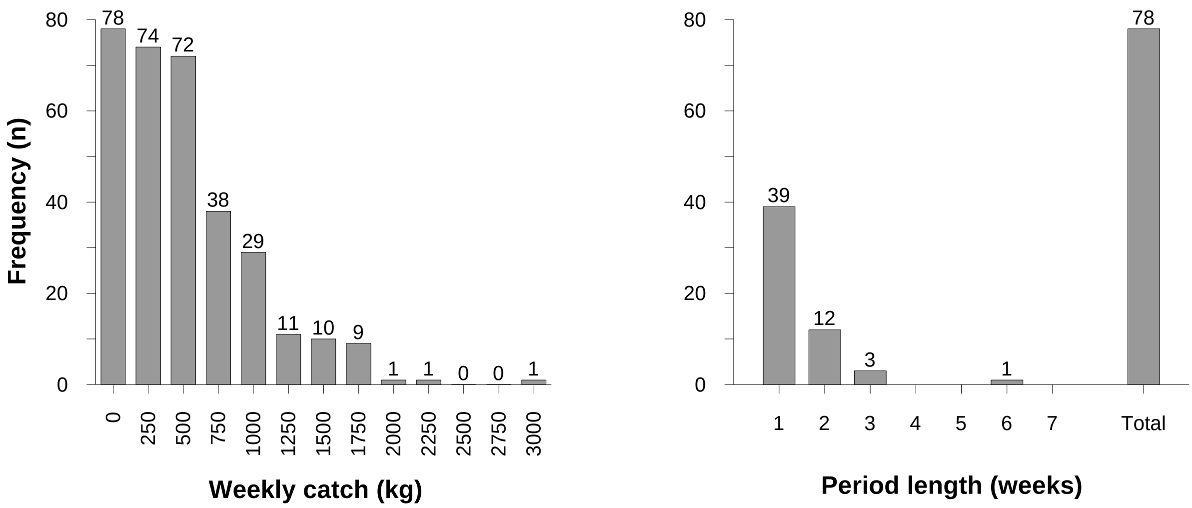


Figure 36. Weekly catch distributions by volume (250 kg bins) as a proxy for market supply (left) and periods of zero catch as a proxy for supply gaps to markets (right) between the 2006/07 and 2011/12 fishing seasons. Weeks are the length of time with zero catch. Total is the number of individual weeks with zero catch. Total weeks = 312.

Supply and demand case study: Sydney Fish Market

Data obtained from the Sydney Fish Market (SFM) highlights the inconsistency in supply of product to the market (Figure 37). Monthly volumes traded through the SFM from all states were low and sporadic prior to 2006. Since 2006 volumes have increased but have continued to vary considerably, fluctuating between 80 kg and 1,747 kg. Similarly, product originating from Tasmania has varied between 0 kg and 1,383 kg per month.

Periwinkle market price has shown a general trend of increasing over time, but has fluctuated greatly with average monthly price varying between $2.00 and $8.68 (Figure 37). Linear regression showed price has increased relative to the Australian CPI (P=0.02); hence the economic circumstances of a periwinkle license holder/fisher have improved since 2001 (Figure 38). Furthermore, periwinkle price has increased relative to other seafood products (P=0.004) indicating that periwinkles are outperforming other seafood products (Figure 38).

There are several notable instances where oversupply led to dramatic reductions in price. These instances are likely to be partly driven by a high price in the preceding month(s) which was only attainable for small volumes of product. Nevertheless mean prices fell by $2.12 (32%) and $2.50/kg (36%) between August and December 2006 and August and December 2007, respectively, following large volumes of product (predominantly originating from Tasmania) entering the market. These two periods followed the opening of the Tasmanian fishery in September and increased activity in the fishery (refer *Catch and effort* section). In both 2006/07 and 2007/08 the Tasmanian TAC in the Developed Zone was reached within eight months of the opening of the fishery. In recent years the TAC has not been reached and catches have been more evenly dispersed throughout the season.

Feedback from fishers and wholesalers at the SFM also gave insights into price fluctuations that extend beyond supply and demand. Very large periwinkles (>55 mm) are less desired by the market and price for boxes of these can fall to as much as a third of the price of smaller periwinkles if offered simultaneously on the market floor. Delays in product reaching the market during periods of peak demand (e.g. Chinese/Vietnamese New Year) have resulted in price reductions when product arrives after the event; weather delaying harvest and unexpected delays in transport have been factors.

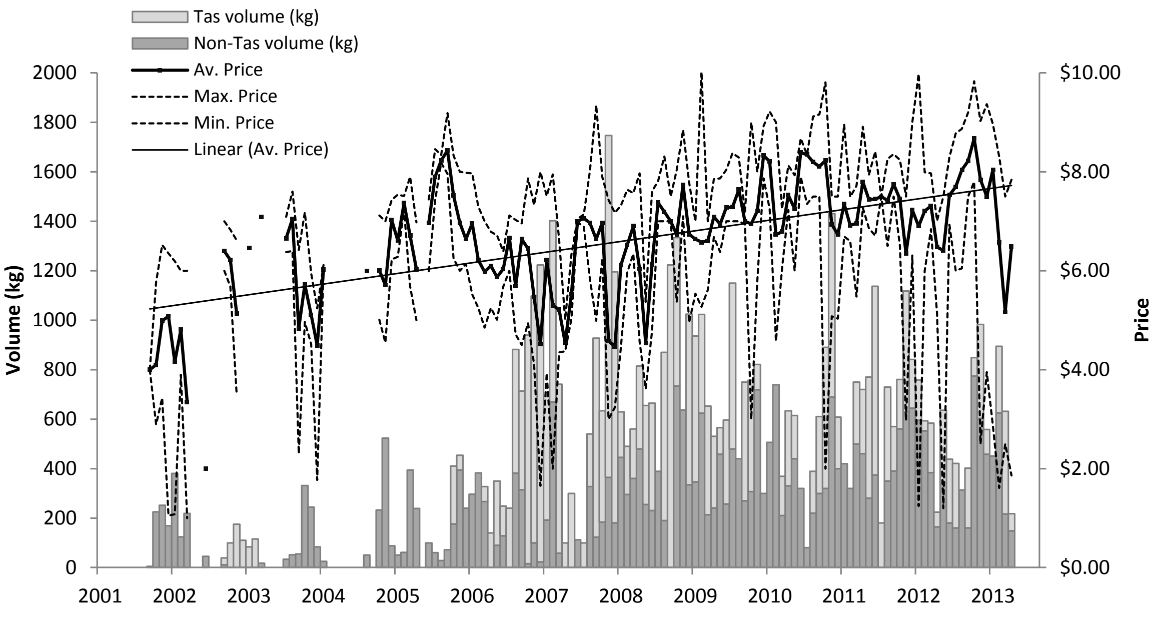


Figure 37. Monthly volume (kg) and real price ($) of periwinkles traded through the Sydney Fish Market from all states.

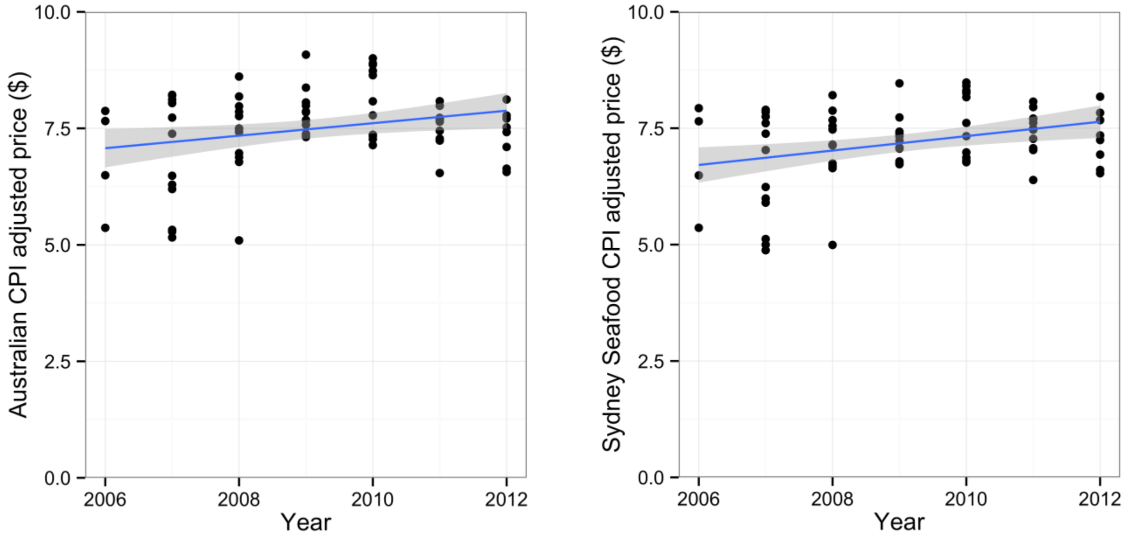


Figure 38. Australian CPI adjusted (left) and Sydney Seafood CPI adjusted (right) monthly average market floor price of periwinkles traded at the Sydney Fish Market.

Market modelling

Generalized linear models were used to formally consider the relationships between both Australian CPI and Sydney Seafood CPI adjusted prices and volume harvested, year and season (Table 13). In both models the volume of product caught in Tasmania was highly significant whilst the volume caught outside of Tasmania was unrelated to the price. Tasmanian and non-Tasmanian volumes were similar over the period modelled (27.5 and 27.3 tonnes, respectively), however, Tasmanian supply was more irregular with larger volumes landed less frequently as well as a higher frequency of months with no catch (Figure 39). A fall in price after large volumes of Tasmanian product landed on the market is reflected by both the Australian and Sydney Seafood CPI models which indicate a decrease in price of $1.43 and $1.26, respectively, for each tonne of product traded in a month.

Harvest year was not significant in both models even though price was shown to increase significantly through time (see previous section). This is indicative that changes in fisher behaviour are leading to increased prices, most likely fishers catching periwinkles at better times of the year and/or in more consistent quantities.

There was a seasonal signal in periwinkle price with the second and third quarters (summer and autumn) having prices $0.72 and $0.94 lower per kg, respectively, than the first and fourth quarters (spring and winter) based on the Australian CPI model (Table 13). Predictions on the impact of Tasmanian production on the Sydney fish market floor price using the Australian CPI model shows a clear link of declining price with increased production (Figure 40). Quarter 1 (spring) and Quarter 4 (winter) have the highest prices overall.

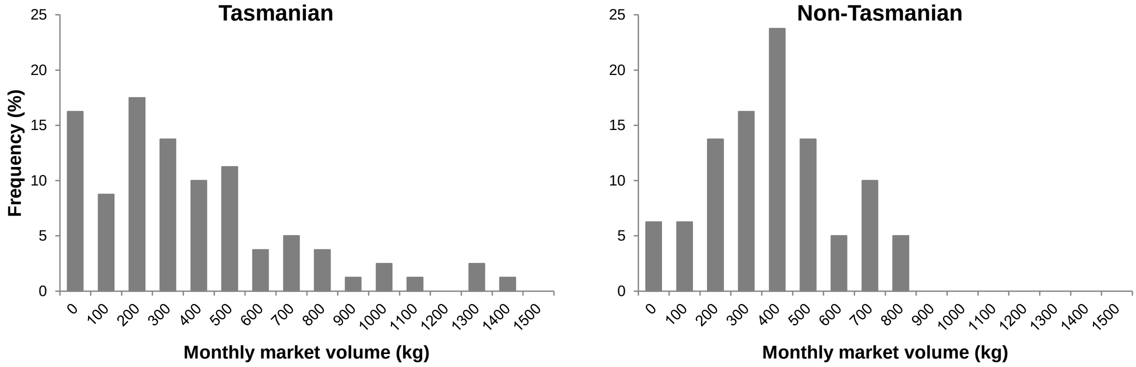


Figure 39. Frequency of monthly volumes traded at the Sydney Fish Market originating from Tasmanian and non-Tasmanian states.

Table 13. Generalized linear model coefficients for Sydney Seafood and Australian CPI indexed response variables to formally consider the relationship between volume harvested (t), year, time of year and the price ($).
Note that for readability the units for volume in this analysis are tonnes.

		95% Confidence Limit		
Australian CPI Model	Coefficient	Lower	Upper	p Value
Constant	8.33	7.65	9.01	0.00
Tasmanian volume	-1.43	-2.02	-0.83	0.00
Non-Tasmanian Volume	-46	-1013	921	0.93
Year	0.04	-0.06	0.15	0.42
Quarter 2	-0.72	-1.18	-0.25	0.00
Quarter 3	-0.94	-1.43	-0.45	0.00
Quarter 4	0.00	-.52	0.50	0.98
Sydney Seafood CPI Model				
Constant	7.93	7.31	8.54	0.00
Tasmanian volume	-1.26	-1.79	-0.73	0.00
Non-Tasmanian Volume	-303	-1174	568	0.50
Year	0.09	-0.01	0.18	0.07
Quarter 2	-0.70	-1.12	-0.28	0.00
Quarter 3	-0.89	-1.33	-0.45	0.00
Quarter 4	0.03	-0.43	0.49	0.91

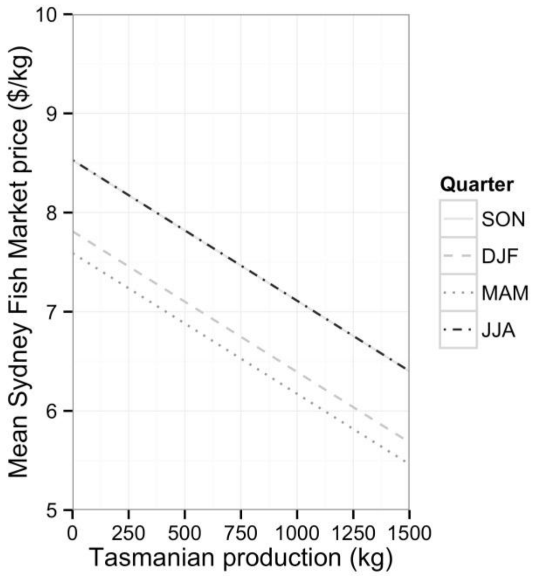


Figure 40. Price model of periwinkles traded at the Sydney Fish Market by volume and season. The seasons were 1. September, October, November, 2. December, January, February, 3. March, April, May, 4. June, July, August. Seasons 1 and 4 overlap due to indistinguishable prices and are shown by the top line.

Market feedback

Supply

The single most important factor identified by distributors and retailers that influenced the market for periwinkles was the lack of consistency and reliability in supply. This uncertainty has resulted in distributors and retailers not always being able to meet demand and, on other occasions while not as frequent, over supplying the market. This supply issue was also reiterated by the restaurant sector, with restaurateurs not always being able to source periwinkles. Distributors reported that after periods of supply shortage demand for the product tended to decrease as periwinkles were removed from restaurant menus.

Restaurateurs faced with inconsistent supply have approached the problem in several ways. Some restaurants accept the variable supply and simply inform customers on occasion that the menu item was “unavailable”. By contrast, high-end restaurants cannot be seen to have menu items unavailable as it tarnishes their image. In this regard one chef reported purchasing a bulk quantity of periwinkles, prepared (steamed and removed from shell) and froze them to overcome supply shortages. Periwinkles on the menu of another restaurant visited as part of this study were not available due to supply shortage, and were subsequently removed from the menu all together. Other restaurants visited indicated they could only source periwinkles about two-thirds of the time during the period they were on the menu.

Size and quality

Feedback from distributors, retailers and restaurateurs highlighted a preference for periwinkles sized 40-55 mm, with 45-50 mm being ideal. Larger periwinkles have a reduced appeal due to fewer servings per kilogram of product; periwinkles are generally sold in set quantities. In addition large periwinkle meats are reportedly ‘intimidating’ and ‘confronting’ to some consumers and are considered undesirable. Larger periwinkles, however, are purportedly preferred by the Greek community although demand is low, and in at least one restaurant visited, meats from large periwinkles are shaved and used as a garnish. Reflecting the limited demand for large periwinkles, distributors reported that they are frequently rejected by the marketplace and tend to be sold at reduced prices. At the other end of the size spectrum, small periwinkles are considered too time consuming to prepare by the restaurant sector. Furthermore, chefs who serve periwinkles in shell require them to be of a consistent size for presentation, and boxes of constant size are more desirable and may attract a premium price.

The Tasmanian size limit for periwinkles has limited the quantities of small periwinkles <40 mm entering the market since 2009. Consistent with the limited demand for large periwinkles, fishers reported that large periwinkles sometimes attract prices as much as 50% lower than that of preferred product. This price pressure has generally limited the supply of large periwinkles to market. Interestingly, periwinkles as small as 20 mm (originating from South Australia) were observed for sale in retail markets in Sydney, such product is both undesirable by markets and unlikely to have reached sexual maturity.

All distributors and retailers interviewed reported receiving high quality product in the main, with only two instances of bad product (mortalities within the shipment) reported. In both instances the mortalities were attributed to transport issues, with one shipment thought to have got too warm, while the second shipment to a different distributor was suspected to have got too cold, with ice bricks placed directly on the product.

Occurrences of un-purged periwinkles entering the market have lessened over the past decade but distributors report that un-purged product still occasionally enters the marketplace. Un-purged product in the market has resulted in reduced sale prices and volumes traded for a period following its sale. Reports of un-purged product by consumers can be found on internet food blogs which can tarnish the product image beyond the initial consumer. Two examples are quoted below.

> *"The 'Tomatoes Stuffed with Snails and Periwinkles' although quite tasty, was less of a success. The snails were undercooked and tough and the periwinkles gritty." (Franz Scheurer: Australian Gourmet Pages, 2003)*

> *"They yielded a very low meat reward to effort ratio and most disturbingly, the vast majority of the periwinkle seemed to be darkly veined gut and stomach contents. The doubt escalated with a mouthful of unappetising muddy "sand" or more likely, faeces and my family chastised the choice of periwinkles, and indirectly me, as it had them eating poo for Chinese New Year. Definitely an inauspicious act by anyone's standards. I think I've had my special dish requests rights revoked for all future feasts." (Trina So: The Gourmet Forager, 2011).*

It is also reported that holding periwinkles too long in live tanks reduces quality. Retailers interviewed reported that the meat reduces in size and the flavour decreases with increasing time kept in captivity.

Transport

Periwinkles originating from Tasmania are freighted in 10 or 20 kg polystyrene boxes by road and sea (across Bass Strait) to mainland markets predominantly in Sydney and Melbourne They are shipped by road as the low value of the product makes air freight non-viable. Periwinkles are robust and their ability to close the operculum makes them suitable for refrigerated road transport.

Transport costs, however, are considered one of the biggest threats to the Tasmanian periwinkle fishery. In recent years the Tasmanian Freight Equalisation Scheme (TFES) is considered not to fully compensate for the sea freight cost disadvantage incurred by shippers of goods moved by sea. In addition, Bass Strait shipping fuel surcharges and the new Port of Melbourne tax are further contribution to freight costs. The combination of these costs is placing Tasmanian suppliers at a disadvantage when competing in mainland markets against mainland harvested product. Fishers have noted that freight costs have increased substantially in recent years and are threatening the viability of the sector. In 2006/07 freight prices were around $0.50/kg to ship product to Sydney markets, now shippers are quoting $1.30 to $2.20/kg for the same service. Transport costs represent a significant cost burden to industry and account for 8-33 % of the value paid to fishers.

The continuation and expansion of the TFES is seen by industry as essential to ensure that Tasmanian fishers are able to compete in mainland markets as well as to provide opportunities to develop the export potential for this species.

Product substitution

Direct substitution of Australian periwinkles is occurring with imported snail meat from Vietnam available in retail outlets (Figure 41). These 250 g frozen blocks were retailing for $5.00 in February 2013. This imported snail meat is also being used in suburban restaurants within Vietnamese communities (Figure 34). Other molluscs, both fresh whole and frozen meats are also available for purchase at retail outlets (Figure 41).

Figure 41. Imported frozen snail meat from Vietnam packed in 250 g cryovaced blocks (left) and Australian molluscs, both fresh whole and frozen meat (right and insert) available for sale at Australian retail outlets.

Marketing

Product identity and branding

Periwinkles lack an identity in the broader marketplace, with many distributors and retailers reporting they lacked knowledge about the fishery as well as processing methods and uses as a food product. This coupled with the low value and low volume turnover, results in some distributors and retailers not trading periwinkles as they do not consider it worthwhile. These distributors and retailers indicated they would be more likely to do so if they knew of potential markets and had basic product information (e.g. handling and processing techniques and consumer utilisation).

The lack of product identity stems from a lack of product knowledge coupled with little to no active marketing. It therefore creates a marketplace where consumers are hesitant or unwilling to buy periwinkles. Distributors believe increasing the identity of periwinkles through increasing product knowledge is essential to boost sales and market share. Furthermore, distributors believe market initiatives to achieve this should be initiated by suppliers (fishers/processors).

Currently there is no branding of periwinkles to aid the development of a product image, or to distinguish product captured from different fishers, regions or states. Descriptive branding is becoming an increasingly important seafood marketing tool as consumers seek more information about the products they eat, including source locations and harvesting methods (Fiorillo 2013). Furthermore, descriptive branding is making its way onto restaurant menus and retail shop signage. Distributors believe the creation of brand for periwinkles would assist creating a product image and aid marketing and promotion. Branding could be at the fisher or fishery level, and capitalise on Tasmania's clean green image. Terminology like 'sustainability harvested', 'hand-picked', 'live', 'wild', 'purged' and 'Tasmanian' could be included in a brand name or slogan. *Spring Bay Mussels* is an example of branding highlighted by distributors that periwinkle suppliers could follow.

Product fact sheet/brochure

The majority of distributors, retailers, restaurateurs and general consumers are knowledge deficient in regard to all aspects of the periwinkle industry. Furthermore, many chefs have not encountered periwinkles and simply do not know how to prepare and cook them. The lack of consumer knowledge is considered by industry as one of the key factors limiting sales of periwinkles.

It has been suggested by distributors that a product fact sheet/brochure detailing the fishery, as well as periwinkle handling and processing techniques, would help alleviate knowledge gaps and encourage the trial and use of periwinkles throughout the restaurant sector. This should lead to increased demand and sales as product awareness increases.

Labelling

The addition of product labels (e.g. sticker) added to boxes sent to market was suggested by distributors to help enhance product image (e.g. Figure 42). Labels should include a form of product branding, as well as some key attributes of the product. Labels could be fisher specific or industry wide and ideally endorsed by the Tasmanian Commercial Divers' Association. Periwinkles need to be purged and this should be clearly identified on the labelling that this has occurred. Labelling would assist in the creation of a brand identity and also add to buyer confidence about product quality.

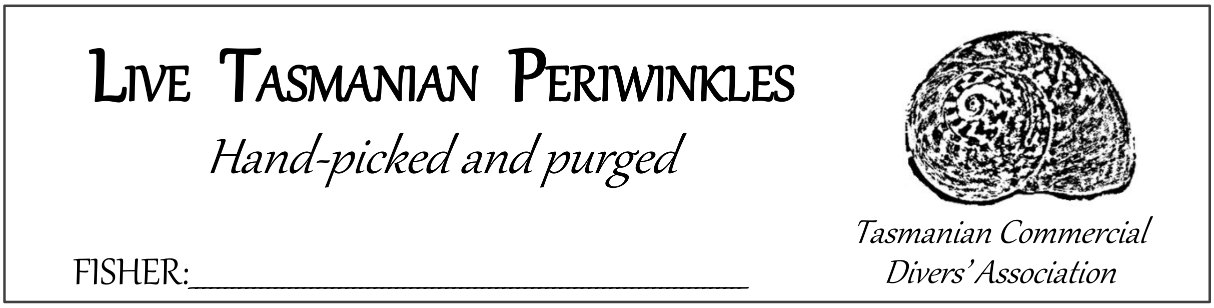


Figure 42. Example of a simple label design suitable for a fishery wide labelling of Tasmanian periwinkles boxes shipped to market.

Box Size

It was suggested by one fisher that the provision of 10 kg as opposed to 20 kg boxes achieved higher market price in open markets (e.g. Sydney Fish Market) as it provides the customer with more flexibility in relation to the volume purchased. However, there is no data available to support or contradict this observation.

Value adding – frozen product

The establishment of a frozen product line is seen to have substantial potential for market development and increasing growth throughout the restaurant sector. A frozen product would consist of periwinkle meat removed from shells and packed in 0.5 or 1 kg blocks, with suppliers believing this could retail for around $35/kg. If successful a frozen product would reduce two current key negative factors for the restaurant sector, namely product availability and processing time. It would also enable fishers to take higher catches at any one time, making harvesting periwinkles in remote locations more viable.

Sample boxes

The provision of small sample boxes of 1-5 kg to the restaurant sector to trial as part of an integrated marketing campaign would lead to greater product awareness, broaden the retail scope and increase usage in restaurants.

Opportunities for market growth

Distributors and restaurateurs who were interviewed believed that there is enormous potential to substantially increase the usage of periwinkles throughout the restaurant sector. They are currently only used in very small number of restaurants which creates a large scope for market growth. Chefs who have used periwinkles see them as a good and versatile product, adding an element of uniqueness and flair to a menu. This positive image needs to be conveyed to the boarder marketplace and if suppliers are able to address the issue of inconsistency in supply and quality (ensuring only purged product is marketed), the uptake of periwinkles in the restaurant sector is expected to flourish.

Growth in the retail sector is also seen as a viable option to increase sales. Currently the retail market is dominated by sales to Vietnamese communities and there is potential to expand this market if consistency of supply can be achieved. Opportunities also exist to grow sales to other multicultural communities such as the Greek and Chinese communities which currently account for small quantities of periwinkles.

Discussion

Structural changes in catch, effort and fisher dynamics – interpretation and management implications

Major changes in the structure of the Tasmanian periwinkle fishery have occurred between 2006/07 and 2012/13, through turn-over of operators and a shift in areas of operation in partial response to management initiatives. These changes need to be considered carefully when interpreting trends in catch and effort data during this period. Changes include an overall decline in catch and effort since the peak of the fishery in 2007/08, as well as a general shift in catch and effort from the south east coast to the north east coast.

As the periwinkle fishery is small with few operators accounting for the majority of the production, changes in the behaviour of even one key operator can have a substantial influence on the fishery dynamics. For instance, the reduction in the total catch from the historical peak in 2007/08 can be attributed to several key fishers either reducing their effort or exiting the fishery. While some of the key operators have retired, others have reduced their effort, claiming low beach prices and rising costs are making their operations less viable. Additionally, fishing effort has been diverted away from periwinkles and to the expanding long-spined sea urchin fishery.

A considerable expansion of catch and effort occurred in the North East (NE) between 2006/07 and 2012/13 whereas in the South East (SE) catch and effort has declined. Although the increased effort in NE was partially initiated by the creation of zones under the 2005 management plan and the TAC being reached in the Developed Zone in 2006/07 and 2007/08, this major shift can be largely attributed to new fishers entering and/or existing fishers increasing effort in the NE, rather than a relocation of effort from fishers in the Developed Zone. The reduction in catches from the SE has mainly resulted from key fishers exiting the fishery and from others having a greater focus on fishing for other species, including abalone.

The fishery-wide decline in CPUE (kg/h) that occurred between 2007/08 and 2009/10 was largely attributable to the regional shift in catch and effort from the SE to the NE rather than indicative of a fishery impact of stocks; CPUE in the NE is significantly lower than for the SE. At a regional scale, CPUE for both the NE and SE has remained relatively stable over time apart from a marked drop in CPUE in the SE during 2012/13. The 2012/13 CPUE decline in the SE can be explained by changed fisher behaviour which occurred following the closure of the NE after the Undeveloped Zone reached its TAC, causing some fishers to redirect effort into the SE. These fishers reported substantially lower CPUE than the more regular fishers; unfamiliarity with the fishing grounds may have contributed to the lower catch rates. The relocated fishers did, however, average longer dive days and take higher daily catches, presumably in an effort to offset some of the additional costs incurred when fishing away from home. The influence of this effort shift on CPUE further highlights the importance of understanding the dynamics of the fishery when interpreting the data. Furthermore, catch and effort in the SE have been very low in the past few seasons with many areas remaining unfished. This further supports the premise the CPUE drop in 2012/13 is not indicative of declining stocks. Catches in the N and W have been insufficient and too sporadic to indicate any patterns in CPUE for these regions.

The average daily harvest of periwinkles, by contrast, declined in most regions during the three to four years following the implementation of the management plan. It seems likely, however, that these initial declines were more a response to changing fishing practices, with fishers increasingly targeting specific quantities to meet market demand rather than to maximise harvest as observed early in the fishery. As such, catch rates based on catch per hour rather than total daily catch are likely to be a more sensitive and appropriate metric to assess trends in stock status.

Resource status

The current levels of stock biomass coupled with key management measures (regional catch limits and minimum legal size) provide a robust framework to reduce the risk of recruitment overfishing. The increase in the size limit to 45 mm, informed by growth and size at maturity data presented in the current study ensures that the majority of the population passes through two reproductive cycles before entering the fishery. In addition, rezoning of the fishery to reflect changes that have occurred since the implementation of the management plan, supports development in under-utilized areas while regulating catch levels and reducing the likelihood of effort concentration in localised areas. Ongoing monitoring of regional catch rates and the spatial distribution of catch will facilitate adjustment of TACs to ensure sustainability. In accordance with the stock status classification guidelines defined in the *Status of Key Australian Fish Stocks Reports 2012* (Flood *et al.* 2012), the Tasmanian periwinkle fishery is assessed as 'sustainable'. Despite this classification, periwinkles are under-utilised as a food product, and the TACs have not been reached in most years primarily due to market influences, with low product demand coupled with low beach price being key influencing factors.

Environmental influences on fisheries biology

Growth in periwinkles was shown to be inversely related to temperature, with mean maximum lengths (and growth rates) decreasing as temperatures increased (warming-degree-days). Mean maximum lengths were as much as 32% smaller for an increase in mean monthly summer temperatures of 1.9°C. The negative relationship between temperature and size is further supported by periwinkles in warmer waters of mid-NSW being found no larger than 36 mm (Smoothey 2008). The largest periwinkle recorded in this study was 66 mm. This pattern of growth follows Atkinson's temperature-size rule which stipulates ectothermic organisms developing at higher temperatures grow to smaller body sizes (Atkinson 1994). Elevated temperatures have also been shown to reduce size in the northern hemisphere periwinkle *Littorina littorea* as well as the gold-ringed cowry *Monetaria annulus* (Irie & Fischer 2009; Melatunan *et al.* 2013). While the role of temperature in the control of growth and metabolism is well known (Gillooly 2001), genetic differences across populations or environmental factors other than temperature can additionally have a significant influence on growth (Partridge & French 1996, Walters & Hassall 2006). For example, growth of *T. sarmaticus* varied significantly when fed on different algal types (Foster *et al.* 1999).

The smallest maximum size and slowest growth rates of the studied populations occurred at the Spikey Beach site. The site is located in Great Oyster Bay, a large semi-enclosed embayment characterised by low currents (0-5 cm^{-2}), which allow for high levels of abiotic heating and cooling (Craig and McLoughlin 1994). This was reflected in the relatively high proportion of heating degree-days at that site. Given that the long-term temperature monitoring sites on the north coast of Tasmania (Northern Zone) are also characterised by a high proportion of warming-degree-days, periwinkle growth rates in this zone are also likely to be relatively slow; anecdotal evidence from fishers indicates that the sizes of individuals within the northern zone are smaller than off the east coast.

The relationships between growth rates and water temperature also indicate that future productivity of periwinkle stocks may be influenced by climate variability. For instance, the waters off eastern Tasmania are recognised as a global warming hotspot and are predicted to increase by 2.5 - 3.0°C by 2070 (Lough 2009), suggesting that productivity levels of east coast populations can be expected to decline over time.

Substantial variation in growth and maximum size may warrant a variable size limit to be implemented for the fishery to maximise the sustainable yield and fully exploit the resource. However, under the current management regime the state wide size limit is based on the maximum growth rates recorded and provides extra protection to slower growing populations. Should the fishery expand and approach the TAC in all zones, there could be a case to reassess size limits and potentially apply lower limits in the slow growing regions in order to maximise yields.

Small growth increments at larger sizes suggest that large periwinkles may potentially be very old. Slot limit/grading may be a useful size-based management tool for the periwinkle fishery to maintain egg production with little impact on the market because very large (>55 mm) periwinkles have lower market value. However, grading by divers may not easily be achieved for practical reasons.

Growth in periwinkles showed strong seasonal variation with almost two thirds of the annual growth occurring in the warmer summer and autumn months and slowest growth during winter. Growth was, however, marginally slower during summer than in autumn, even though summer temperatures were higher. It is possible that this may reflect energy being diverted to maturation over the summer period and/or a response to the inhibiting effects of higher temperatures on growth, as indicated by the relationship between maximum size and warming-degree days. Notwithstanding this, the data on which these observations are based may be slightly biased since growth slows with increasing size and the study was conducted over a full year of growth commencing in autumn.

The pattern of growth in the periwinkle *L. undulata* parallels that of the closely related but slightly larger *L. torquata*, indicating similar life history traits (Figure 43, Joll 1975). Periwinkles reached 50% of their maximum size within 1.3-1.7 years of age depending on location, matching that of *L. torquata* which has been shown to be 1.6 years (Joll 1975). Growth of *Turbo intercostalis* is initially more rapid than that of the two *Lunella* species, reaching 50% of their maximum size after 0.7 years with the steeper growth curve indicating a much quicker growth rate (Figure 43, Joll 1975).

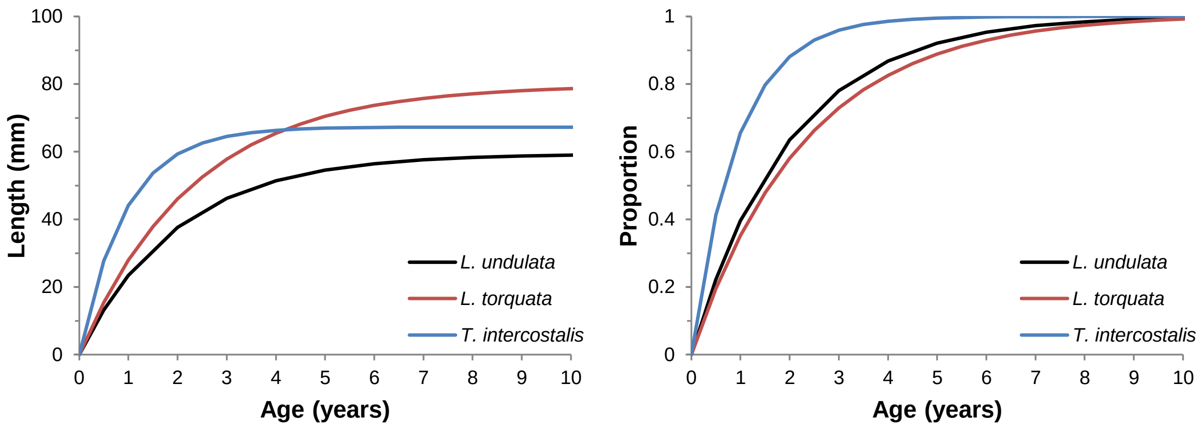


Figure 43. Comparison of von Bertalanffy growth curves for *L. undulata*, *L. torquata* and *T. intercostalis* expresses by total length (left) and proportion of total length (right).
Data sources: *L. undulata*, this study (Bull Bay); *L. torquata* and *T. intercostalis* (Joll 1975).

Seasonal variation in gonad maturation stages, GSI and anecdotal evidence from fishers indicated that periwinkles have an annual reproductive cycle with a protracted period of gonadal activity. In Tasmania the spawning season occurs between October and April, with a clear peak in spawning activity in January and February. This parallels the spawning season reported in NSW which is described to be from October to June (Underwood 1974).

Histological examination suggests periwinkles often undergo partial spawning with unspawned eggs retained until the next spawning event. In addition, spawning was asynchronous within a population, with females at various stages of development frequently observed within a given spawning event. These two traits are also reported for the closely related *L. torquata* (Joll 1975; Ward and Davis 2002). Furthermore, the timing of spawning in *L. torquata* can vary between populations separated by as little a tens of kilometres, a trait likely to be also observed in periwinkles. In this study, *L, lunata* commenced vitellogenesis immediately after spawning, with mature oocytes accumulated for the next spawning event (also reported by Underwood (1974) and for *L. torquata* by Joll (1975)).

Maximising economic returns

The Tasmanian periwinkle fishery has failed to reach its full economic revenue, with the fishery considered under-fished and product under-utilised. The estimated beach price value of the periwinkle harvest in 2012 was $80,000, well below the estimated $220,000 had the fishery operated at full capacity. The potential value of production was increased in 2013 with a 50% increase in the TAC which would see a maximum gross value of product of approximately $340,000 if the TAC was fully harvested at current market prices. Failure to reach full economic revenue in this fishery results primarily from low levels of effort.

Annual catches averaged 61% of the available TAC between 2006 and 2013, the low catches are due largely to low market demand which fishers are also frequently not meeting. The latter is a reflection of small profit margins especially when compared with other species taken by divers. The low value of the product is insufficient to cover fishing costs and salaries for fishers. To develop the fishery to a level where it utilised the full productivity of the resource a market environment needs to be created that demands higher quantities and is willing to pay higher prices.

The primary means to significantly increase market demand is through increasing both consumer awareness and confidence in the product. Consumer awareness of periwinkles as a food product is low, with many distributors, retailers, chefs and end users lacking basic product knowledge relating to source locations and harvesting, processing and handling methods, as well as cooking options. Increased consumer awareness of the product is vital to increasing demand and could be achieved by providing basic product information to the marketplace, coupled with marketing and promotion. A product fact sheet/brochure represents an option to disperse a large amount of information throughout the market. Additional measures such as branding and labelling, as well as the provision of sample boxes should be used concurrently to help promote product recognition and demand.

Consumer confidence needs to be addressed through guarantee of supply and consistency in the quality of the product. The importance of supply certainty is most evident in the restaurant sector where shortfalls result in periwinkles being removed from menus. Distributors have also been frustrated about the inability to source consistent supply for the restaurant sector. Supply shortfalls could be minimised by educating fishers on the essential nature of consistent supply, the development and use of low-cost live-holding facilities and/or development of a pre-processed frozen product for market. Inconsistent supply, especially supply shortages, is often the result of fishers switching target species to alternate and more valuable species. This occurs because profit margins for periwinkles are low, especially under increasing cost pressures such as fuel and transport. As there would appear to be little scope to reduce costs within the industry, beach prices need to be driven up by working to increase demand. Targeted marketing and promotion activities along with firm commitments from industry to ensure product quality and supply would appear prerequisites if the fishery is to develop and meet this potential.

The responsibility for increasing both consumer awareness and consumer confidence needs to be accepted, at least initially, by suppliers (including fishers). Distributors and retailers appear reluctant to initiate and commit resources to marking and promoting a low value and low volume product, especially when many have experienced difficulties in obtaining consistent supply. Furthermore, most distributors and retailers know little about the periwinkle fishery and utilisation of the product, and as such they represent a key target group of any marketing and promotion. Despite their reluctance to initiate marketing, distributors and retailers appear willing to support periwinkle marketing measures.

Analysis of SFM data show periwinkle prices have increased in both absolute and CPI adjusted terms. The increase in price appears to be due to improved timing of the catch, both seasonally and through the supply of more consistent levels of catch (thereby avoiding the price penalty associated with over supply). However, rising fuel and transport costs have outpaced the CPI, (in particular shipping across Bass Strait) and have impacted on returns to fishers that likely to outweigh the increases in market price.

In summary, the development of niche markets for unique products such as periwinkles requires targeted marketing and promotion, as well as certainty of supply. If achieved, a low-value product can become highly sort-after and achieve high market price. Pipi’s (*Donax deltoides*) are such an example where 15 years ago they were trading at very low prices and were largely unwanted by markets to the extent that large quantities were occasionally dumped. After promotion and usage by celebrity chefs the demand for the product has boomed and pipi’s currently sell for in excess of $20/kg (David Doyle, Doyles Seafood, *pers. comm.*). Distributors cannot see why periwinkles could not achieve similar market growth and acceptance if marketed and promoted effectively.

Fishery Report Card

Key results of the project are summarised and presented as a fishery report card.

Tasmanian Commercial Dive Fishery

Report Card: Periwinkles

Scientific name: *Lunella undulata*

Previous name: *Turbo undulatus*

Common names: periwinkles, turban shells or snails, turbos, wavy turbo, warrener.

Standard fish name: PERIWINKLES

Image © John Keane

Background

Periwinkles are a moderately sized marine gastropod growing to approximately 65 mm. They are found on exposed reef and boulder habitat in shallow temperate waters (0-20 m) from New South Wales to southern Western Australia, including Tasmania. They are generalist herbivores consuming a wide variety of algae with a prominence of brown and green macroalgae and articulated coralline algae.

Periwinkles are harvested commercially by hand from sub-tidal reefs around the coast of Tasmania, New South Wales, Victoria and South Australia, with large aggregations readily targeted by divers in shallow water.

In Tasmania, periwinkles have been fished commercially since the 1980s as a part of the Tasmanian Commercial Dive Fishery. A management plan, first introduced in 2005, saw the introduction of two fishing zones; the Developed Zone in the south east (now called the South East Zone) and the Undeveloped Zone covering the remainder of the State (Fig. 1).

Total allowable catches (TACs) of 17.6 tonnes were applied in each zone (fishery-wide TAC of 35.2 tonnes), these limits being set based on previous catch history. Spatial changes in catch and effort lead to the fishery being rezoned for the 2013/14 fishing season and the TAC set at 52.8 tonnes (Fig. 1)

A minimum size limit of 30 mm was introduced in 2005. This was increased to 40 mm in 2009 and 45 mm in 2013. There are currently 55 licence holders in the fishery, however less than 10% of fishers generally land over 80% of the total catch of periwinkles.

Catch

Periwinkle landings have fluctuated throughout the history of the fishery, largely the result of fishers entering and exiting the industry, as well as switching to target alternate species. Landings increased steadily from the establishment of the fishery, reaching 32 tonnes by 1997 (Fig. 2). Since then catches have fluctuated between 13 and 35 tonnes, averaging 23 tonnes p.a.

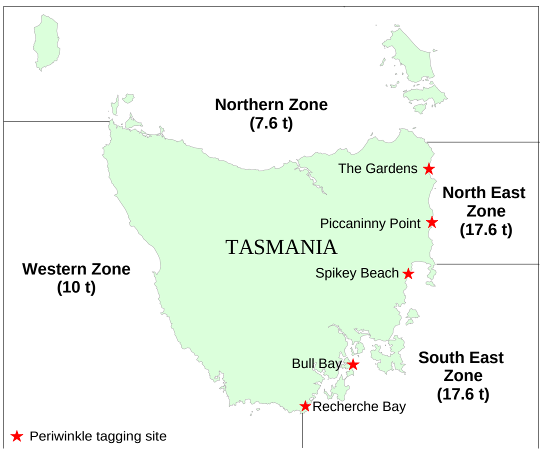


Fig. 1. Fishing zones, TAC, and research sites.

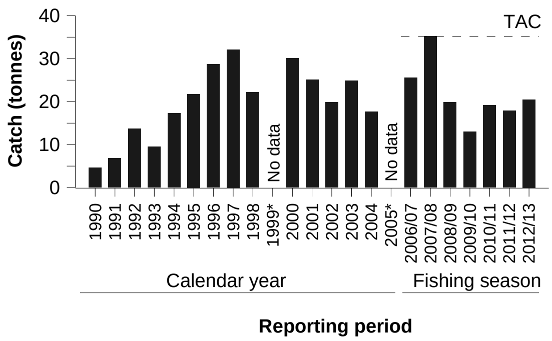


Fig. 2. Annual periwinkle harvest.

Stock status

Periwinkles are classified as under-fished in Tasmania with the TAC not reached in six seasons due to low levels of effort. Large sections of coastline have had minimal to no catch taken. Regional catch rates (kg/h) have remained relatively stable since effort data was first recorded in 2007, indicating catch levels are sustainable. The resource is under-utilised and has the potential to sustain harvest levels higher than those currently being taken.

Growth

Growth of periwinkles is rapid with animals reaching between 36 and 46 mm, equivalent to 80-88% of the average maximum length, within three years (Fig 3). Variability in growth is evident with average maximum lengths differing by as much as 32%, ranging between 47 mm at Spikey Beach and 62 mm at Piccaninny Point and Recherche Bay. Growth is considerably slower at Spikey Beach, taking four years to reach the commercial fishery size limit of 40 mm, compared to other east coast sites which take 2.2 to 2.7 years.

On average there is a 10-fold increase in periwinkle weight between 30 mm and 65 mm; the number of individuals per kilogram decreases from 127 to 12 over this same range (Table 1).

Size at maturity

Sex and maturity status of periwinkles are easily distinguishable by visual examination of the gonad (Table 2). Mature males have a creamy-white gonad while mature females have a green gonad of variable shades.

The length at which 50% of periwinkles are mature ($LM_{50\%}$) varies between 23 and 26 mm on the east coast of Tasmania, with individuals in the north maturing at smaller sizes compared with the south (Table 3). Lengths after two years of growth following maturity range between 39 and 47 mm.

Periwinkles reach $LM_{50\%}$ between 1.1 and 1.6 years of age and enter the fishery (45 mm) 1.7 to 5.1 years later. These findings indicate that all individuals have an opportunity to spawn at least once, and most twice, before being susceptible to fishing at the current size limit and justify increasing the size limit from 30 mm to 40 mm in 2009 and to 45 mm in 2013.

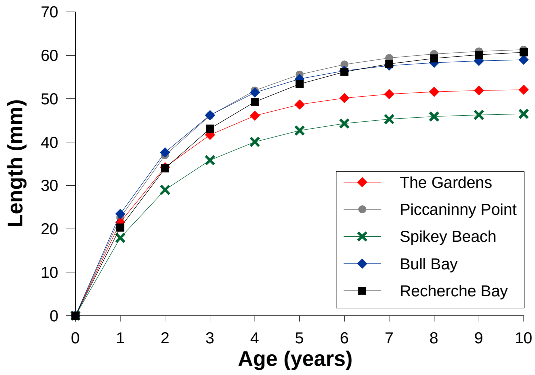


Fig. 3. Periwinkle growth curves for different east coast locations (refer Fig. 1).

Table 1. Predicted weights and numbers/kg of periwinkles at varying lengths.

Length (mm)	Weight (g)	No./kg
30	8	127
35	13	80
40	19	53
45	27	37
50	37	27
55	49	20
60	64	16
65	81	12

Table 2. Sexual maturity in periwinkles.

	Immature	Mature
Female		
Male		

Table 3. Lengths of periwinkles (mm) at 50% maturity ($LM_{50\%}$) and at $LM_{50\%}$ +1 and +2 years growth.

Site	$LM_{50\%}$	+ 1 yr	+ 2 yr
The Gardens	23.2	35.2	42.2
Piccaninny Point	23.6	37.6	46.5
Spikey Beach	24.8	33.3	38.5
Bull Bay	25.8	39.1	47.1
Recherche Bay	26.2	37.9	45.8

Fishery value

The annual value (beach price) of the Tasmanian periwinkle fishery to the economy has averaged $120,000 (CPI adjusted) between 2007 and 2012. The value fluctuates annually with varying levels of catch; however harvesting the full TAC would result in returns of approximately $340,000.

Markets

Restaurant and retail sectors represent the primary market for periwinkles, with the majority of the product sold in the metropolitan areas of Sydney and Melbourne. Restaurants offering periwinkles include top-end restaurants looking for unique and edgy products as well as ethnic restaurants in cultural hubs (Fig. 4). The retail sector for periwinkles is predominantly comprised of seafood retailers in the Vietnamese communities. Markets prefer periwinkles in the 40-55 mm size class.

Market opportunities

Interstate seafood suppliers and retailers have been canvassed about the market potential for periwinkles and have identified considerable room for market expansion. The key factors necessary to achieve this growth are:

Supply consistency
Maintaining a constant supply to market is one of the key factors to achieve market growth. Fluctuating supply has resulted in distributors and retailers not always able to meet demand and restaurateurs not always able to source periwinkles. During periods of supply shortage, demand also decreases as periwinkles are removed from restaurant menus. Conversely, on occasions markets have been over-supplied with large quantities dumped on the market, resulting in the price falling.

Branding, marketing and promotion
Tasmanian periwinkles lack an identity in the boarder marketplace and branding would assist in the creation of a strong product image and aid marketing and promotion. Branding could be at the fisher or fishery level via positive naming, labelling and logos.

Promotional messages to consumers and retailers should be around the sustainable, well managed fishery with product sourced by hand collection (i.e. not industrial or farmed). The industry should also aim to capitalise on the clean green Tasmania brand.

Product awareness
A product fact sheet/brochure is required to alleviate knowledge gaps and encourage the trial and use of periwinkles throughout the restaurant and retail sectors. A lack of knowledge about periwinkles exists amongst distributors, retailers, restaurateurs and consumers in regard to all aspects of the fishery, as well as processing methods and uses as a food product. Furthermore, many chefs have not encountered periwinkles and simply do not know how to prepare and cook them. Increasing product knowledge should help alleviate knowledge gaps and boost sales.

Value adding, frozen product
The establishment of a frozen product line is seen by distributors to have substantial potential for market development and increasing growth throughout the restaurant sector. A frozen product, consisting of periwinkle meat packed in 0.5 or 1 kg blocks is suspected to retail for as much as $35/kg. If successful, a frozen product line would address two of the key negative factors of periwinkles for the restaurant sector, namely product availability and preparation time. It would also enable fishers to take higher catches on a trip, making harvesting periwinkles in remote locations more viable as well as enabling product to be stockpiled to cover periods of undersupply.

Fig. 4. Periwinkles served at two Sydney restaurants.

Fishery issues

Zoning and TAC

Developed and Undeveloped zones established in 2005 (Fig. 1) became inappropriate following a substantial shift in effort, expanding considerably along the north-east coast. In some years the TAC in the Undeveloped zone was almost fully attained from catches along the north-east, with very little fishing occurring on the north and west coasts. Under such circumstances, the western and northern coasts were closed to fishing, inhibiting further exploration and development of the fishery. Rezoning of the fishery in 2013 to split the Undeveloped zone into three zones has largely addressed this issue.

Latent effort

There are 55 licence holders in the Commercial Dive Fishery yet only 8 - 15 fishers have targeted periwinkles in any given year. Concern exists amongst active fishers about the substantial latent capacity within this niche fishery. An influx of fishers targeting periwinkles that could result from market expansion and/or declines in other sectors of the Commercial Dive Fishery (e.g. urchins) has the potential to affect the stability of markets through short-term oversupply, increased pressure on localised periwinkle stocks, both influencing the economic viability of individual operators.

Transportation

Transport costs to freight product to mainland markets have increased substantially in recent years. Bass Strait shipping fuel surcharges and the new Port of Melbourne tax have further increased costs, while the Tasmanian Freight Equalisation Scheme no longer fully compensates for the sea freight cost disadvantage. The combination of these freight charges place Tasmanian suppliers at a significant disadvantage when competing in mainland markets against mainland harvested product.

Localised overfishing

Localised overfishing at sites close to key ports has been observed, with decreases in both average size and biomass evident. Such sites are typically targeted by multiple fishers predominantly due to the low expenses involved (fuel costs) and ease of access. While such behaviour and consequences may be unavoidable due to low profit margins in the fishery, the relatively large minimum size limit will help to ensure that spawning stocks remain healthy. In areas where depletion of large animals has occurred there is still evidence of a consistent supply of juveniles recruiting to the population.

Paralytic shellfish toxins

Paralytic shellfish toxins derived from blooms of the dinoflagellate alga *Alexandrium tamarense* forced the closure of the fishery in 2012 and disrupted supply volumes to market. Product should be sourced from other locations if possible during bloom times to elevate supply shortages.

Synopsis

Based on current management measures and fishery indicators (e.g. regional catch rates) the periwinkle fishery is considered sustainable, though under-utilised. On-going monitoring of catch and catch rate trends, interpreted in the context of the dynamics of fisher activity, will be important in assessing the fishery status into the future.

There is potential for expansion and sustainable and profitable development of the fishery should be encouraged, particularly in areas such as the north and west coasts which are currently underexploited. Active marketing and promotion of periwinkles by fishers along with a commitment to greater consistency in supply to markets will yield improved economic returns to the Tasmanian industry.

Further Reading

DPIPWE (2005) *Policy Document for the Tasmanian Commercial Dive Fishery*. Department of Primary Industries, Parks, Water and Environment, 36p.

DPIPWE (2011) *2011 Update of Policy Document for the Tasmanian Commercial Dive Fishery*. Department of Primary Industries, Parks, Water and Environment, 9p.

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Conclusion

All four project objective have been met.

Based on current management measures and fishery indicators (e.g. regional catch rates), the Tasmanian periwinkle fishery is sustainable and well managed, although there is considerable latent capacity that if activated could impact on the economic viability of existing operators. Concerns of poor stock recovery after heavy fishing and signs of declining catch rates between 2006 and 2009 appear to have been largely reversed, due in part to size limit increases; the latest informed by the present study. The current size limit allows periwinkles to pass through one, and for most at least two reproductive seasons before recruiting to the fishery. On-going monitoring of regional catch rates and the spatial distribution of the catch will be important in assessing the future status of stocks, as will be the evaluation of fisher dynamics and behaviour when interpreting these data, especially if the fishery expands to meet its full potential.

Recent management changes, including rezoning, an allowance for a small incidental quantity of undersize individuals in landings and provision for multispecies trips, provide an operating environment that has freed up operators to further develop the fishery. There is potential for expansion, particularly in areas that are currently underexploited on the north and west coasts and area specific TACs for these areas provide scope for industry to develop these areas. Supplier driven marketing initiatives to increase product image and knowledge are seen as critical if strong positive market growth is to be achieved. Reliability in quality and supply of live product to markets along with expansion of the product range to include shelled, frozen meat will be important in increasing economic returns to the Tasmanian industry.

Implications

This project has contributed directly to two significant changes to the management of the Tasmanian Commercial Dive Fishery relating to the zoning of the fishery zones and the minimum size limit. In addition, the study has identified opportunities and a pathway to expand the market for the product.

Consultation with resource managers and industry and the synthesis of the fishery data contributed to the decision to restructure the management zones in an effort to facilitate development of the fishery in previously under-utilised areas. The Undeveloped Zone was subdivided into the North East Zone, the region where the majority of the catch is currently taken, and two other zones, namely the Northern and Western Zones, this change taking effect at the commencement of the 2013/14 season. The TAC of 17.6 tonnes from the Undeveloped Zone was maintained in the North East Zone. A TAC of 10 tonnes was applied to the Western Zone coast and 7.6 tonnes to the Northern Zone, increasing the state-wide TAC by 50% to 52.8 tonnes. Rezoning is seen as an important strategy to support the development of the fishery by allowing the west and north coast's to remain open to fishing should catches in the North East Zone reached the TAC.

The size limit of periwinkles was increased from 40 mm to 45 mm based on size at maturity and growth information originating from this project. Although this increase does impinge on the preferred size range of 40-55 mm identified by most distributors, retailers and chefs, it does leave an ample range within the preferred sizes. Fishers were consulted in the process of revising the size limit and anticipate it will have a negligible impact their operations.

Recommendations

The following recommendations have been derived from this project:

- A restructure of the management zones to reflect developments in the fishery since the introduction of the management plan in 2005, in particular recognising the development of the fishery on the north east coast and opportunities for further development of the fishery in other under-utilised or unfished areas (especially on the north and west coasts) - implemented September 2013.
- Revise the minimum size limit based on size at maturity and growth data to ensure that periwinkles have the opportunity to spawn at least once before recruiting to the fishery - implemented September 2013.
- Fishers recognise that reliability/consistency in the supply of high quality (purged) product to the market is critical to if prices are to be maximised and demand increased.
- Commercial dive industry be proactive in the marketing and promotion of periwinkles in the interstate markets, including retail and restaurant sectors. Initiatives should be developed in conjunction with distributors and aim to increase product knowledge (information sheets targeted at distributors and consumers, promoting sustainability), include consideration of product branding, as well as investigating alternative product lines (e.g. frozen meat).

Further development

The Tasmanian periwinkle fishery is at a crossroads, management changes since 2010 have largely freed up industry to expand production, especially in previously under-utilised areas. If this increase in production is to be realised and economic returns maximised, there is a need to develop an integrated marketing campaign for periwinkles to increase awareness and promote the species as a high quality niche seafood.

Ideally, such a campaign would be initiated and supported by the commercial dive industry (suppliers/fishers) since distributors and retailers appear reluctant to do so at this stage. Due to the low value/small scale nature of the fishery, an industry-wide approach should be considered for cost effectiveness and be conducted under the auspices of the TCDA. There are likely to be considerable benefits from engaging marketing professionals to design materials and promotional activities.

Further analyses of growth data could be investigated using the seasonalised VBGF to investigate seasonal influences on growth among sites. Additionally, tag recapture rates may be used to provide data for estimating mortality which could be useful base line information for the fishery, especially if markets develop and TACs increase (McGarvey et al 2009). Such estimates may also be useful for potential management on finer spatial scales.

Extension and Adoption

The project team has maintained on-going contact with key commercial fishers about the project's progress and they have been very helpful and cooperative in providing information and assistance. The team also participated in numerous commercial fishing trips and collected catch samples as well as informally discussing key issues surrounding the species, fishery and markets.

A presentation outlining objectives and preliminary progress was delivered to the Tasmanian Commercial Divers Association (TCDA) at its 2012 annual general meeting (31st August, 2012). The meeting was attended by over fifteen periwinkle divers and processors. A further progress update was given to a 6-monthly TCDA meeting on 9th April, 2013; stakeholders present included commercial divers as well as representatives from DPIPWE and the Tasmanian Seafood Industry Council (TSIC). A final presentation highlighting the results of the study and opportunities for the industry to develop markets was given at the 2013 TCDA annual general meeting (18th October, 2013). The meeting was attended by over ten industry members and there was considerable interest in the project's findings and acknowledgement of the outputs in terms of recent management changes.

Throughout the project regular communication has been maintained with the Senior Fisheries Management Officer (Dive Fisheries), including provision of commercial catch and effort summaries and discussions about project data and progress. Management responded rapidly to the results of the project implementing key changes to the management plan including increasing the size limit to 45 mm, rezoning of the fishery and increasing the Statewide TAC to promote development in under exploited regions.

The project team has also held discussions with Dr Lianos Triantafillos from the Department of Primary Industries and Resources of South Australia (PIRSA) concerning the South Australian periwinkle fishery. Information from the current project is likely to assist in the future management of the SA fishery, which has few management regulations, including the lack of a minimum size limit.

Fish markets, distributors, retailers and restaurateurs that have processed, utilised or consumed periwinkles in both Sydney and Melbourne were visited in February 2013 by Dr Keane to gain insights into markets and assess avenues for future market development. Further discussions regarding periwinkles were held with Barbara Konstas, CEO of the Melbourne Seafood Centre, Gus Dannoun, supply manager at the Sydney Fish Market, and Erik Poole, quality assurance officer at the Sydney Fish Market.

Project coverage

The project has been covered in print and radio media:

- The project was featured in an article in the FRDC magazine *FISH* (2011, vol. 19, No. 3). (http://frdc.com.au/knowledge/publications/fish/Documents/FISH 19-3 Time to get to know our mysterious periwinkles.pdf);
- An article about the project appeared in the Tasmanian seafood industry news magazine *Fishing Today* (2012, vol. 24, No. 6);
- A media release in late November saw the project covered by *The Mercury* newspaper on 2 December 2011. The article was entitled ‘A shellfish attitude change’; and
- Dr Keane conducted a radio interview with ABC presenter Sally Dakis about the periwinkle fishery and project which this was aired on the Tasmanian Country Hour on the 8 February 2012.

Appendices

List of researchers and project staff

The following IMAS staff and volunteers contributed to this project:

- Dr Jeremy Lyle
- Dr John Keane
- Dr Craig Mundy
- Dr Klaas Hartman
- Ruari Colquhoun
- Ivan Hinojosa
- Kylie Cahill
- Lucy Taylor
- Kelly Campbell
- Mike Porteus
- Dane Jones
- Graeme Ewing

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