SETTLEMENT PATTERNS, BIOLOGY AND COLLECTION OF PUERULI AND EARLY JUVENILES OF THE WEST COAST ROCK LOBSTER *JASUS LALANDII*

Thesis submitted in fulfillment of the requirements for the Degree of

MASTER OF SCIENCE

University of Cape Town

by

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January 2007

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ACKNOWLEDGEMENTS

First and foremost I would like to thank my supervisors, Prof. George Branch (UCT) and Dr. Johan Groeneveld (MCM), for taking me on as a student in the beginning, and for your great academic guidance and unlimited support throughout this task. I am extremely grateful! I would also like to thank you both for the facilitation and funding you made available for my project.

To Mr Danie van Zyl and Mr Andrew MacLachlan – I would like to express my deepest thanks to you both for your dedication and enthusiasm towards this project, and for all the time and effort in the field – without both of you there would have been no project! Your support on a personal level will always be remembered. Baie dankie!

Many thanks go to Steven, Bradley, Neil, Brett Richardo, Cliffie, Pharo, Gilly, Hilka, the staff at the oyster farm, and many others, who spent a lot of time helping me with the sampling and administration essential to this project. I would also like to thank Marcel van den Burg, Ruth Branch and Ruth Farre for their help in obtaining and analysing the environmental data needed for this project.

On a personal level I owe so much to Nicholas for his amazing support throughout this journey. He deserves his own Masters degree in the management of a Masters student. To my parents (who earned their masters in parenting many years ago) and my sister and brother, thank you for your unconditional support in all I attempt to accomplish.

ABSTRACT

Catches of the West Coast rock lobster *Jasus lalandii* have declined from around 16 000 t in the 1950s to present catches of 2857 t due to over-exploitation and large-scale environmental changes in the Benguela Current Large Marine Ecosystem. Exploitation of *J. lalandii* in South Africa and Namibia is currently limited to harvesting adults from the wild. Ongrowing (farming) of postlarval lobsters to a marketable size could increase production, and potentially relieve fishing pressure and enhance natural populations through reseeding areas with cultured lobsters. Postlarval lobsters are, however, not yet available in sufficient quantities through culture from egg to puerulus, so postlarvae for ongrowing need to be harvested from the wild. Finding a good source of wild postlarvae has hindered the development of lobster farming in South Africa. My study was designed to locate a site of high postlarval settlement and to (1) investigate numbers available for collection (standing-stock), temporal patterns of settlement and their relationships with environmental conditions, postlarval size-distributions and growth, (2) test the relative efficacy of various collector designs for effective collection of postlarvae, and (3) make recommendations for postlarval collection in the future. An oyster farm in Saldanha Bay was chosen as the study site. Postlarval lobsters were collected over a 12-month period from mesh bags used at the farm. Collector trials were also conducted there to test the efficiency of the following collectors: oyster bags filled with (1) live oysters, (2) live mussels, (3) oyster shells, (4) mussel shells or (5) pieces of trawl net; (6) empty oyster bags (control); and (7) an existing collector design – the bottlebrush collector (the collector of choice for *J. edwardsii* in Tasmania).

Almost all settlement occurred November 2005 - March 2006 and consisted of pueruli and early-juveniles < 20 mm carapace length (CL). The total annual input of pueruli was estimated to be 130 000 for the entire farm at full operation. Two distinct puerulus settlement events (of two separate cohorts), and three distinct peaks in juvenile abundance occurred during this time. Cohorts of pueruli and early-juveniles settled on the farm at sizes of 9.5 and 10.0 mm carapace lengths (CL) respectively. Postlarvae remained on the oyster farm for at least a two-month period, growing to 15-18 mm CL in size, after which the cohorts ceased to be detectable in size-frequency distributions. Peaks in puerulus settlement correlated with periods of above-average water temperatures when upwelling was reduced, usually during periods of full moon and above-average tidal height. Lapses or reversals in prevailing southerly winds that occur between November and April were correlated with above-average settlement 2-4 weeks later. Mean catch-rates on collectors over the peak settlement period ranged between 0.5 and 1.9 postlarvae per collector, and there were no significant differences among collector types. Soak-time (intervals between collections) and fouling (mass of natural marine growth on collectors) had minor influences on settlement, with a weak parabolic polynomial relationship in the case of soak time, and a weak negative semi-logarithmic relationship for fouling.

Postlarvae can simply and easily be collected from the farm while harvesting oysters, and the collectors tested are likely to be satisfactory for collecting postlarvae at other locations in the future. Levels of settlement will vary year-to-year, but long-term monitoring has the potential to predict variations in adult stocks. Levels of settlement at the oyster farm in Saldanha Bay were lower than those experienced in Luderitz Bay, Namibia, but the numbers settling are sufficient to support long-term monitoring of settlement levels, further research on collection structures, and ongrowing experiments. Economic feasibility studies will be necessary to determine if levels of settlement in Saldanha Bay are high enough to support lobster farming.

CHAPTER 1

GENERAL INTRODUCTION

1.1 OVERVIEW OF THE WEST COAST ROCK LOBSTER FISHERY

The West Coast rock lobster *Jasus lalandii* is a temperate, shallow-water palinurid lobster found in the southern waters of the Benguela Current Large Marine Ecosystem (BCLME), and is fished commercially between 25° S (in southern Namibia) and 34° S (Cape Point, South Africa) (Johnston and Butterworth, 2005). Until the late 1800s the West Coast rock lobster was regarded as a low-value species, in fact 'shunned by the middle-class', and utilized primarily as bait or as a reliable, all-year-round dietary supplement by poorer people. Commercial exploitation began in 1875, purely for export to Europe, and catches increased gradually from < 1000 tons in 1891, to record landings of 16 754 tons by 1951, by which time a local market had developed and the value of West Coast rock lobster products had increased dramatically. Traditional hoop-net fishing methods and smaller (usually unmotorised) boats were replaced with trap fishing from larger motorized vessels in the 1960s, enabling more efficient harvesting from deeper waters further off-shore (Melville-Smith and van Sittert, 2005).

Landed catches declined dramatically after 1951 to a low of around 1 600 tons in 1996 – an effect attributed not only to over-exploitation but to decreased lobster growth-rates and large-scale environmental changes in the BCLME. Various management strategies been introduced over recent years such as the development of sanctuaries, closed seasons and a ban on harvesting ovigerous females. A minimum size-limit of 89 mm carapace length (CL) was introduced in 1933, but only properly enforced after 1970, and was later relaxed to 75 mm CL, in the early 1990s, to compensate for a reduced rate in somantic growth rates experienced in the fishery and to minimize capture of undersized animals (Cockcroft and Payne, 1999; Mayfield *et al.*, 2000; Melville-Smith and van Sittert, 2005). Periodic anoxic water-conditions along the west coast, which cause 'walk outs' and stranding of large numbers of adult lobsters, have also been shown to have a significant negative effect on fishery stocks (Cockcroft, 2001). A total allowable catch or TAC of around 4000 tons was introduced in the early 1980s, and was decreased to 3790 tons in 1991/2 and again to 1500 tons in 1995/6, but then was increased to 1900 tons by 1998/9 As the stocks recovered, the TAC was increased again, and the present catch has stabilised at about 2875 tons (approximately 18% of historic highs in the 1950s) (Cockcroft and Payne, 1999; Mayfield *et al.*, 2000; Melville-Smith and van Sittert, 2005; D. van Zyl, Marine and Coastal Management, Cape Town, 2006, pers. comm.).

Despite lower catch-rates over last the few years, South Africa is still regarded as one of the top suppliers of lobster products to world lobster markets – alongside Australia, New Zealand, Cuba, Brazil, Mexico and the USA (Esterhuizen, 2004; Keulder, 2005). The combined fishery for the West Coast rock lobster *Jasus lalandii* from South Africa and Namibia supplies 2.4 % (roughly 3000 tons per year) of the world's total export market of around 123 000 tons of spiny lobster products (Anon., 2002; Esterhuizen, 2004; Keulder, 2005). Besides being valued at R200 million in 2000, the resource is invaluable to the approximately 1300 fishers and 3000 onshore employees whose livelihoods depend upon the West Coast rock lobster fishery (Anon., 2002). Production of lobster in South Africa and Namibia is currently limited to the harvesting of adults from wild populations. In the face of declining natural populations, commercial ongrowing (farming) of early settlement-stage lobsters to a marketable size may not only provide the means to increase production (Kittaka, 1997), but may potentially relieve fishing pressure and conserve, and perhaps even enhance, natural stocks (see Gardner *et al.*, 2006).

1.2 DEVELOPMENTS TOWARDS LOBSTER FARMING AROUND THE WORLD

Harvesting of settlement-stage (postlarval) lobsters from the wild is currently the only feasible way to supply 'seed' for ongrowing due to very low survival rates of postlarvae produced through larval culture (Kittaka, 1988, 1997). Over the last 35 years many specially designed structures ('collectors') for catching postlarval lobsters from the wild have been developed and tested (see Chapter 3 for more information on collectors) and many sites of high settlement on natural (rocks and crevices along shorelines) and artificial (boat hulls, harbour walls, submerged mussels aquaculture ropes) substrata have been identified (Phillips and Booth, 1994). Postlarvae of many spiny lobster species have also been successfully grown out to larger juvenile sizes (and in some cases marketable sizes) under laboratory and small-scale commercial conditions in many regions (some examples include: *Panulirus argus* in Cuba and Florida, USA; *P. homarus* in India; *P. ornatus* in the South China Sea region; *P. cygnus* in Western Australia; *P. interruptus* in California, USA; *P. japonicus* in Japan and *J. edwardsii* in Australia, Tasmania and New Zealand – see Booth and Kittaka, 2000 for review of optimal conditions for rearing spiny/rock lobster species). However, to date large-scale/commercial farming has only been achieved in a handful of countries.

Lobster farming in Vietnam began in the early 1990s and grew rapidly to the current production level of 1500-2000 tons per year, making Vietnam the largest producer of cultured spiny lobster (mainly tropical lobster *Panulirus ornatus*) in the world (Tuan and Mao, 2004; Williams, 2004).

With a profit margin of 50 %, lobster farming has become a very viable source of income for the approximately 4000 households involved in the Vietnam industry. Farming of *P. ornatus* in the Philippines began even earlier (1970s), although annual production is much lower at 90 tons. In both countries wild-harvested postlarvae are cultured in submerged cages (Tuan and Mao, 2004; Williams, 2004). Commercial lobster ongrowing farms have also been established in Taiwan (late 1980s), India, Singapore and the USA and market-size lobsters of 300 g can be produced in three years, with a smaller marketable size of 200 g (popular in the East) produced in two years (Esterhuizen, 2004; Keulder, 2005).

Over the last three years Australia and New Zealand have introduced legislation allowing the commercial harvesting of postlarval lobsters for ongrowing – as will Tasmania in the near future (Anon., 2004; Gardener *et al.*, 2006). Although the implementation of commercial lobster farming has taken longer in these countries, a lot of time and effort has been spent on investigating various aspects of lobster farming – such as effective postlarval collection structures and collection methods, effects of removal of postlarvae on future adult populations and opportunities to enhance natural stocks through returning captive-reared lobsters to the wild – in order to develop effective management of the resource (Phillips and Booth, 1994; Phillips *et al.*, 2001; Phillips *et al.*, 2003; Gardner *et al.*, 2006). Very little research of this nature has been done since the beginning of lobster farming in Vietnam and the Philippines and removal of postlarval lobsters in these areas may be a contributory cause of large declines in adult and juvenile populations there (Williams, 2004).

1.3 CONTRIBUTIONS TOWARDS LOBSTER FARMING OF JASUS LALANDII

Luderitz Bay in southern Namibia has been established as a site of high settlement for the West Coast rock lobster *Jasus lalandii.* Postlarvae have been successfully collected from the mesh culture bags and crates at an oyster farm within the bay since 1999, and patterns of settlement in the area (see Discussion, Chapter 2) are now quite well known (Keulder, 2005). No commercial ongrowing of the species is occurring in Namibia yet but the development of an industry for rock lobster aquaculture was recently listed as a high priority by the Ministry of Fisheries and Marine Resources (MFMR) (Iitembu, 2005).

In 1999 the South African Department of Agriculture formed the West Coast Rock Lobster Steering Committee to investigate various components of lobster farming (Bailey and Fielding, 2002). Postlarval lobsters (supplied by MFMR) were successfully grown in captivity in two studies aimed at determining optimal conditions for growth (such as diet, water temperature, stocking density and degree of shelter) (Dubber *et al.*, 2004; Esterhuizen, 2004). Esterhuizen (2004) conducted a feasibility study that modeled a lobster farm on the culture facilities of an abalone farm (see Discussion, Chapter 2 for more detail). Other studies involved finding a source of wild postlarval lobsters in South Africa and developing effective methods of collecting postlarvae for ongrowing. A selection of collector types was deployed at various sites along the South African west coast (see Chapter 3 for more details) but very few postlarvae were collected (Bailey and Fielding, 2002). Thus, providing a viable source of postlarvae remains the biggest hurdle to the development of lobster farming in South Africa. The present study was therefore dedicated at finding a site of high settlement of postlarval *J. lalandii* in South Africa and finding effective ways to collect postlarvae.

1.4 LARVAL, POSTLARVAL AND JUVENILE ECOLOGY OF SPINY LOBSTERS

Hatching in spring-summer as a short-lived prephyllosoma (called a naupliosoma in *Jasus* sp.), the larval phase of spiny lobsters begins in the coastal waters of the parental grounds, after which they are rapidly transported by offshore currents into oceanic waters where they spend their long-lived phyllosoma lives, moulting through many phyllosomal stages (12-22 months larval duration and 11-13 stages for *J. lalandii*) (Kittaka, 1997; Booth and Ovenden, 2000; Phillips *et al.*, 2006). Late-stage phyllosomas return to the shelf edge (around the 1000 m depth contour) where they moult into the first settlement stage called a puerulus (Booth and Ovenden, 2000; Phillips *et al.*, 2006).

The puerulus is a non-feeding stage and is identical to a juvenile in body shape, but is smaller (6-12 mm CL), entirely transparent, and has elongated, setose pleopods allowing forward swimming at speeds of 6-64 cm.s^{-1} (Jeffs and Holland, 2000; Phillips *et al.*, 2006). Alternating between surface-swimming at night and spending time on or near the sea floor during the day, the puerulus directs its movement inshore and settles into crevices or amongst marine vegetation at various depths along the coastline (Butler *et al.*, 2006). The duration of the puerulus stage is believed to depend on the width of the coastline and the time taken to swim across it, but once pueruli have settled they develop a digestive gland and pigmentation and finally moult into first-instar juveniles within a few days (Dubber et al, 2004; Butler *et al.*, 2006; Phillips *et al.*, 2006).

It is these postlarval stages (pueruli and early-juveniles) that are collected for ongrowing, but they are not always easy to find. This is because postlarval lobsters are asocial (only becoming gregarious at larger sizes), widely dispersed along the coast-line, cryptically coloured, and tend to stay well hidden to avoid predation, which is the main cause of mortality in these early life-stages – overall survival has been calculated at 1.3 - 3 % for some spiny lobster species (Booth, 2006; Gardner *et al.*, 2006; Phillips *et al.*, 2006). Pueruli have, however, been known to settle in large numbers and on accessible substrates (natural and man-made) in some areas (Phillips and Booth, 1994), which has provided an intermediary source of seed for lobster farming until viable numbers of postlarvae are available through larval culture (Phillips and Booth, 1994; Mills and Crear, 2000).

1.5 OUTLINE OF THE PRESENT STUDY

This thesis comprises four chapters, the first being this introductory chapter. Chapter 2 investigates levels of postlarval *Jasus lalandii* settlement at an oyster farm in Saldanha Bay and documents the numbers, settlement patterns (environmental and seasonal), size-distributions and (deduced) growth-rate of postlarvae settling on the farm. Chapter 3 explores the relative efficacy of different settlement devices (collectors) in attracting postlarvae. Chapter 4 is a brief synthesis of findings coupled with recommendations for the future.

CHAPTER 2

SETTLEMENT PATTERNS AND HARVESTING OF POSTLARVAL JASUS LALANDII *IN SALDANHA BAY*

2.1. INTRODUCTION

Nearly all commercial lobster ongrowing enterprises, and even experimental ongrowing, currently rely on collections from the wild of the first puerulus stage and/or small juvenile lobsters (together called postlarvae). The numbers that can be harvested may vary greatly over time, both seasonally and interannually. Large catches coincide with peak recruitment periods, which in turn depend on the reproductive cycle of adults, larval characteristics and behaviour, and environmental conditions (Booth, 2006; Butler *et al.*, 2006). Interannual fluctuations in recruitment strength have also been related to upwelling events, wind direction and speed, sea-surface temperature and ocean current anomalies (Keulder, 2005; Booth, 2006; Phillips *et al.*, 2006). Identification of temporal recruitment trends and of the environmental factors that may affect recruitment strength, may assist prediction of future catches in lobster fisheries (see Caputi *et al.*, 2003) and contribute to providing guidelines for the harvesting of postlarvae for ongrowing purposes (Gardner *et al.*, 2006).

Ongrowing of lobsters to a marketable size is an industry with considerable economic potential. In Vietnam, ongrowing of the tropical lobster *Panulirus ornatus* produces an estimated 2000 tons per year (Tuan and Mao, 2004). In New Zealand and Australia ongrowing of *Jasus edwardsii* and *P. cygnus* is in a developmental stage, both on land and in sea-cages (Jeffs and James, 2001; Gardner *et al.*, 2006). However, the removal of large numbers of postlarvae from wild populations for ongrowing may have ecological impacts and may affect existing fisheries (Phillips *et al.*, 2003; Gardner *et al.*, 2006). Obtaining postlarvae by culture from eggs is not yet possible on a large scale because of the long duration of larval life and high larval mortalities during culture in artificial environments. Larval culture of *Jasus lalandii* from egg to puerulus has been achieved under laboratory conditions in Japan, but yields were very low: from 15 800 phyllosoma larvae only one survived through full larval culture, moulting into a puerulus after 306 days (Kittaka, 1988). Nevertheless, much progress has been made for several species (Kittaka, 1988; Kittaka, 1997, Booth and Kittaka, 2000; Kittaka *et al.,* 2001; Wahle and Fogarty, 2006). It is anticipated that when culture from eggs to postlarvae becomes viable on a commercial scale, ongrowing will have the potential to rapidly exceed global production from wild lobster fisheries (Wahle and Fogarty, 2006).

In the interim, harvesting from wild stocks remains the only source of postlarvae available for experiments to determine optimal growth and survival rates and improve grow-out systems, and therefore considerable research on settlement and collection of postlarvae has been done in several countries, including Namibia, Australia, New Zealand and Vietnam (Phillips *et al.,* 2001; Mills and Crear, 2004; Williams, 2004; Keulder, 2005; Phillips *et al.*, 2005). Harvesting methods and ongrowing protocols are species-specific for local conditions of settlement and growth. *Jasus lalandii* postlarvae have been successfully harvested in Luderitz Bay, Namibia (Keulder, 2005) but not yet in South Africa, where some pueruli and early-juveniles have been captured, but never on a scale worth pursuing (Bailey and Fielding, 2002; Keulder, 2005; Esterhuizen 2004). The scarcity of locally available *J. lalandii* postlarvae in South Africa is stalling progress towards commercial lobster ongrowing, and further experimentation with grow-out systems can only be attempted when a substantial and reliable source of postlarvae becomes available.

Pueruli and early-juvenile *Jasus lalandii* have been observed on mussel and oyster farm structures in Saldanha Bay (D. van Zyl, Marine and Coastal Management, Cape Town, 2005, pers. comm.). Preliminary observations from the oyster farm suggested that numbers increase during summer, and that a source of postlarval *J. lalandii* exists on the oyster farm. My study investigated the potential of the oyster farm in Saldanha Bay as a site from which pueruli and juvenile *J. lalandii* can be harvested for ongrowing trails on a commercial scale. This chapter focuses on a determination of the standing stock and growth of postlarvae available on the farm, assesses seasonal trends in settlement and investigates the potential relationships of water temperature, upwelling, tidal height, and wind strength and direction with settlement patterns.

2.2. MATERIALS AND METHODS

2.2.1 Study site and collection methods

Saldanha Bay is a large semi-enclosed bay on the west coast of South Africa, adjacent to the cold-water Benguela Current. It is home to a major fishing harbour, an iron-ore jetty for large ships, and several areas are set aside for mariculture. An extension of the bay forms a sheltered lagoon – Langebaan – and constitutes part of the West Coast National Park. The oyster farm in Saldanha Bay is located in 'Big Bay' on the eastern side of the iron ore jetty (Fig. 2.1a). The farm is organised into five blocks running northeast (block 5) to southwest (block 1) and

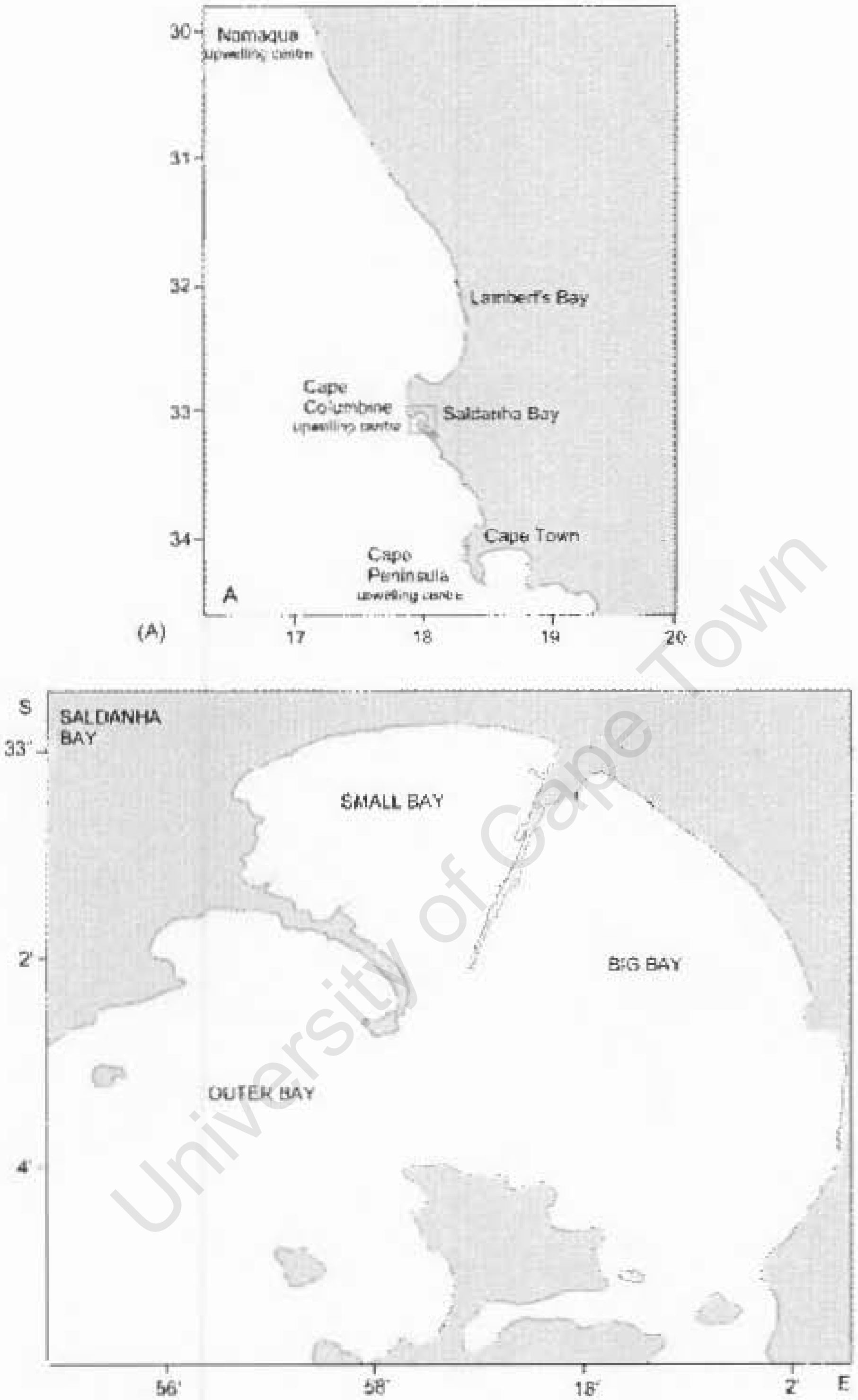


Figure 2.1 a: Map of Saldanha Bay (from Joyce *et al*, 2005), situated on the west Coast 100 km north of Cape Town, indicating the position of the oyster farm.

covering an area of 5 ha per block. Each block contains 11 surface lines, in parallel, each with a length of 30 m (Fig. 2.1b). Oysters are ongrown in mesh bags (23 mm mesh size) suspended in stacks of five bags (Fig. 2.2) from the surface lines, with 30 stacks per line. Individual oyster stacks of five bags each were used as the standard sampling unit for this study. Each bag was 50 cm x 100 cm and about 15 cm tall when filled with oysters (volume = *ca* 0.075 m^3). The bags become inundated with fouling plants and animals after prolonged submersion and are lifted and cleaned approximately every 4 - 6 weeks.

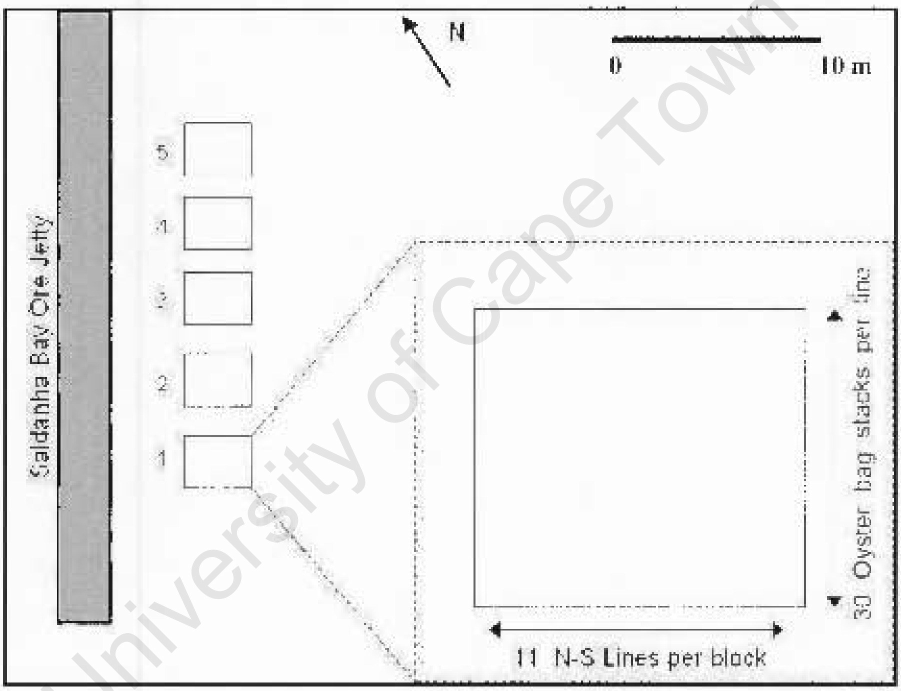


Figure 2.1 b: Schematic representation of the oyster farm layout. Culture blocks are numbered 1 to 5, with block 1 enlarged to indicate orientation of lines and stacks.

The sampling period ran from August 2005 to July 2006, and oyster stacks were sampled for postlarval lobsters during the commercial harvesting of oysters. Access to the farm was by boat, and the oyster stacks were winched out of the water and into the boat. Each stack was shaken vigorously onto the deck of the boat and the deck was then thoroughly searched for pueruli and juveniles. The numbers of postlarvae found were counted and a record kept of the numbers of stacks harvested and the soak-times of individual stacks (duration in the water prior to the harvest).

Figure 2.2: Picture of one oyster stack, consisting of five bags. Stacks are suspended from the surface lines as demonstrated.

2.2.2 Biological sampling

The postlarvae were categorized as pueruli or juveniles (see section 1.4 for morphological distinction between pueruli and juveniles) and the numbers of individuals in each category counted. Sub-samples of at least 25 live specimens from each category were randomly selected and their sizes determined. Measurements taken were carapace length (CL ± 0.1 mm), measured dorsally from the rostral tip to the posterior edge of the carapace, and total length (TL ± 0.1 mm), measured dorsally from the rostral tip to the end of the tail. All live specimens were retained in seawater tanks at the oyster farm for ongrowing experiments. Specimens that were accidentally killed during the collection process were taken to a laboratory at Marine and

Coastal Management (MCM) in Cape Town, where random sub-samples of at least 25 specimens were measured as above, blotted dry, and the wet body-mass (BM ± 0.001 g) weighed on an electronic Sartorius balance (0.0001 g precision).

Size-frequency distributions (per 0.5 mm CL size-class) were constructed for pueruli and juveniles respectively. Monthly size-frequency distributions were also constructed for the period when settlement peaked (October 2005 to March 2006), and normal curves fitted to cohorts recognized within the monthly distributions. Cohorts were followed through time to approximate growth rates. Length-mass relationships and CL/TL relationships were determined for pueruli and juveniles $\leq$ 20 mm CL, based on the least squares method in STATISTICA (Version 6, 2004).

2.2.3 Seasonal fluctuations in catch-rates

Catch-rates were calculated for pueruli and juveniles respectively, and for both categories combined, by dividing the numbers collected by the number of stacks sampled on each sampling trip. The effect of stack soak-time (duration in water) on catch-rate was tested by fitting a range of regressions, which showed that a polynomial relationship yielded the highest coefficient of determination. Catch-rates were plotted against time to identify peaks. For seasonal comparisons, data were grouped as follows to reflect the seasons of the year: spring (August – October 2005), summer (November 2005 – January 2006), autumn (February – April 2006) and winter (May – July 2006). Levene's test revealed significant departure from homogeneity of variances ($F_{3,31} = 6.732$, $p = 0.001$) and data were log (x+1) transformed to meet the assumptions of ANOVA. The log-transformed catch-rates were then compared among seasons by means of an ANOVA followed by a Tukey's honestly significant difference test (Zar, 1984).

2.2.4 Standing stock calculations

The numbers per stack per collection day were extrapolated to represent the total number of postlarvae likely to be present on the oyster farm, using the equation:

$$Y_i = X_i * N_t$$

where X_i is the catch-rate (lobsters/stack) on day *i*, N_t is the total number of stacks on the farm and Y_i is the estimated total number of lobsters on the oyster farm on day *i*. This was done for all postlarval stages combined and for pueruli separately. At maximum capacity the oyster farm consists of five blocks of floating lines with 11 lines per block, and 30 stacks per line (a total of 1650 stacks) and covers approximately 25 ha of water.

2.2.5 Environmental data

Water temperatures (± 0.001°C) at the farm were measured at hourly intervals at 1 m depth, using an underwater temperature-recorder supplied by Marine and Coastal Management. A daily index of upwelling strength (between 0 and 1) was derived from data for Cape Columbine (33° S), which lies 50 km North of Saldanha Bay, and was based on the equation:

$$\text{Upwelling Index} = (T_o - T_i)/(T_o - T_b)$$

T_i = daily inshore sea temperature measured just off the shore 1 m below low tide at 7 am to avoid diurnal heating effects; T_o = the offshore sea surface temperature derived from satellite imagery for 1° box beyond the coastal front at the shelf break approximately 190 km offshore; and T_b = minimum temperature (8°C) derived from archival data for the minimum sea temperature at the sea bottom deeper than 150 m, at the shelf break approximately 15 nautical miles offshore (R. Branch, Zoology Department, University of Cape Town, 2006, pers. comm.).

Tidal height (± 0.1 cm above mean sea level) was measured in Small Bay within Saldanha Bay (Fig. 2.1) at three-minute intervals, and moon phases were obtained from the Hydrographic Office of the South African Navy. Wind strength (± 0.1 $m.s^{-1}$) and wind direction (degrees clockwise from north), measured at hourly intervals at a height of 7 m above mean sea level were obtained from the South African Weather Bureau for Geelbek (33° 12' S) at the southern point of Langebaan Lagoon.

The effects of the environmental variables on puerulus settlement patterns were examined for the peak puerulus settlement season (see section 2.3). Daily values for water temperature, upwelling and tidal-height were converted into weekly mean values, and weekly puerulus catch-rates were calculated as follows:

$C_i = L_i / S_i$

L_i is the total number of lobsters collected in week i, S_i is the total number of stacks sampled in week i and C_i is the catch-rate per stack for week i. Seasonal means for the period during which pueruli settled were calculated, and the weekly settlement variations from these means determined. Short-term trends in puerulus settlement during the settlement peak were then compared with water temperature, upwelling, wind, lunar-phase and tidal trends.

Wind data were analysed using CMS (Marine and Coastal Management in-house program written by G. Nelson for analysis of wind and current data) and are presented graphically as vectors of combined wind strength and direction per hour. The lengths of the vectors indicate wind strength, and vectors above the axis indicate southerly winds. Puerulus settlement was then related to the southerly (above the axis) and northerly (below the axis) wind components during the peak settlement season.

2.3. RESULTS

2.3.1 Numbers and sizes of pueruli and juvenile lobsters

Collections were made on 35 separate sampling trips over the 11-month sampling period, and the number of stacks sampled per trip ranged from 2 - 47. The mean (± SD) sampling frequency was one trip per 8.5 (± 12) days, although the intervals between trips ranged between 1 and 57 days, depending on the harvesting schedule of the farm and the availability of the boat. The longest periods without sampling were in September 2005 (breakdown of boat) and over the Christmas period during which no harvesting of oysters was done. A total of 927 stacks was sampled from which 14 000 postlarval lobsters were collected (3842 pueruli and 10 158 juveniles). The overall postlarval mortality rate arising from capture was 17 %. Pueruli ranged between 7.3 - 10.4 mm CL with a mean of 9.1 ± 0.4 mm CL (n = 678) and juveniles between 8.5 - 25.1 mm CL with a mean of 11.5 ± 2.9 mm CL (n = 722). Juvenile and pueruli size-classes overlapped between 8.5 and 10.4 mm CL and the most common size-class for pueruli was 9.5 mm CL and that for juveniles was 10.0 mm CL (Fig. 2.3 a), with frequencies of 47.9% and 29.6% respectively. The size-range of juveniles suggested that collections included more than one juvenile instar, but almost all specimens (98.3%) were ≤ 20 mm CL (likely < 1 y old; Grobler and Ndjaula, 2001).

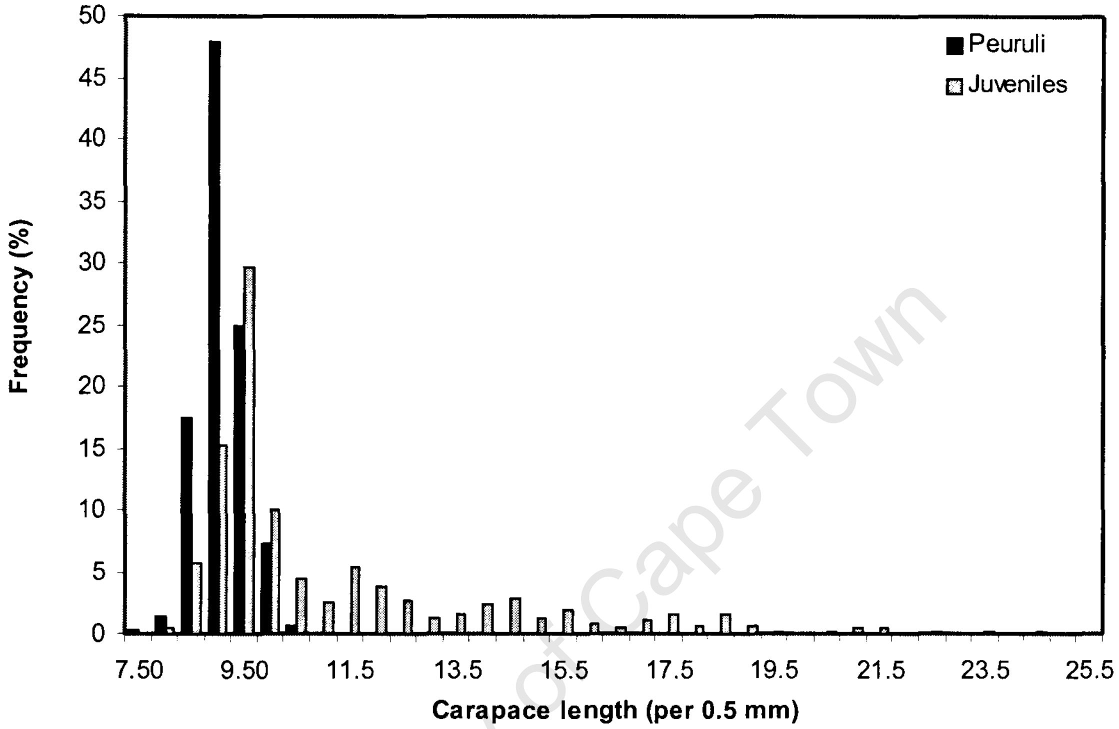


Figure 2.3 a: Size-frequency distribution of pueruli and juveniles settling at the oyster farm.

Two different cohorts were identified from monthly size-frequency distributions (Fig. 2.3 b). Animals settling in October - November 2005 as part of the first cohort appeared to grow from about 9 mm CL to about 18 mm by January 2006. The second cohort settled in January 2006 at about 10 mm CL, and grew to about 15 mm CL by March. Growth rates for the two cohorts were therefore about 3.0 mm and 2.5 mm CL per month, respectively.

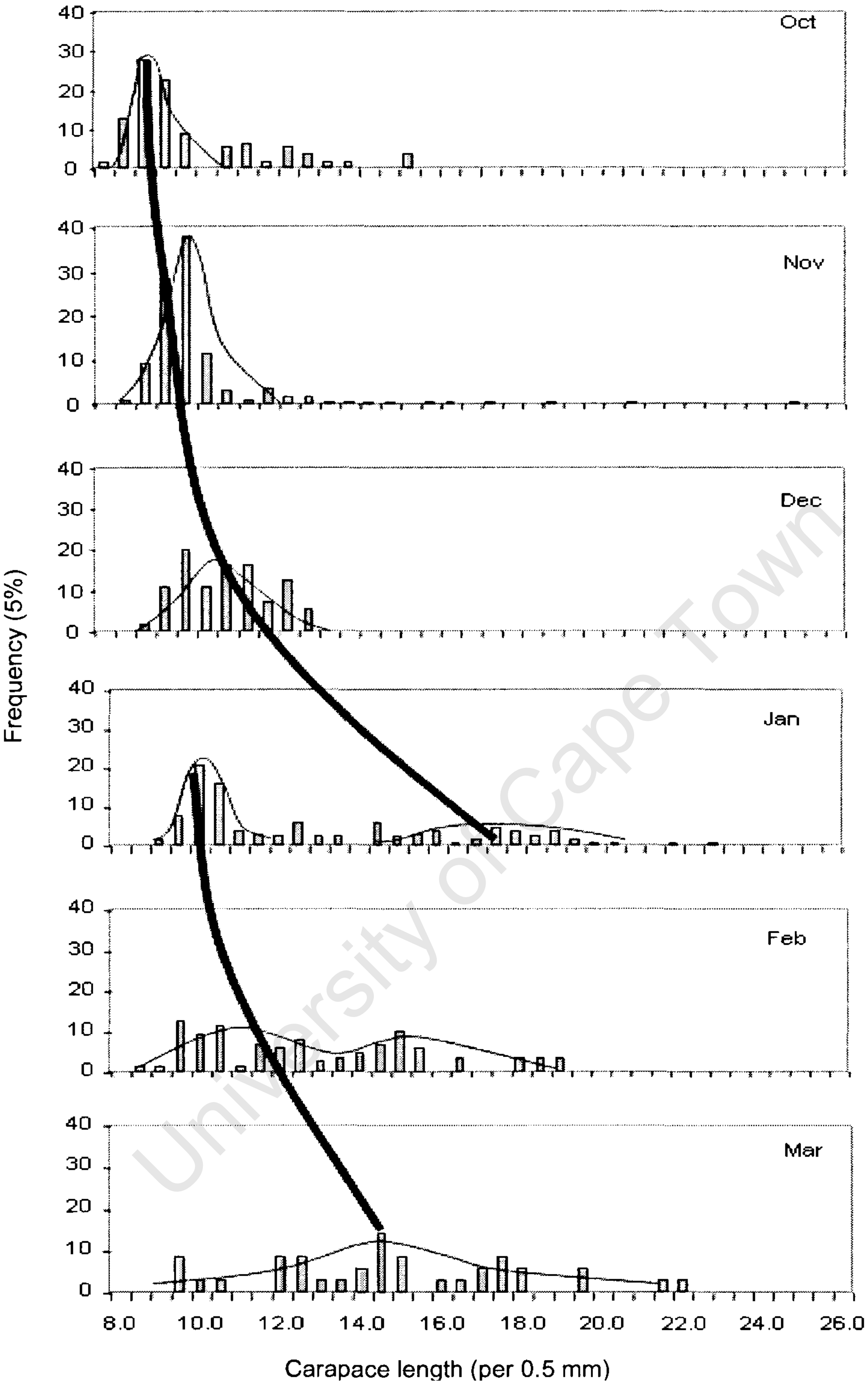


Figure 2.3 b: Monthly size-frequency distributions of postlarvae settling at the oyster farm. Curved lines fitted to distributions indicate individual cohorts and the thick black lines follow individual cohorts through each month.

A weak but significant relationship ($n = 318$, $R^2 = 0.207$, $p < 0.0001$) between puerulus CL and BM was explained by the equation $BM = 0.0067CL^{1.73}$ (Fig. 2.4 a). A stronger relationship existed between juvenile CL and BM ($n = 302$, $R^2 = 0.7697$, $p < 0.0001$) and was explained by the equation $BM = 0.003CL^{3.24}$ (Fig. 2.4 b). Relationships between CL and TL were $TL = 1.872CL + 7.505$ for pueruli ($n = 671$, $R^2 = 0.575$, $p < 0.0001$) and $TL = 2.686CL + 0.575$ for juveniles ($n = 648$, $R^2 = 0.969$, $p < 0.0001$).

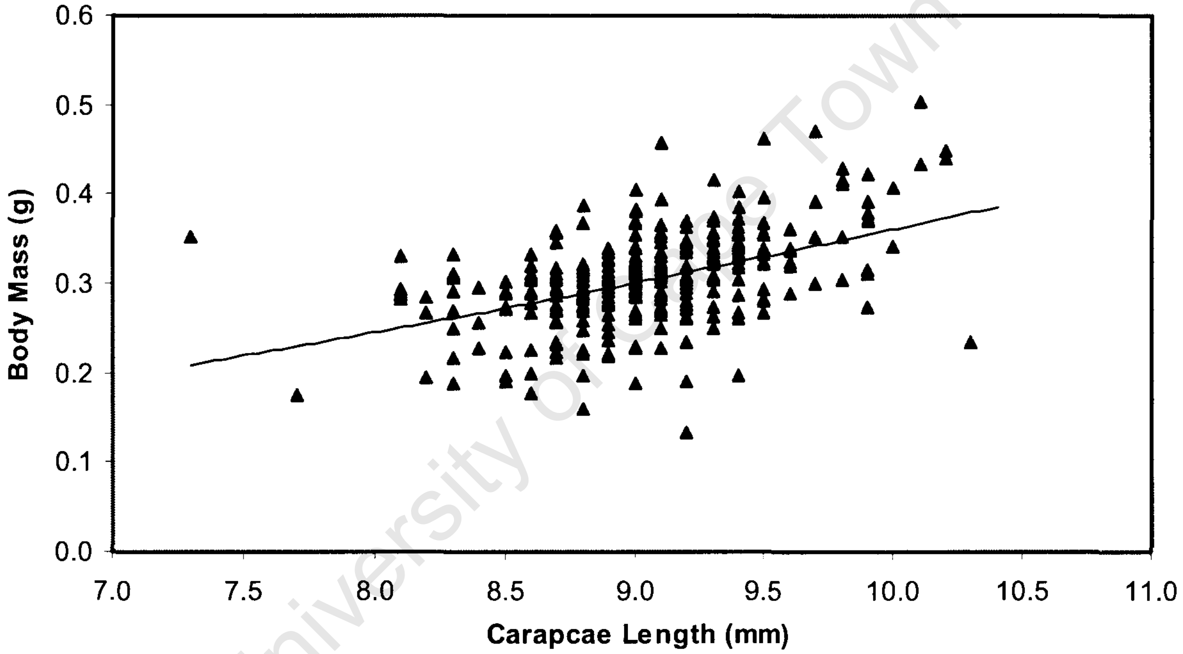


Figure 2.4 a: Relationship between CL and BM of pueruli settling at the oyster farm.

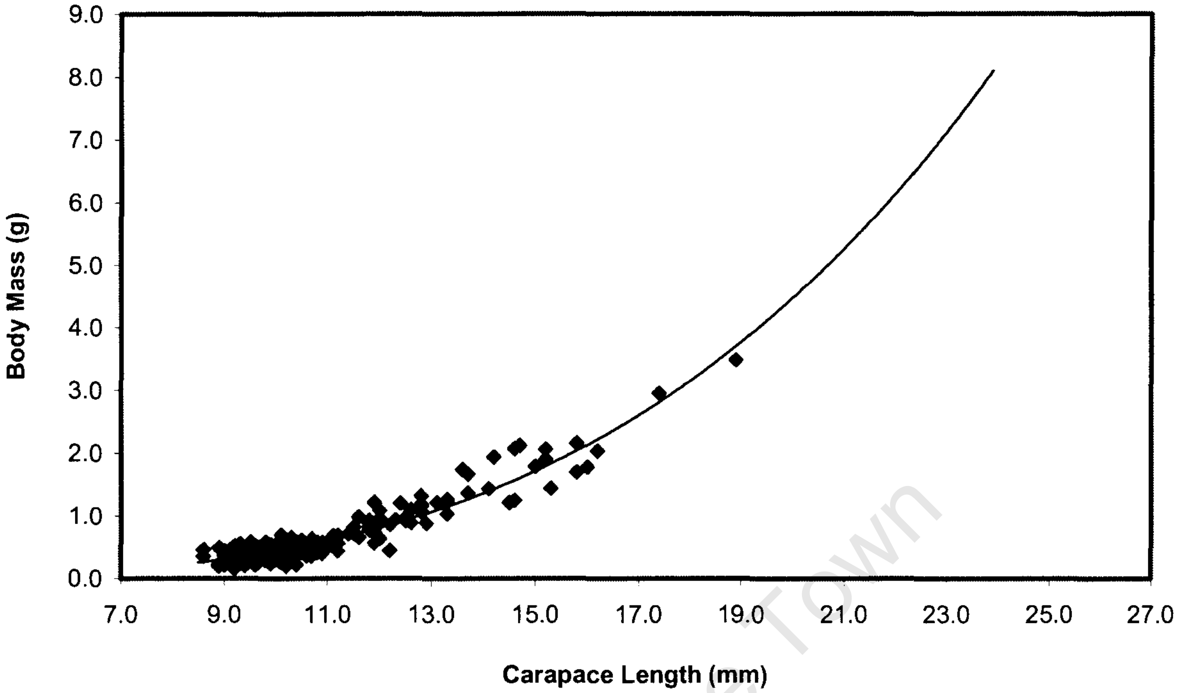


Figure 2.4 b: Relationship between CL and BM of juveniles settling at the oyster farm.

2.3.2 Influence of stack soak-time on catch-rates

Stack soak-times ranged from 4.5 to 11 weeks over the whole sampling period. Regression analyses were performed between stack soak-time and catch-rates (pueruli and juveniles combined) for samples between November 2005 and April 2006 (the period when sufficient settlement was detected to justify analysis) and a significant, but weak, polynomial relationship was found (Fig. 2.5; $y = -14.59x^2 + 215.69x - 759.62$; $n = 24$, $R^2 = 0.1707$, $p = 0.045$).

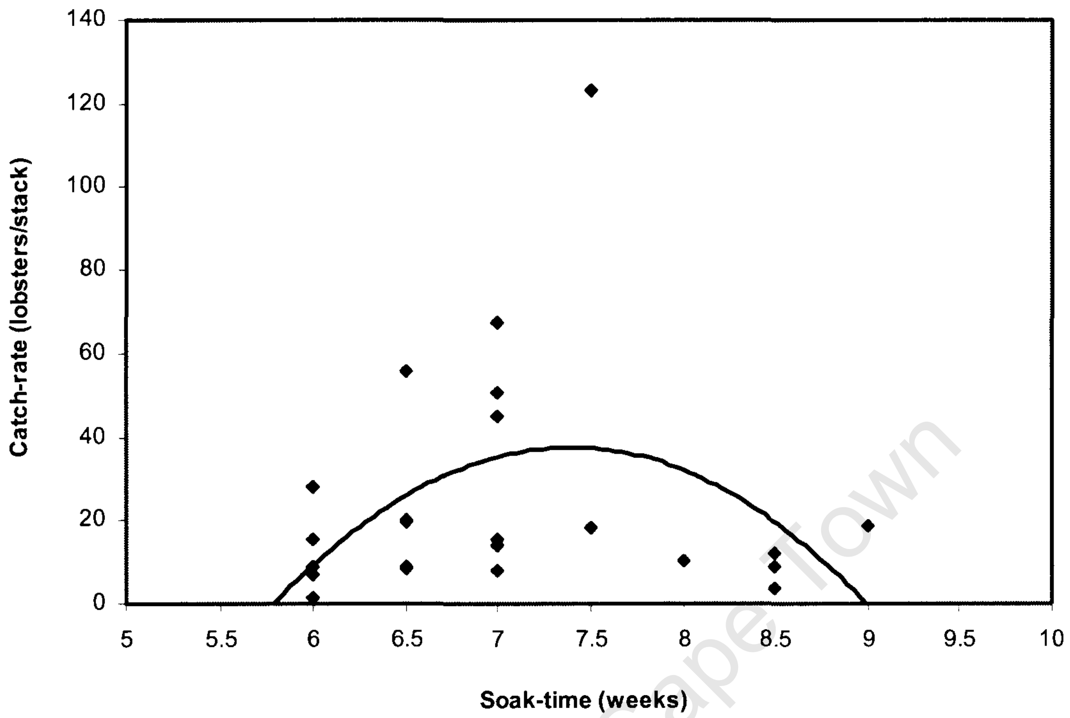


Figure 2.5: Relationship between soak-time and catch-rate of postlarvae of stacks for each sampling trip from Nov 2005 to Feb 2006.

2.3.3 Seasonality of settlement

All samples

Ninety-four percent of all postlarvae were found in samples collected between November – January and February – April and catch-rates indicated three separate peaks within a 5-month period (Fig. 2.6a). These were around 14 November (66.42 lobsters/stack), 9 January (122.19 lobsters/stack) and 8 March (17.57 lobsters/stack). Mean catch-rates (Table 1) differed significantly among the four seasons (ANOVA, $F_{3,31} = 16.9$, $P < 0.001$), and a Tukey test indicated a significant difference between summer-autumn (November – April), when there were high catch rates, and winter-spring (May – October) when there were low catch-rates (Tukey, $q_{31,4} = 3.845$, $p < 0.05$), but no difference between seasons within each of these two groupings.

Pueruli

Most pueruli were found in November – January, when two separate peaks were seen on 14 November (49.17 pueruli/stack) and 9 January (27.95 pueruli/stack) (Fig. 2.6b). Mean catch-rates (Table 1) also differed significantly among seasons (ANOVA, $F_{3,31} = 10.432$, $p < 0.001$), with significantly greater catch-rates in summer (November – January) than during any other time ($p < 0.05$), and no difference between the three remaining seasons.

Juveniles

Most juveniles were found in November – March and three separate peaks were observed on 17 November (23 juveniles/stack), 9 January (94.24 juveniles /stack) and 8 March (17.32 juveniles/stack) (Fig. 2.6c). Mean catch-rates (Table 2.1) differed significantly among seasons (ANOVA, $F_{3,31} = 12.286$, $p < 0.001$). The two periods November – January and February – April had significantly higher means as a group than for the periods August – October and May – July ($p < 0.05$), but no difference could be found between the two highest means, or between the two lowest means.

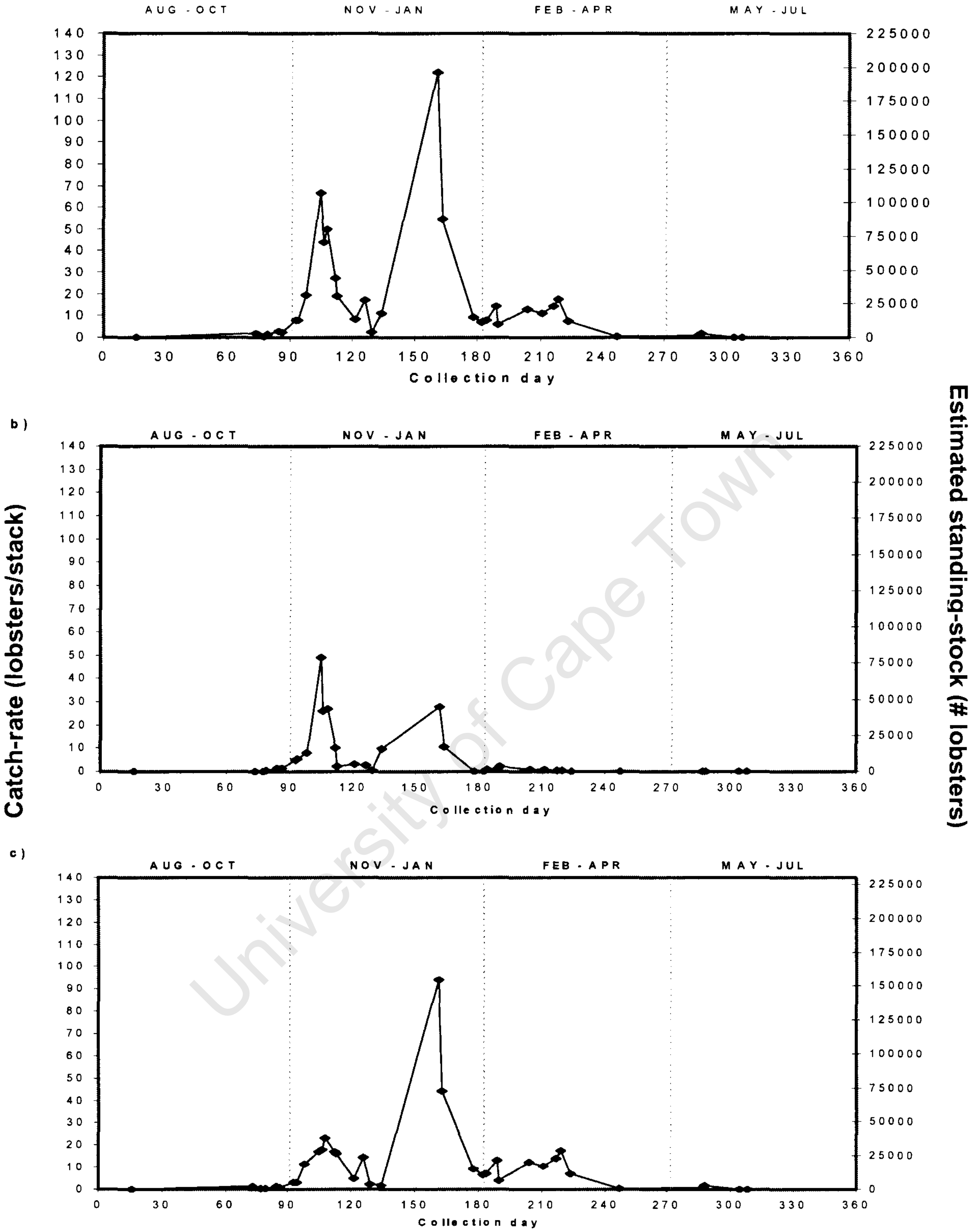


Figure 2.6: Recorded catch-rates and standing-stock estimates for each collection day for a) all postlarvae, b) pueruli and c) juveniles

Table 2.1: Seasonal catch-rates per stack of all postlarvae collected (a), pueruli only (b) and juveniles only (c).

Collection period	Sampling events	Number of stacks	Number of lobster	Catch-rate (mean ± SD)	Catch-rate Min	Catch-rate Max
a) All samples						
Aug – Oct	6	96	156	1.44 ± 1.08	0	2.77
Nov – Jan	16	406	10286	29.58 ± 31.58	2.51	122.19
Feb – Apr	9	324	3498	10.26 ± 5.37	0.32	17.57
May – Jul	4	101	60	0.61 ± 0.80	0	1.68
Whole period	35	927	14000	16.48 ± 24.65	0	122.19
b) Pueruli						
Aug – Oct	6	96	76	0.64 ± 0.67	0	1.50
Nov – Jan	16	406	3513	11.69 ± 13.77	0.15	49.17
Feb – Apr	9	324	251	0.77 ± 0.64	0.05	2.00
May – Jul	4	101	2	0.02 ± 0.04	0	0.08
Whole period	35	927	3842	5.65 ± 10.74	0	49.17
c) Juveniles						
Aug – Oct	6	96	80	0.80 ± 0.58	0	1.50
Nov – Jan	16	406	6773	17.82 ± 23.05	1.72	94.24
Feb – Apr	9	324	3247	9.49 ± 5.38	0.27	17.32
May – Jul	4	101	58	0.59 ± 0.76	0	1.60
Whole period	35	927	10158	10.57 ± 17.17	0	94.24

2.3.4 Standing stock

Standing stock estimates indicated that for the three catch-rate peaks as many as 109 587, 201 614 and 28 997 postlarvae (pueruli and juveniles combined) may have been present on the farm (Fig. 2.6a). Estimates of standing stock of pueruli alone at the two recruitment peaks were 81 125 and 46 121 pueruli respectively (Fig. 2.6b); *ca* 130 000 per annum.

2.3.5 Environmental patterns

Pueruli settled mainly in November – January and during this period weekly variations in puerulus catch-rate around the seasonal mean (± SD) of 17.95 (± 20.11) lobsters/stack reflected two peaks in puerulus settlement during 14-20 November and 9-15 January. These two recruitment peaks correlated with two distinct increases in water temperature above the seasonal mean (± SD) of 17.17 °C (± 1.42) (Fig. 2.7a), and with two distinct reductions in upwelling strength below the seasonal mean (± SD) of 0.678 ± 0.11 (Fig. 2.7b). The two highest peaks in puerulus catch-rate occurred in weeks when the moon was full and tidal height was above the mean (± SD) of 118.1 (± 13.7) cm for the puerulus settlement period (Fig. 2.7c). Unavailability of catch-rate data between 19 December – 8 January makes environmental correlations with the two puerulus peaks difficult, but it appears that weekly settlement differed little from the mean in this period, when water temperatures were generally below average and upwelling consistently above average.

Moderate to strong southerly winds were predominant during most of the puerulus settlement season and seldom decreased or changed direction during this time (Fig. 2.8). A 4-day period of moderate to low northerly winds (10-14 November) occurred prior to the week of the first and highest settlement peak; and northerly and weak southerly wind occurred during the second peak of settlement (10-16 January). Between the two settlement peaks (21 November - 8 January) a moderate to strong southerly wind blew consistently except for two days of gentle, northerly winds. It seems that weekly settlement was below or differed little from the mean during periods of constant southerly winds, and that changes in this predominant wind pattern may initiate occasions of above-average settlement.

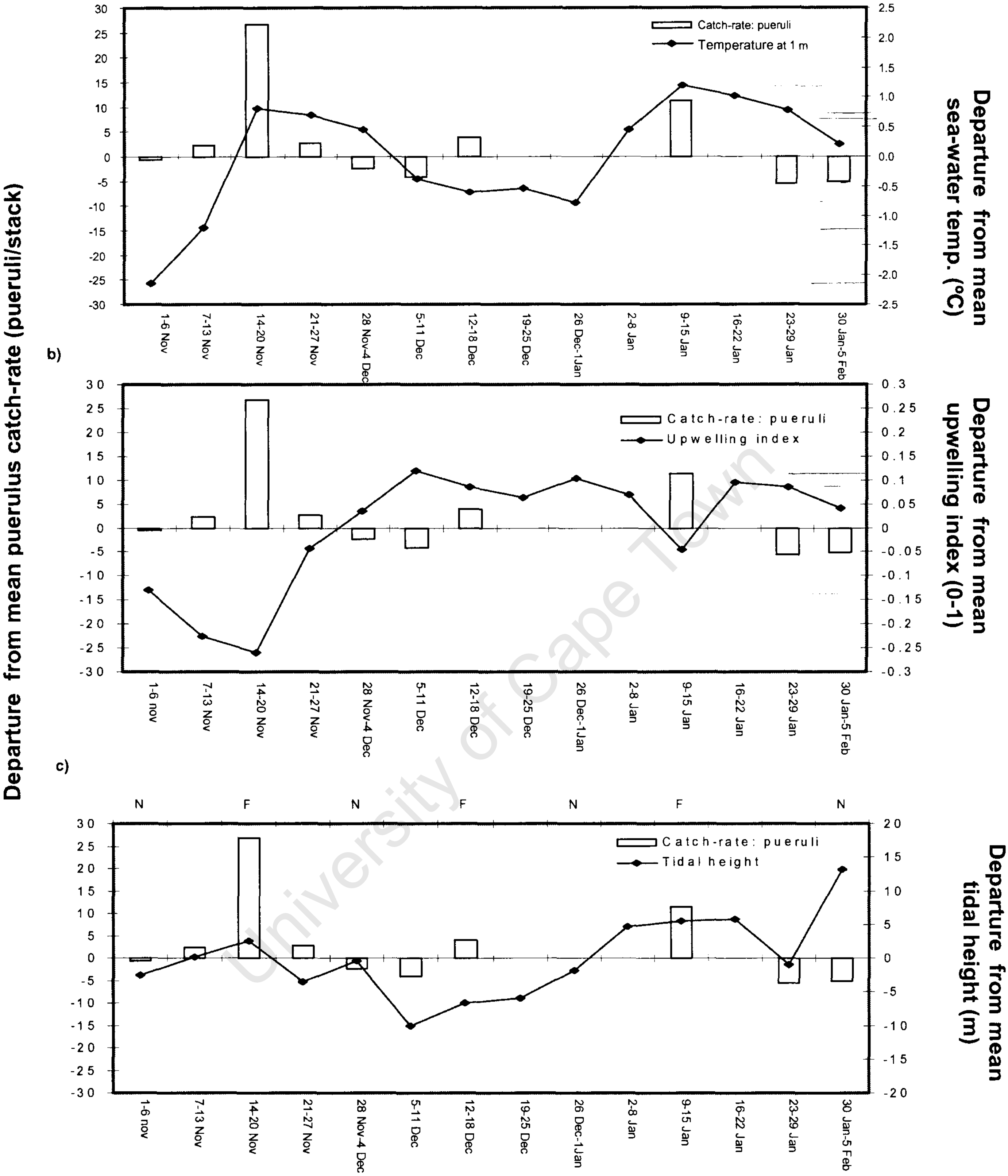


Figure 2.7: Weekly departures from the mean puerulus catch-rate in relation to weekly departures from the mean of (a) water temperature at 1m, (b) upwelling strength and c) tidal height. Weeks during the full (F) or new (N) moons are indicated at the top of (c).

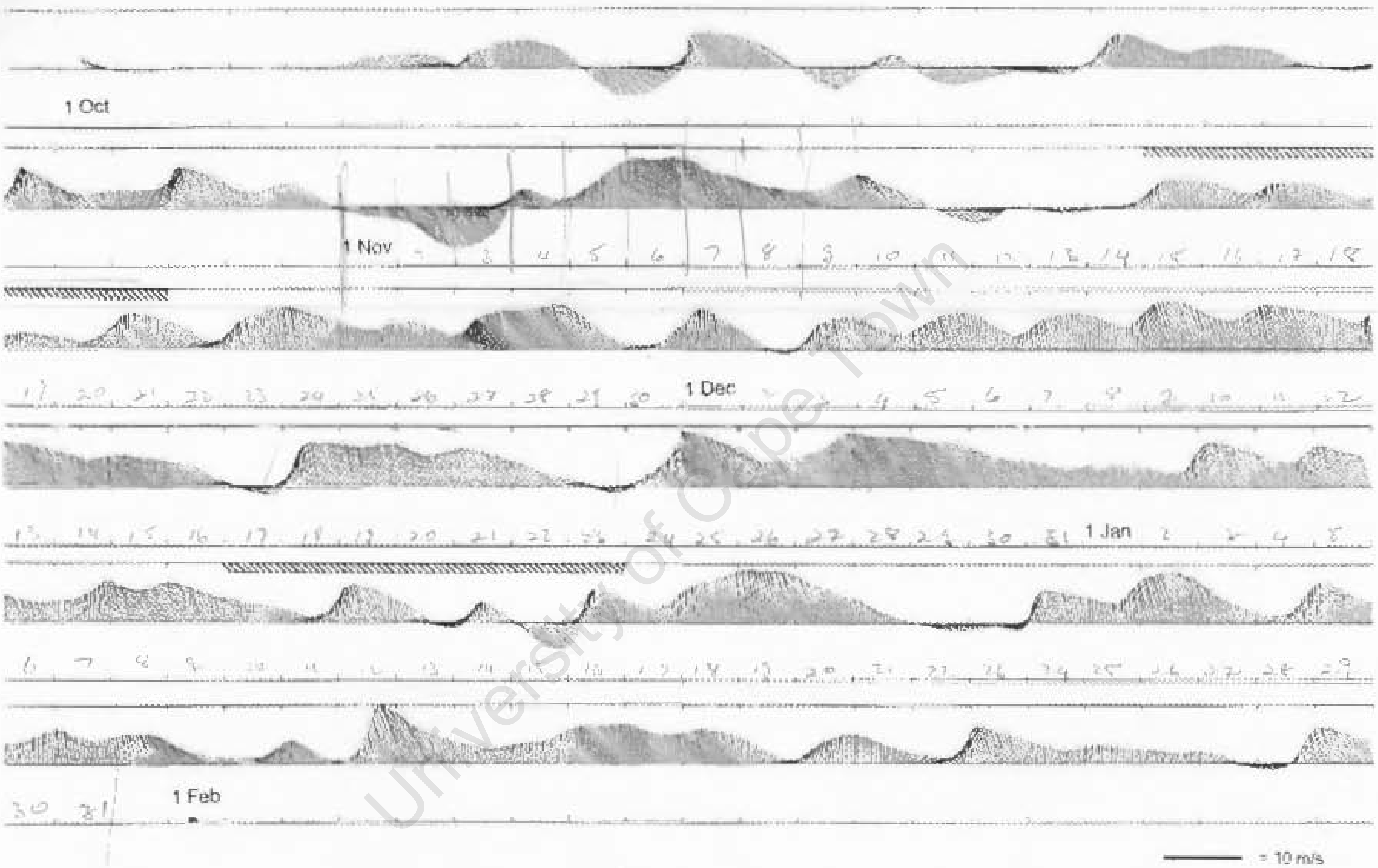


Figure 2.8: Hourly wind strength and direction at Geelbeck at the southern tip of Langebaan Lagoon. Each tick mark is a 24-hour period. Vectors above the line indicate southerly winds; those below are northerly. Shaded bars indicate periods of peak postlarval settlement.

2.4 DISCUSSION

Large populations of *Jasus lalandii* of all sizes, from adults (approximately 2500 tons available for commercial exploitation per year) down to small juveniles occur along the South African west coast (Hazell *et al.*, 2001; Johnston and Butterworth, 2005). Thus a large pool of larvae and postlarvae must exist in the region. The first postlarval stages are cryptic, and not easy to find, as has been seen during several past attempts at locating pueruli (Bailey and Fielding, 2002). There is anecdotal evidence from divers of dense concentrations of pueruli at times (G.M. Branch, Zoology Department, University of Cape Town and C. Grobler, Ministry of Fisheries and Marine Research, Namibia, 2006, pers. comm.), although this has never been quantified. This study is the first to locate and collect significant numbers of pueruli and early-juvenile *J. lalandii* in South African waters, and to quantify their recruitment.

Luderitz Bay in Namibia is the only other location were postlarval *J. lalandii* have been collected in high numbers, also on an oyster farm. Luderitz Bay and Saldanha Bay are environmentally similar in that they both lie on the west coast of southern Africa adjacent to the Benguela Current and are therefore supplied with upwelled nutrient-rich waters, and both comprise sheltered bays that breech the exposed coastline at their mouths and lead to shallow lagoons (Pitcher and Calder, 1998; Keulder, 2005). Both bays have sandy bottoms dominated by an algal cover of *Gracilaria verrucosa* (Anderson *et al.*, 1993; Keulder, 2005). Strong upwelling occurs offshore both bays, and the forcing mechanism in both regions is primarily influenced by the South Atlantic high-pressure system (Shannon, 1985). Populations of *J. lalandii* in Luderitz Bay and Saldanha Bay are genetically similar (A.C. Cockcroft, Marine and Coastal Management, 2006, unpublished data), most likely as a result of larval mixing during the prolonged offshore larval drifting phase. It is therefore likely that pueruli settling in Luderitz Bay and Saldanha Bay have been subjected to similar environmental conditions during their larval phases and should display similar biological and settlement characteristics.

A slightly wider size-range (7.3 - 10.4 mm CL) was observed for pueruli settling in Saldanha Bay than in for those settling in Luderitz Bay (8.6 - 9.5 mm CL), although mean carapace lengths (9.1 mm CL) were the same for both locations (Keulder, 2005) and the modal size-class of pueruli settling in Saldanha Bay was only marginally larger than that for Luderitz Bay (9.5 and 8.3 mm CL respectively). No information on the size-range of juveniles collected in Luderitz Bay is available, but almost all juveniles collected there are ≤ 20 mm CL (Keulder, 2005), as was found for juveniles collected in Saldanha Bay. As in Saldanha Bay, high variation in the puerulus length-mass relationship was reported for individuals settling in Luderitz Bay (Grobler and Ndjaula, 2001). Water retention during the weighing of pueruli may cause some variation, but the nutritional condition, and therefore mass of pueruli, may also differ significantly among pueruli settling at different times within a settlement season (Keulder, 2005). A stronger length-mass relationship for juveniles was reported by Grobler and Ndjaula (2001) due to the exclusion of individuals that were either about to moult, or had just moulted, because they contain slightly more water.

The 2005/6 puerulus settlement season in Saldanha Bay occurred during summer (November – January) and was characterized by two distinct peaks in puerulus settlement – an initial maximum peak around 14 November followed two months later by a lower peak. Settlement outside of this period was very low. Juvenile abundance peaked at similar times to the puerulus peaks, but with an additional smaller peak in February – March so that their numbers remained high for an additional two months after the puerulus settlement period. *Jasus* *lalandii* pueruli usually moult into juveniles roughly 10 days after settlement (Dubber *et al.*, 2004) and patterns in juvenile abundance should reflect puerulus settlement occurring in preceding weeks. A maximum peak in juvenile abundance (9 January) was observed two months after the initial peak in puerulus settlement. Similarly, a lower peak in juvenile abundance (8 March) followed two months after the second peak in puerulus settlement. The presence of the initial moderate peak in juvenile abundance at the onset of the puerulus settlement season may have been as a result of the accumulation of individuals from low levels of puerulus settlement over an extended period prior to the puerulus settlement peak, or I may simply have failed to detect the earlier settlement of pueruli giving rise to this first juvenile peak. Similar patterns of postlarval abundance have been reported from Luderitz Bay, with juvenile abundance peaking approximately two months after peaks in puerulus settlement, and very little settlement occurring outside of these periods. However, puerulus and juvenile numbers peaked there earlier in the year (August – September and November – December respectively) than in Saldanha Bay (Keulder, 2005).

Several cues for orientation used by pueruli to navigate towards coastal waters have been suggested, including underwater sound, chemical gradients such as changes in salinity, detection of coastal waves etc., but the common understanding is that pueruli are able to direct their swimming inshore (Jeffs, 2005). To date attempts at relating settlement to environmental factors such as wind, currents, water temperatures, tides and upwelling have not produced any strong relationships and many interpretations are contradictory (Phillips *et al.*, 2006). However, when relating puerulus swimming speed to the distances they cover it is evident that swimming must be aided by shoreward movements of water bodies, such as wind-drift of surface layers (Jeffs, 2005; Phillips *et al.*, 2006). Along the west coast of South Africa southerly winds (vectors above the axis in Fig. 2.8) are responsible for offshore transport of water, which arises as a result of eastward deflections of northward moving surface waters due to Coriolus force – a process known as Ekman transport (Price *et al.*, 1987; Verheye *et al.*, 1991). For the 2005/6 puerulus settlement season in Saldanha Bay (November – January) moderate to strong southerly winds were absent before the first peak of settlement and for periods during the second (and larger) peak. This suggests that a switch to northerly winds could contribute to the shoreward movement of pueruli. However, based on present data, any relationship between northerly winds and settlement is tentative.

The offshore transport of water during southerly winds is responsible for strong upwelling that occurs in the region (Pitcher and Calder, 1998). The upwelling occurring in Saldanha Bay is linked to the Cape Columbine upwelling cell, situated about 50 km north of the bay. This upwelling cell is highly seasonal with upwelling concentrated in summer and autumn every year (Probyn *et al.*, 2001). At the onset of the puerulus settlement season upwelling strength had decreased to a low point, and during this time the offshore movement of surface waters over the continental shelf would have weakened or ceased, resulting in a retreat of cold upwelling waters, and a flow of warmer surface waters into the bay (Pitcher and Calder, 1998). This inflow of surface waters into Saldanha Bay may have assisted pueruli to reach the inshore oyster farm, thus resulting in a settlement peak when upwelling was at its weakest. Once upwelling strength increased again puerulus settlement differed little from the mean. Upwelling decreased again later in the season (9 - 15 January) followed by a second peak in settlement. Temperatures on the farm reflected the effect of upwelling of coastal water temperatures by increasing as upwelling strength decreased and vice versa, with peaks of above-average temperatures occurring at times when upwelling was lowest. Thus the peaks in water temperature at the farm coincided with puerulus peaks due the effect of upwelling on both. Keulder (2005) found that peaks in puerulus settlement in Luderitz Bay occurred several days (4 - 10 days) after strong upwelling, i.e. once upwelling strength had diminished. An alternative interpretation of how upwelling effects settlement involves the theory that phyllosoma larvae (final stage larvae) use high production levels associated with strong upwelling to feed and reach a nutritional threshold that enables them to moult into pueruli with high levels of stored energy for swimming from the shelf break to coastal waters (McWilliam and Phillips 1997; Keulder, 2005). The result is high puerulus settlement that lags periods of intense upwelling.

Behavior of shoreward swimming pueruli is poorly understood, but pueruli have been visually observed, or caught in nets, most frequently in surface waters at night, and in deeper waters during the day, suggesting predator avoidance in surface waters in the daylight. A further example of predator evasion behaviour in spiny lobster pueruli is that of the Caribbean spiny lobster *Panulirus argus*, which is observed in its highest numbers during new moon when light levels are low. Keulder (2005) reported high settlement of *J. lalandii* associated with high tides during new and full moon, but no other lunar relationship has been shown for *Jasus* species (Phillips *et al.*, 2006). For the 2005/6 settlement season in Saldanha Bay the occurrence of settlement peaks during full moon - times of above-average tidal height - may indicate additional tidal assistance to shoreward movement of swimming pueruli. However, the significance of this effect needs to be established to determine whether large tidal movements increase settlement, since this perceived effect might only be coincidental with upwelling patterns. The presence of high number of pueruli on the farm during full moon appears to contradict the hypothesis that settlement occurs mainly during dark moons to reduce predation, but may also only be coincidental with upwelling patterns. Notably, the full moon of 12 – 18 December, which coincided with strong upwelling, yielded no more than average settlement. An alternative interpretation of apparent settlement during the full moon may be that high densities of pueruli occur on the shelf during new moon but are only detected on the coastline two weeks later when the moon is full.

From my survey, the most obvious patterns are that settlement is concentrated in summer when upwelling is most frequent and intense, but peaks of settlement within this period coincide with periods of reduced upwelling and high temperatures. Although these patterns are suggestive, longer-term observations will be necessary to confirm their generality.

Settlement (or recruitment) strength, location and timing can vary significantly among years (Booth, 2006) but it appears that Saldanha Bay may be a consistent site of puerulus settlement as it occurred there in unquantified amounts in years preceding this study (A. MacLachlan, Comfish, Saldanha Bay, 2006 pers. comm.). Keulder (2005) estimated mean settlement on the culture bags of the oyster farm in Luderitz Bay as 3.69 pueruli per bag during peak settlement. Oyster culture bags used in Luderitz Bay are similar to those used in Saldanha Bay, where 5 stacked oyster bags were used as a sampling unit. The mean puerulus catch-rate for Saldanha Bay during the peak puerulus settlement season (November – January) was 2.34 pueruli per bag (or 11.69 per stack of 5 bags, Table 2.1).

The maximum numbers of postlarvae potentially present on the Saldanha Bay oyster farm, at full operational capacity for oyster production (1650 stacks made up of 8250 bags covering 25 ha of water), were estimated at > 200 000 animals during peak settlement periods. Considering only the pueruli as 'new' settlers (as juveniles may have been resident from earlier settlement) narrows the window between settlement and collection to less than two weeks (after which pueruli would have moulted into juveniles; Booth, 2006), and reduces the abundance of settlers to approximately 80 000 pueruli during peak settlement. Nevertheless, using the catch-rate of pueruli, and noting that the two puerulus peaks recorded in this study fell much more than two weeks apart, suggests strongly that the second peak (est. 46 000 pueruli) consisted of an entirely new cohort of settlers. Thus, two collections (one per settlement peak) could have yielded a total of *ca* 130 000 pueruli over the November – January season. As the time interval between peaks of pueruli was approximately 7 – 8 weeks and a soak time of about 7.5 weeks yielded the highest numbers of pueruli, a minimum harvesting frequency of seven weeks is recommended. This period can be shortened during times of high settlement. Retention time of settling postlarvae on oyster stacks is at least two months since juvenile abundances peaked two months after puerulus settlement peaked, which may be important when harvesting outside of peak periods where the trade-off between cost and return will necessitate less frequent harvesting.

Cohort analyses further support the occurrence and timing of two separate puerulus settlement events, as well as the proposed stack retention time of two months. The first cohort settled in October – November and was tracked over the following two months, to December 2005, after which the cohort (consisting of ± 18 mm CL juveniles) was no longer present on the farm in notable numbers. The second cohort settled in December, and could also be tracked over the next two months, until February 2006, after which juveniles > 15 mm CL also began to diminish in the oyster stacks.

The feasibility of lobster farming in South Africa was addressed by the Department of Agriculture in 2002 - 2005 by involving scientists and industry in studies on puerulus collection and ongrowing and the economic viability of lobster farming (Bailey and Fielding, 2002). Neither locations of high settlement numbers of pueruli nor efficient methods of collection were established during this time, highlighting these aspects as the main factors hindering progress towards lobster farming in South Africa. However successful ongrowing studies were undertaken under laboratory conditions (Dubber *et al.*, 2004; Esterhuizen, 2004), and Esterhuizen (2004) also produced a desktop framework for a hypothetical lobster farm based on the shore-based systems of an abalone farm. He reported that *Jasus lalandii* postlarvae could be grown to market size of 210-220 g within 4 – 5 years and for a farm producing 50 tons of sizeable lobsters at the end of five years (with a conservative mortality rate of 80%) an estimated 300 000 pueruli were required – more than double the estimated new settlement (standing stock) that occurred on the oyster farm during this study.

In the light of my study, and previous unquantified observations, it appears that a large amount of ‘new’ settlement (pueruli) occurs every summer in Saldanha Bay and that collection of animals from the oyster farm is a simple and effective method of harvesting, which can be modified to increase the numbers of lobsters that can be collected by increasing the number of stacks harvested in peak settlement times and by reducing the mortality rate during the collection process – the death of 17 % of lobsters on collection in this study occurred mostly due to the roughness of the process of harvesting oysters and many of the lobsters that died had been crushed or physically damaged. Longer-term monitoring of variation in settlement numbers and patterns at the site would be necessary to determine reliability of this source of postlarvae for harvesting, and to determine the feasibility of commercial ongrowing in South Africa. Finding this site of high settlement in South Africa does also provide the opportunity to supply animals for studies on the biology and behaviour of newly settled lobsters as well as for further ongrowing experiments.

CHAPTER 3

DEVELOPING AND TESTING COLLECTION STRUCTURES FOR HARVESTING JASUS LALANDII PUERULI AND EARLY-JUVENILES

3.1. INTRODUCTION

The development of collectors began in the late 1960s as a means to provide postlarval lobsters (pueruli and early-juveniles) for laboratory studies, to monitor levels of settlement and how they are related to adults stocks in the future, and to secure a source of seed for mariculture enterprises (Phillips and Booth, 1994). Natural settlement of postlarval spiny lobsters often occurs in high numbers in accessible locations, such as along rocky shorelines, in sheltered bays, along harbour walls, on mussel and oyster culture structures, even in the sea-water inlets of a coastal power station (Phillips and Booth, 1994; Mills and Crear, 2000; Jeffs, 2005). Regular collection of lobsters occurs at many of these locations without the use of collectors. For example, most postlarvae collected for farming in Vietnam, where annual production of cultured lobsters (*Panulirus ornatus*) is around 2000 tons, are collected on snorkel in sheltered bays where natural settlement is high (up to two million animals being collected in the 2003/4 season) (Tuan and Mao, 2004). The development of collectors has, however, presented ways to access additional sources of good postlarval settlement, as well as being a more controlled and accurate way of recording relative levels of settlement (Phillips and Booth, 1994).

Several collector types have been developed over the last 35 years for the effective collection of various species of spiny lobster. The variety of collector types is due to the high level of species-specificity associated with collector design (Phillips and Booth, 1994). For example 'Hogs-hair' collectors are the collector of choice for *Panulirus argus* (Caribbean) but are not as effective as 'Phillips' collectors for *P. cygnus* (Western Australia), which in turn are not as effective as 'Booth crevice' collectors for *Jasus edwardsii* (New Zealand) (see review by Phillips and Booth, 1994). Collector-choice experiments are not possible in the laboratory because pueruli stop swimming in captivity. Thus, determining the most effective collector for any spiny lobster species has involved field trials comparing different collector types.

Existing collector types were, however, not designed to collect the large numbers of postlarvae required for commercial ongrowing (Phillips *et al.*, 2001). Developing new designs for this purpose will require extensive field trials, so as a short-term solution, the most common approach is to modify current collector designs to improve their efficiency for commercial collection of postlarvae (Phillips *et al.*, 2001; Mills and Crear, 2000; Mills and Crear, 2004). For example, increasing collector sizes may increase catches, and finding cheaper materials for building collectors will increase cost effectiveness. Modifying collectors for long-line attachment as apposed to individual mooring, which is common practice for most existing designs, lowers costs even further, and will also increase the numbers of collectors that can be installed, and the ease at which an operator can deploy and service collectors.

Only a small amount of work has been done towards testing collector designs for the postlarvae of the West Coast rock lobster *Jasus lalandii*. In 1999, three existing collector types, namely Booth crevice, Hogs-hair and Bottlebrush collectors, were selected for collector trials at various sites along the South African west coast (Bailey and Fielding, 2002). Booth crevice collectors consist of eight hardwood boards (40 x 40 cm) positioned horizontally in a steel frame with 2.5-cm gaps between boards. The horizontal boards are then angled slightly to create triangular-shaped crevices between each board. These collectors are usually set on the sea floor. Hogs-hair collectors consist of a ladder-shaped PVC frame that is moored to the seabed and suspended horizontally near the surface using floats. Each frame has six rungs over which sheets of air-conditioner filter material are hung; forming 12 'leaves' that hang down into the water column (Phillips and Booth, 1994). Bottlebrush collectors are explained in section 3.2.1 below. Unfortunately settlement on all three collectors was low, and findings were never published (Bailey and Fielding, 2002).

Kuelder (2005) implemented collector trials using Booth crevice and Hogs-hair collectors in Luderitz Bay, Namibia. Hogs-hair collectors were quickly destroyed by even the moderate wave action that occurs in the bay and were therefore discontinued. Booth crevice collectors were successful in collecting pueruli and early-juveniles and mean catch-rates during peak settlement periods of 18-20 pueruli/collector were similar to the peak of 15-20 pueruli/collector for *J. edwardsii* on Booth crevice collectors in Tasmania (Keulder, 2005).

In this study I tested an existing collector design – the bottlebrush design – for efficiency in collecting the postlarvae of *J. lalandii* at the oyster farm in Saldanha Bay, where settlement is known to be high (Chapter 2). I also compared this with yields obtained from the mesh bags used for the outgrowing of oysters as a design for a collector for *J. lalandii*. Many postlarvae settle on these oyster-filled bags every year, indicating their potential suitability as collectors. As part of this comparison six different bag contents (including live oysters) were suspended in the oyster bags to investigate settlement preferences by *J. lalandii* postlarvae. A further two aims were to identify any seasonal patterns of settlement on collectors, and to determine whether soak-time (interval between collections) or fouling (biological growth on collectors) influenced the numbers of lobsters that settled onto the collectors.

3.2. MATERIALS AND METHODS

3.2.1 Study site, collection methods and biological sampling

The oyster farm in Saldanha Bay is known to have high settlements of post-larval *Jasus lalandii*, and was the site selected for the study on post-larval settlement patterns described in Chapter 2. A detailed description and maps of Saldanha Bay and the study site are included in section 2.1 of Chapter 2. A dedicated surface line was set up in an east-west direction in front of Block 1 for collector trials (see Figs 2.1 and 2.2 in Chapter 2).

Eight collector types were employed for collector trials. The first six collector types were designed as variations of the oyster culture bags used on the oyster farm (see Fig. 2.2) by filling individual oyster bags with the following substrata: live oysters, live mussels, empty oyster shells, empty mussel shells, bundles of the red alga *Gracilaria verrucosa* or sheets of trawl net (two 0.2 × 1.0 m sheets of net with an approximately 20 mm mesh-size). Each bag was 50 cm x 100 cm and about 15 cm tall in the middle of the bag when filled with oysters. The seventh collector type comprised an empty oyster bag to serve as a control. The eighth collector, the bottlebrush collector (Fig. 3.1), was constructed using a design described by Mills and Crear (2004). Black shade net (or 'windbreak mesh') was cut into 1.8 x 0.4 m strips which were then folded in a zigzag fashion along the 0.4 m axis, to form a concertina of approximately ten folds. Folded strips were inserted through the windings of a 10 - 15 mm diameter rope, so that the rope was positioned in the middle of the strip with a space of approximately 10 mm (one winding of the rope) between strips. Both ends of each strip were then fanned out to form a 'rosette' (with a 0.4 m diameter), which was cable-tied to hold its shape. Five folded strips were used per bottlebrush and whole bottlebrushes were approximately 1 m long. All collector types based on bags had a volume of approximately 0.059 m^3 – based on the volume of an elliptical cylinder where major and minor axes were 0.5 m and 0.15 m respectively, and length was 1 m. Bottlebrush collectors were about 0.126 m^3 (almost twice the volume of bag type).

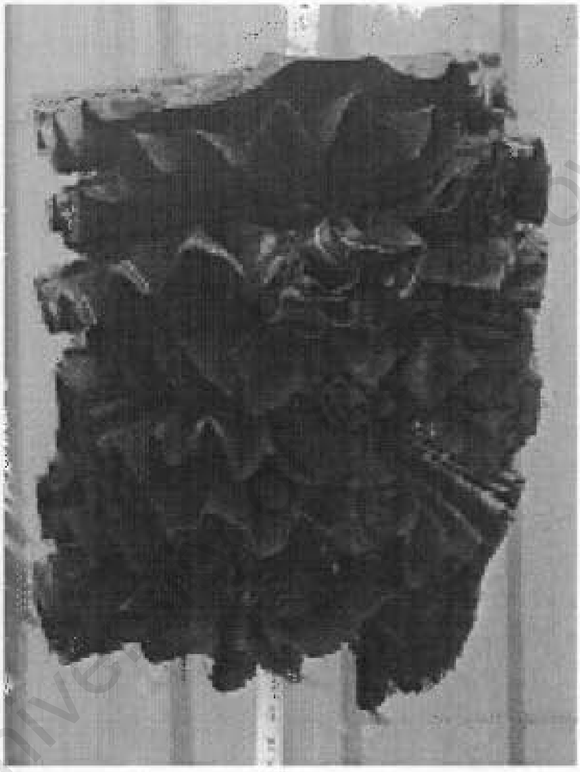


Figure 3.1: Bottlebrush collector from Mills and Crear, 2004. Strips of shade-cloth mesh (1.8 x 0.4 m) are folded "concertina-style" and fastened around a section of rope or PVC piping, forming zigzagged rosettes.

Five replicates of each collector type (i.e. a total of 40 collectors) were suspended in the water from 5-m lengths of rope at 1-m intervals along the collector line. Initial collector weights were determined when deployed on the 4 of July 2005. Collector trials ran from 21 July 2005 to 19 July 2006 and collectors were sampled approximately every three weeks.

Collectors were accessed by boat and sampled individually by first enclosing them in a net sack (2.0 m long x 1.5 m diameter, made of anchovy net with 6-mm mesh size) before raising them onto the deck of the boat. Each collector was weighed (to the nearest kilogram) on a hanging scale. Collectors based on oyster bags were opened and the contents (including substrata and bio-fouling) emptied into the net and all post-larvae removed. Thereafter the substratum was replaced in each bag and the bag resealed. Postlarvae found on bottlebrush collectors were also removed. The rate of fouling in Saldanha Bay is high, so fouling on collectors and substrata was removed each time samples were taken. Collectors were then replaced onto the collector line.

The number of postlarvae collected on each sampling trip was recorded per replicate. Fouling (kg) that accumulated on collectors between sampling events was calculated as the weight at sampling less the initial weight on installation. Soak-time (number of days in the water) between sampling events was determined for each replicate sampled.

3.2.2. Analysis of settlement patterns on collectors

The mean catch-rate ± SE (number of postlarvae per replicate) for each month was calculated for the period August 2005 to July 2006 (the collection period) and presented over time for each collector type separately, and for all types pooled. In some months more than one batch of sampling was undertaken, so that the number of replicates per month exceeded five in these instances. The bag collectors containing *Gracilaria* were excluded from analysis as the alga died and disappeared in less than a month.

3.2.3 Analysis of collector performance

Collector performance, with respect to numbers of postlarvae caught, was compared among collector types for the period November 2005-February 2006, i.e. during the peak settlement season (Chapter 2). Mean catch-rates over this period were calculated for each collector. As some collectors were lost, sample size was reduced to four replicates per collector. One collector type (mussel shells) had only two replicates, so each value was duplicated (to balance the design while maintaining the mean value and variance). Levene's test for homogeneity of variances showed a non-normal distribution ($F_{6,21} = 3.135$, $p = 0.02$) and data were $\log(x + 1)$ transformed accordingly. A one-way ANOVA among collector types was then performed on the transformed data.

Volumes of bag type collectors and the bottlebrush collectors differed, so mean catch-rates per m^3 were calculated to standardise comparisons. Levene's test again showed a non-normal distribution ($F_{6,21} = 3.742$, $p = 0.01$) and the data were once more $\log(x + 1)$ transformed. A one-way ANOVA among collector types was also performed on transformed catch-rate/m^3 values.

3.2.4 Influence of soak-time and fouling on settlement

Regression analyses were performed to determine if the number of postlarvae caught per replicate was related to either collector soak-time (number of days between samples) or fouling (kg of biological growth accumulated between samples). These analyses were based on data pooled across all collector types for two reasons: (a) sample sizes were small, and (b) no statistical difference emerged among collector types ($p = 0.87$; see section 3.2), and were undertaken for only the peak settlement period (November 2005 – February 2006) established in Chapter 2 (see section 2.3.2).

3.3. RESULTS

3.3.1 Settlement patterns on collectors

Collections were made on 13 separate sampling trips between August 2005 and July 2006. Intervals between sampling trips ranged between 14 and 62 days and the mean (± SD) sampling frequency was one trip per 28 (± 16.5) days. High rates of fouling in the bay and increased turbulence due to storm events caused the intermittent loss of a few replicates, spread across all collector types, at different times during the sampling period. Lost replicates were replaced throughout the sampling period, with the greatest number of replacements occurring during March and April 2006. The first postlarvae to settle onto collectors were recorded in September 2005 in three different collector types (oyster, empty, and bottle-brush collectors). A total of 143 postlarvae (from 246 replicates sampled) were collected throughout the period of study.

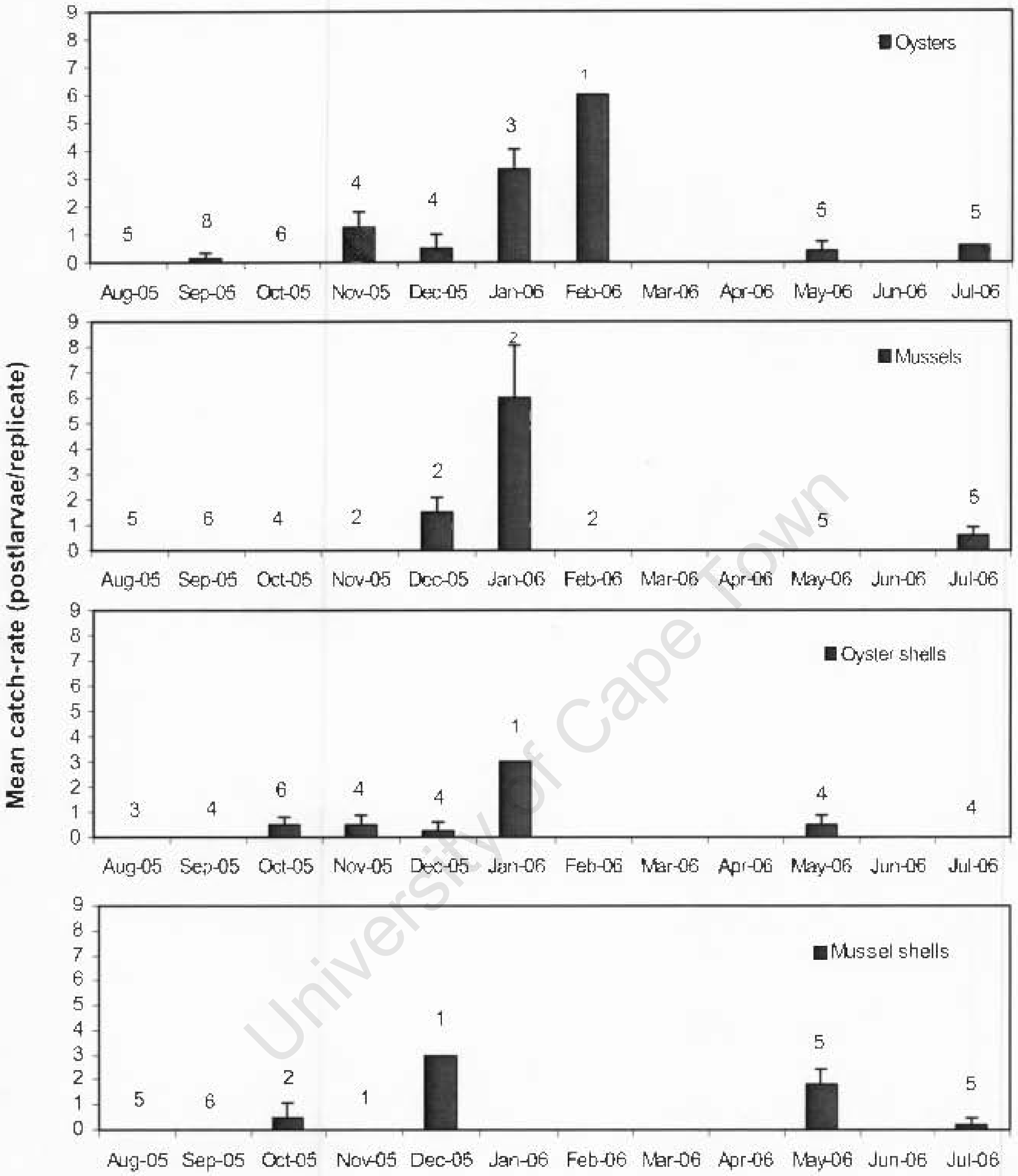
Mean monthly catch-rates for all collector types combined increased gradually per month from September 2005 and peaked November – February 2006 (Fig. 3.2). The absence of sampling in March and April obscured the overall settlement pattern. However, catch-rates were low prior to November 2005 and from May 2006 onwards. A maximum of 12 postlarvae was caught in a single mussel-bag replicate in January 2006. The maximum mean catch-rate (number of postlarvae per replicate) was 6, and was recorded on the bag-type collectors containing live oysters and live mussels in February 2006 and January 2006 respectively (Fig. 3.2). The number of replicates of each collector type, indicated by column labels in Figure 3.2, differed among months due to losses and replacement of replicates throughout the sampling period.

3.3.2 Collector performance

Table 3.1: Mean catch-rates for each replicate over the peak settlement period of November 2005-February 2006 including mean catch-rates, and mean-catch per unit volume, for each collector type. Replicates not sampled during this period are indicated by (-). The proportions of juveniles in the total number of postlarvae caught on each collector over the collection period are indicated.

Collector type	**Mean catch-rate for each replicate**					**Mean (± SD) catch-rate for each type**	**Mean (± SD) catch-rate/m^3 for each type**	**Rank**	**Proportion of juveniles**
	1	**2**	**3**	**4**	**5**				
Oysters	3.5	1.7	0	-	1.3	1.6 (± 1.5)	27.5 (± 24.5)	2	0.64
Mussels	1	0.5	6	0	-	1.9 (± 2.8)	31.8 (± 47.1)	1	0.87
Oyster shells	-	1	1	0.5	0	0.6 (± 0.5)	10.6 (± 8.1)	6	0.30
Mussel shells	3	0	0	3	-	1.5 (± 1.7)	25.4 (± 29.4)	3	0.91
Trawl net	1.25	1.5	-	1	0	0.9 (± 0.7)	15.89 (± 11.1)	5	0.86
Empty	2.5	2.5	0	1	-	1.5 (± 1.2)	25.4 (± 20.8)	3	0.46
Bottlebrush	1.5	0.5	-	0	0	0.5 (± 0.7)	4.0 (± 5.6)	7	0.13

The two highest mean catch-rates for the November 2005 – February 2006 period was for bags filled with live mussels and live oysters, and the two lowest for oyster shells and bottlebrushes (Table 3.1). The empty bag 'control' ranked in the middle. However, analysis of variance of mean catch-rates showed no statistical differences among collector types (ANOVA: $F_{6,21}$ = 0.391, p = 0.876). Mean (± SD) catch-rate for all bag-type collectors combined over this period was 1.3 (± 0.5), and 0.5 (± 0.7) pueruli per collector for bottlebrushes.


Mean catch-rate (postlarvae/replicate)
Oysters
Mussels
Oyster shells
Mussel shells
0
1
2
3
4
5
6
7
8
9
Aug-05
Sep-05
Oct-05
Nov-05
Dec-05
Jan-06
Feb-06
Mar-06
Apr-06
May-06
Jun-06
Jul-06
5
8
6
4
4
3
1
5
5
5
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(Figure 3.2…)

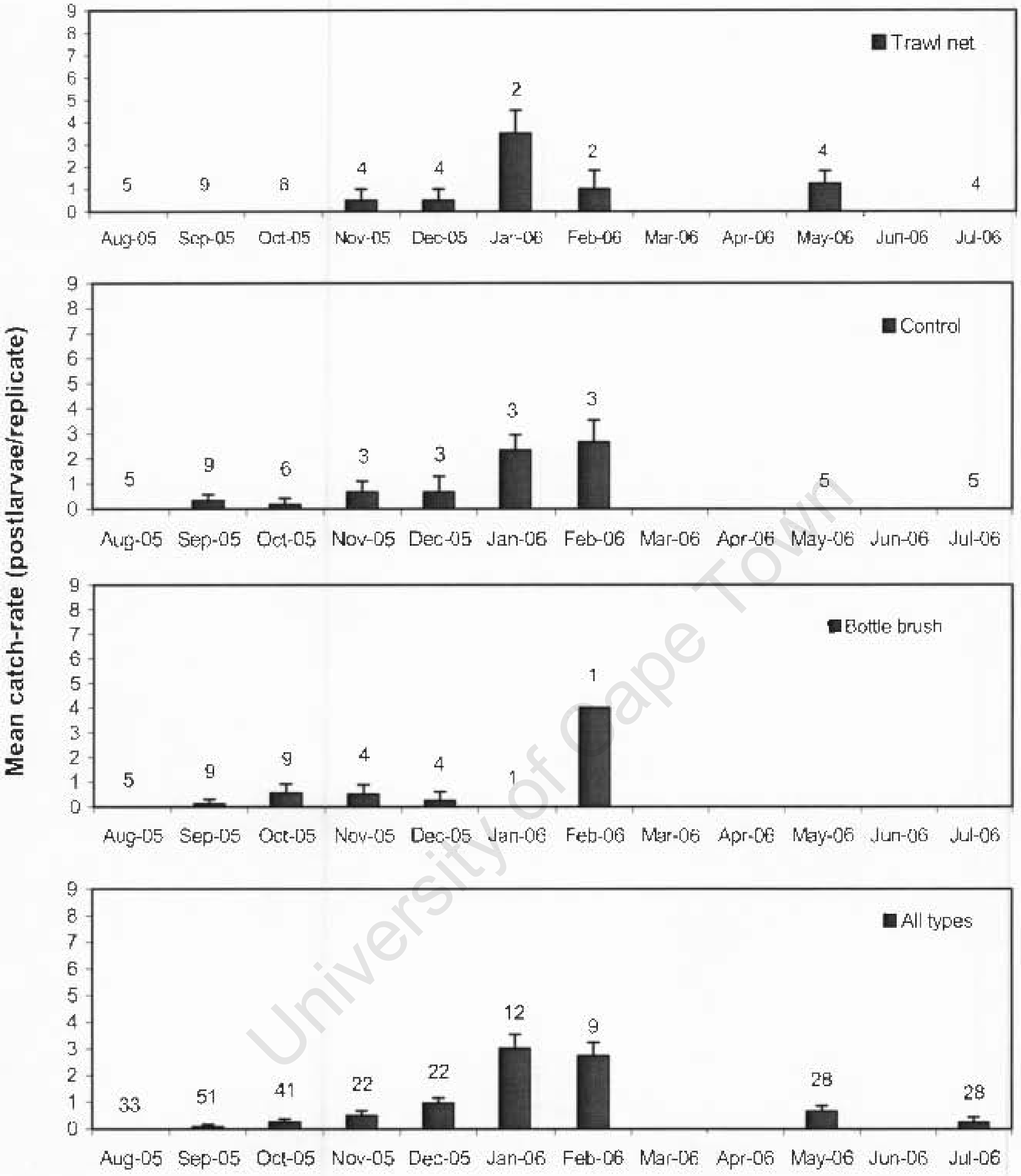

Figure 3.2: Mean monthly catch-rates for each collector type. Column labels indicate the number of replicates sampled each month (no label = 0 replicates sampled), which sometimes exceeds five when two samples were taken in a given month.

By determining mean catch-rates per m^3 of collector volume the catch-rate for the bottle brush collector decreased dramatically with respect to the other collectors. However, there were still no differences in mean catch-rates among collector types (ANOVA: $F_{6,21} = 0.408$, $p = 0.865$).

The proportions of juveniles to pueruli were highest for collectors containing mussel shells, live mussels, trawl net and live oysters (0.91, 0.87, 0.86 and 0.64 respectively). Pueruli were best represented in catches taken from bottlebrush collectors and collectors filled with oyster shells, where the proportions of juveniles in these catches were low – 0.13 and 0.30 respectively. Not enough data were available for statistical analysis of ratios of pueruli to juveniles caught on each collector type.

3.3.3 Influence of soak-time and fouling on settlement

Neither soak-time nor the amount of fouling differed among treatments (ANOVA: $F_{6,47} = 0.195$, $p = 0.977$ for soak-time and $F_{6,48} = 0.377$, $p = 0.89$ for fouling). Means (± SDs) calculated for soak-time and fouling, for replicates sampled between November 2005 and February 2006 were 24.5 (± 10.0) days and 8.8 (± 7.2) kg respectively. A weak polynomial relationship ($y = 0.0026x^2 - 0.091x + 2.5766$) existed between collector soak-time and the number of postlarvae caught for the November 2005 – February 2006 period ($n = 63$, $r^2 = 0.1423$, $p = 0.002$; Fig. 3.3 a). A weakly negative semi-logarithmic relationship was found between fouling and the number of postlarvae caught ($n = 54$, $r^2 = 0.144$, $p = 0.005$) and was explained by the equation $y = -0.556\ln(x) + 3.3383$ (Fig. 3.3 b).

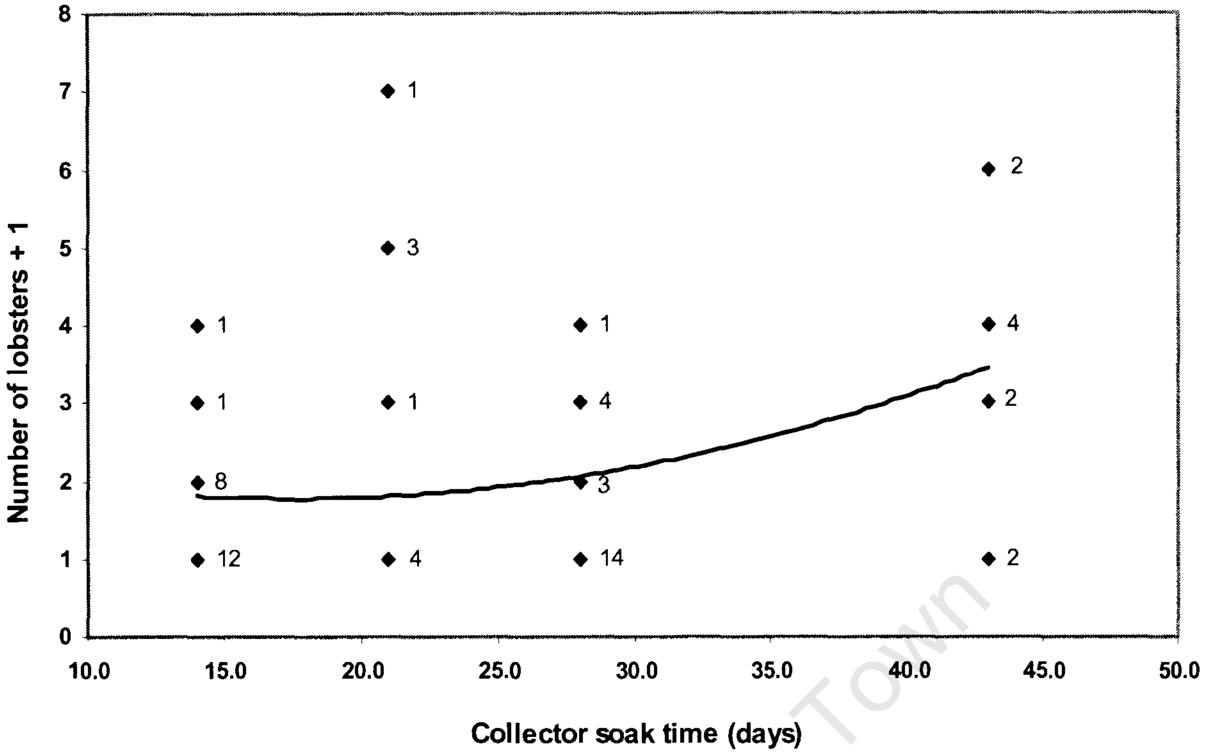

Figure 3.3 a: regression analysis for the relationship between soak-time and the number lobsters collected on individual replicates of all collector types. Labels to the right of markers indicate number of points represented by a given marker.

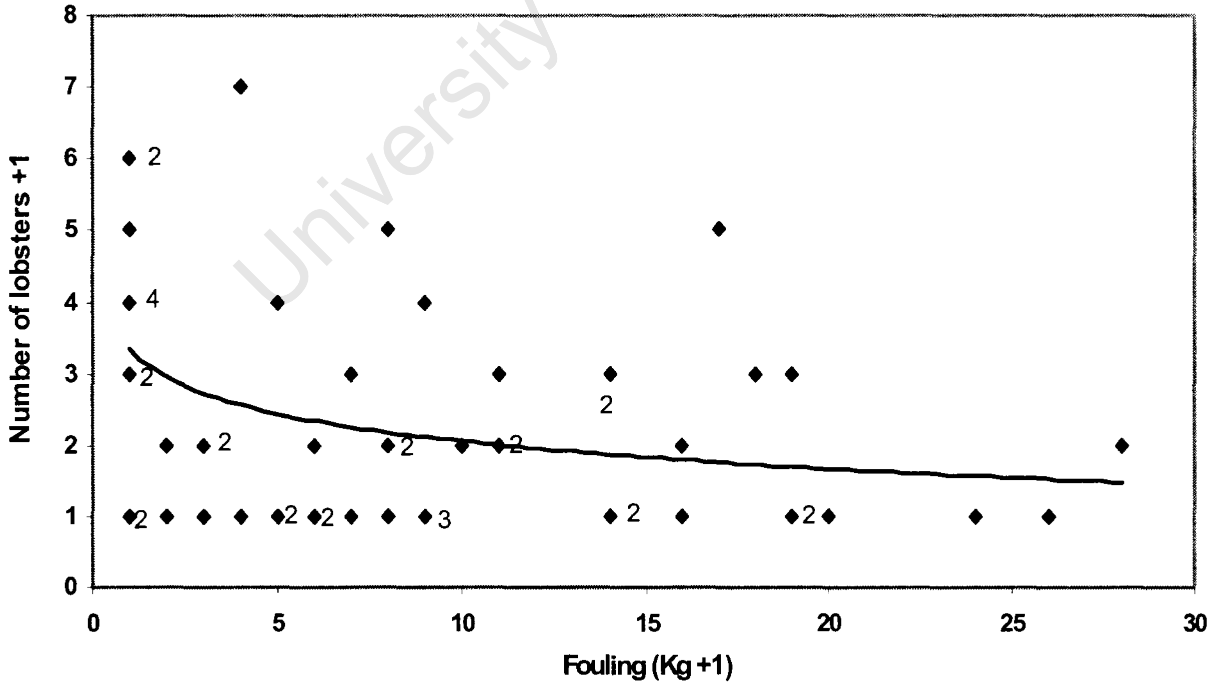

Figure 3.3 b: regression analysis for the relationship between fouling and the number lobsters collected on individual replicates of all collector types. Labels to the right of markers indicate where > 1 points are represented by a given marker.

3.4 DISCUSSION

The seasonal pattern of summer settlement (November – January) of postlarval *Jasus lalandii* occurring at the oyster farm in Saldanha Bay (Chapter 2) was reflected in postlarval settlement recorded on all collector types deployed at the farm, with collector catch-rates peaking November 2005 – February 2006. Catch-rate data were not available for March and April 2006, but it is likely that the high settlement in autumn (February – April) shown in Chapter 2 would also have been reflected in collector catch-rates over this time because relatively high collector catch-rates were still recorded in May 2006. Almost no settlement occurred outside the summer/autumn months, on both the oyster stacks and the collectors. For scientific purposes, an important element of collector design is that settlement-patterns on collectors should adequately represent the settlement patterns occurring in the area (Phillips and Booth, 1994). 'Oyster-bag' type collectors therefore have the potential to be useful settlement structures for year-to-year monitoring of settlement patterns in Saldanha Bay and other sites along the South African west coast.

Collector performance was analysed for the period of November 2005 – February 2006 to correspond with the summer/autumn settlement season determined in Chapter 2. No significant preference by the postlarvae for any of the substrata tested in the oyster-bag collectors was exhibited, as postlarvae were even found in similar numbers in the fouling growing on the empty oyster bags. Thus, postlarval lobsters are not necessarily attracted to settle at the oyster farm because of the high density of oysters but rather to the architecturally complex habitat offered by oyster bags and their contents. Mean catch-rates (lobsters per bag) for the summer period (November – December) were higher for the oyster stacks (5.9 postlarvae per bag or

29.58 per stack of five bags, Chapter 2), than for the collectors, which comprised single oyster bags (1.62 postlarvae per bag). It is thought that on reaching the coastline pueruli rely on visual orientation in searching for settlement habitat (Phillip and Booth, 1994), and the larger size of the oyster stacks on the farm may increase settlement there, in comparison with that on single bags. Settlement on bottlebrush collectors was not significantly different from that on the oyster-bag collectors and may also have the potential to act as a suitable collector for *J. lalandii,* as well as providing a standardised collection structure for comparing settlement levels between areas where bottlebrush collectors are used – for example high catch- and cost-effectiveness make bottlebrush collectors the recommended collector for *J. edwardsii* postlarvae in Tasmania (Mills and Crear, 2000, 2004).

In this chapter pueruli and juveniles were analysed together as postlarvae due to the low numbers collected in each stage. Since catch-rates for oyster bags sampled in Luderitz Bay were based on puerulus settlement only (Keulder, 2005) they are not directly comparable to postlarval settlement recorded on bag-type collectors in this chapter. However, in Chapter 2, comparisons between peak season puerulus catch-rates recorded on oyster bags at the oyster farm in Luderitz Bay, Namibia (3.96) and those recorded on the oyster stacks on the farm in Saldanha Bay (2.34 per bag), indicated puerulus settlement is higher in Luderitz Bay. Thus it can be inferred that overall postlarval catch-rates per bag were also higher in Luderitz Bay, than for bag-type collectors in Saldanha Bay. Postlarval catch-rates of 0.5 postlarvae per collector on bottlebrushes can, however, be compared to postlarval settlement on bottlebrushes in Bicheno Bay – the site of highest settlement of *J. edwardsii* in Tasmania. Here, higher catch-rates of 4.5-7.5 postlarvae per collector were recorded over the best three months of settlement (Mills and Crear, 2000). Both comparisons indicate that settlement during the 2005/6 season in Saldanha Bay was lower than levels of settlement at the other two locations. However, comparisons of catch-rates between locations should be considered tentatively since natural variation in settlement between years, locations and species is high and methods of sampling and data analysis differed considerably between the studies. Further monitoring, and standardisation of methods, will be necessary for more concise comparisons of levels of settlement among areas of interest.

Before collections begin, a 1-2 month collector emersion (conditioning) time is recommended to leach out chemicals, and to allow fouling on the collector by other marine organisms, which is believed to increase the effectiveness of a collector (Booth and Phillips, 1994). The effect of fouling on numbers of pueruli collected, however, varies greatly between species and collector types. For example, optimal collection of *P. argus* on Witham collectors is only achieved after a 2-month conditioning period, but number of *J. edwardsii* collected on Booth crevice collectors after 24 hours are similar to the numbers caught one month later on the same collectors (Booth and Phillips, 1994). Collectors tested in this study were deployed on 4 July 2005 and the first lobsters were collected only in September, and then in small amounts. This effect was probably due to the low levels of settlement in Saldanha Bay that preceded the main settlement season that began late October 2005. Therefore, it is not possible to assess the initial benefits of conditioning, such as chemical-leaching, in this study. During the settlement season, the amount of fouling that accumulated on collectors between sampling trips was only weakly related to the numbers of lobsters settling between sampling trips – at least within the range of fouling experienced in this study (0-28 kg). Settlement on collectors did not differ much with respect to the intervals (soak-times) between collections, which spanned 2 – 9 weeks. A collection interval of 7.5 weeks is recommended to maximise numbers that can be collected for ongrowing when collecting from the oyster stacks on the oyster farm, but longer intervals between collections (up to nine weeks) would be adequate, and more cost-effective, for the purpose of monitoring settlement on collectors.

Bottlebrush collectors are cheap and easy to construct and service, and adequately collected *J. lalandii* in this study. Moreover they offer a standardised collector to compare settlement in South Africa with other places where they are already in use. It appears that concentrating many oyster bags in a small area increases the catch-rate of individual bags, as was the effect of the many oyster stacks hanging at the oyster farm. This effect could be tested for bottlebrush collectors by concentrating large numbers of the collectors in a small area – thereby assessing the potential of the low-cost bottlebrushes for commercial puerulus collection. The existing set-up of oyster bags on the oyster farm, however, presents a feasible way to monitor settlement at the same time as collecting postlarvae for ongrowing, by making collections from oyster bags during the normal oyster-harvesting activities taking place on the oyster farm.

CHAPTER 4

GENERAL DISCUSSION

The central findings of my thesis are as follows: (1) A reliable source of large numbers of the West Coast rock lobster *Jasus lalandii* postlarvae was located at the oyster farm in Saldanha Bay. (2) Settlement is concentrated in summer or early autumn. (3) Two (or possibly three) peaks of settlement occurred during that period, seemingly following or taking place during periods of above-average sea temperatures and below-average upwelling, (4) Growth rates of settlers were 2.5-3.0 mm per month. (5) No significant difference existed among settlement rates in different types of collectors. (6) Soak time had a minor effect on settlement rate, with a peak at about 7.5 weeks. (7) Natural fouling of collectors had a slightly negative effect on numbers of harvestable postlarvae.

Expanding on this, my first significant finding was that postlarvae were successfully collected in high numbers from the oyster farm in Saldanha Bay. Previous reports of high settlement in the area were invaluable to the initiation and success of this project, so a foremost recommendation for future study would be a coast-wide survey of the occurrence of settlement-stage *J. lalandii* along the west coast of South Africa, to pinpoint other sites of good postlarval settlement. The establishment of Saldanha Bay as a good source of postlarvae in this study has, however, provided an important starting point for further research.

Puerulus standing stock during the November 2005 - April 2006 settlement season at the oyster farm in Saldanha Bay was estimated to be around 130 000 – if the farm operates at full capacity

(1650 oyster stacks, covering 25 ha of water). The timing of future settlement peaks is likely to fall in summer/autumn but cannot be precisely predicted, so stacks should be deployed some time before the suspected settlement season, and monitored to detect when the numbers of settlers start increasing. Given a residence time of two months for pueruli settling on the oyster stacks (Chapter 2), stacks should be lifted at least once every 7 – 8 weeks following a puerulus settlement peak to maximise numbers that can be collected. Levels of settlement will vary among years, as is shown for other spiny lobster species (see review by Phillips *et al.*, 2006). However, the level of settlement on the oyster farm is certainly sufficient to effectively monitor annual settlement, further develop methods of collection, and provide animals for laboratory studies on ongrowing. Data-sets accumulated in other countries have also been used to relate levels of settlement to adult stocks in the years to come, and have shown that monitoring postlarval settlement can be a good predictive tool in fishery stock dynamics (Phillips and Hall, 1978; Phillips and Booth, 1994; Caputi *et al.*, 2003, Gardner *et al.*, 2006). Ongoing information about settlement at sites such as Saldanha Bay would at least allow statistical analysis to test the generality of these data in South Africa.

Determining whether the numbers of postlarvae settling on the oyster farm in Saldanha Bay will support commercial ongrowing is beyond the scope of this project. Esterhuizen (2004) estimated that approximately 500 000 postlarvae would be required for economically viable ongrowing production at facilities such as those at existing abalone farms. However, it is important to point out that the facilities in place for abalone farming may not be the most appropriate or cost-effective way to farm lobsters. Simpler and cheaper on-shore facilities designed specifically for lobster farming, or even the use of sea-cage farming, which is successful in Vietnam and the Philippines (Tuan and Mao, 2004) and in New Zealand (Jeffs and James, 2001), need to be investigated before the economic feasibility of lobster farming can be assessed with respect to the amount of postlarvae available for harvesting.

A lot of effort has been spent on resource management studies in New Zealand, Australia and Tasmania. Although research into collecting lobsters started there around 30 years ago, permits for the commercial harvesting of postlarvae were only issued recently once proper management strategies for the resource were established (Gardner *et al.*, 2006). Management strategies proposed by Gardener *et al.* (2006) involve a trade-off system where quotas for adult stocks are traded for permits to harvest pueruli – as an attempt to achieve biological neutrality. The number of pueruli that can be traded for a unit of fishing quota is based on the number of pueruli expected to survive in the wild and fill that unit of quota should the pueruli have recruited into the adult fishery. In conjunction with economic feasibility studies for lobster farming in South Africa, the effects on future stocks of removing commercial numbers of postlarvae need to be investigated.

There are a few aspects specific to Saldanha Bay that should be considered in future puerulus studies there. Firstly, since the conclusion of this project, the oyster farm has been moved several hundred meters, in a southeast direction, towards Langebaan Lagoon. Pueruli did recruit once again to the farm at this new location in the summer 2006 season. Variations in settlement between locations are likely, even at a small scale of 100s of meters, so monitoring at the new location and additional sites within the bay will be necessary to compare levels of settlement at various locations in the bay. Secondly, the oyster farm may effectively constitute a 'sink' for postlarvae. The postlarval lobsters collected from the oyster stacks and the deck of the boat would probably have died incidentally during oyster harvesting. Almost certainly a large number of postlarvae are lost in this way each settlement season. Collecting lobsters during the harvesting of oysters will therefore not be adding to loss of postlarvae associated with harvesting, and returning any proportion of 'salvaged' lobsters to the wild after a year of culture should enhance the juvenile population. Thirdly, is it uncertain what happens to the pueruli and early juveniles in Saldanha Bay after settlement. Low numbers of larger juveniles have been sighted under jetties, but adults are rare or absent in the bay system (D. van Zyl, Marine and Coastal Management, Cape Town, 2005, pers. comm.). Therefore, an important question that needs to be investigated is whether the lobsters move out of the bay as they reach larger sizes, or if there is high natural mortality within the bay. This will be important in establishing whether Saldanha Bay is a sink or source of postlarvae for recruitment to adult stocks. Settlement of pueruli appears, however, to not be confined to sheltered bays since sightings of large numbers of postlarvae and very small juveniles have been seen in other areas along the South African west coast (G.M. Branch, Zoology Department, University of Cape Town and C. Grobler, Ministry of Fisheries and Marine Research, Namibia, 2006, pers. comm.). Thus further research into the occurrence of postlarval lobsters along the west coast is necessary to answer questions about postlarval settlement-behavior and habitat selection.

Production of sufficient numbers of postlarval lobsters through full larval culture is a long-term goal that is expected to allow lobster farming to reach its full potential. In the mean time, providing postlarvae from the wild has enabled development of lobster farming methods and the establishment of a market for cultured lobsters - the necessary 'infrastructure' for lobster farming so to speak – for when this goal is finally realised. Although research on lobster farming is in its infancy in South Africa, research on collection and ongrowing already done in other countries can be used to accelerate the progress towards lobster farming here, now that a good source of postlarval settlement has been established.

The most important recommendations flowing from my thesis are thus: (1) Substantial numbers of *J. lalandii* postlarvae can be collected from the oyster farm in Saldanha Bay; but the economic viability of doing so for purposes of ongrowing lobsters needs investigation, and surveys need to be extended to other parts of the bay. (2) Research on the potential effects of removing postlarvae is imperative to explore the consequences for wild stocks. (3) Harvesting should be confined to summer and early autumn (November – March) when settlement peaks. (4) The harvest intervals should be about 7 – 8 weeks to coincide with the duration between settlement peaks and optimal soak times, and to avoid excessive fouling. (5) Oyster bags containing live oysters appear the most effective collectors. Although no significant differences existed among collector types, those with oysters had the second-highest yield and are cost-effective and convenient because they are in any case being deployed to ongrow oysters.

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