AN ANALYSIS OF PUERULUS SETTLEMENT OF THE CARIBBEAN SPINY LOBSTER (*Panulirus argus*) STOCK IN JAMAICA WITH PRACTICAL MANAGEMENT RECOMMENDATIONS

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ABSTRACT

Jamaica's spiny lobster fishery is the second most important in the country. As such it is necessary to have a clear understanding of the various developmental stages within the stock so measures can be put in place to protect the most vulnerable stages throughout the year. This project was therefore undertaken as a result of said necessity. The settlement pattern of the puerulus stage of the spiny lobster was analyzed by comparing it to environmental parameters of sea surface temperature and chlorophyll a as well as with recruitment. Management strategies practiced by Jamaica and other countries within the Caribbean region and beyond its borders were also examined. A yield per recruit analysis was carried out to ascertain the effectiveness of closed season scenarios and varying minimum legal sizes; length frequency data and female spawning stages were also looked at. It was found that Bowden Bay had an annual settlement peak period of January to April and that settlement was correlated to temperature and chlorophyll a. The settlement patterns were not as clear for Coquar Bay. More information is necessary to assess the significance of the current closed season (April - June), even so, it has demonstrated that it may be having a possible effect on recruitment to the fishery (March – June). Jamaica could potentially increase its spiny lobster yield by increasing the minimum legal size (MLS) close to a carapace length (CL) of 93 mm though other actions such as banning the catching of tar spot lobster could also increase its recruiting potential.

This paper should be cited as:
Cook-Panton, K. 2015. *An analysis of puerulus settlement of the Caribbean Spiny lobster (Panulirus argus) stock in Jamaica with practical management recommendations*. United Nations University Fisheries Training Programme, Iceland [final project]. http://www.unuftp.is/static/fellows/document/Kim14prf.pdf

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1 INTRODUCTION

1.1 Overview of Jamaica

Jamaica is the third largest island within the Greater Antilles of the Caribbean. The main island is approximately 10,991 km², located 145 km south of Cuba and 161 km west of Haiti. Jamaica has a relatively large maritime space estimated to be 25 times the total area of the main island, and consisting of numerous coastline-mangrove-seagrass-coral reef complexes which constitute less than 15% of the maritime space but account for over 90% of the marine capture fisheries. Within this maritime space there are over 61 small rocks, cays and shoals. Important cays are the Pedro and Morant Cays which are utilized by fishers as landing and rest stops. The two most important fisheries are the queen conch (*Strombus gigas*) and spiny lobster (*Panulirus argus*).

1.2 Rationale

The current management regime for Jamaica’s lobster stock is underdeveloped (Morris, 2010) due in part to a number of gaps including: the lack of extensive and reliable research programme for pueruli and other lobster life stages. As a result, patterns of settlement and recruitment of juveniles are poorly understood. Given this background, this research will aim to further develop the body of knowledge which now exists.

The objectives of this study were thus:

1. To determine the relationship amongst pueruli settlement, environmental parameters (temperature and chlorophyll) and recruitment which can assist in establishing seasonality as well as explaining the possible causes of fluctuations in pueruli settlement.
2. To assess the current management strategy for Jamaica’s lobster fishery and to formulate a list of effective monitoring recommendations for the spiny lobster fishery.

2 JAMAICA SPINY LOBSTER FISHERY

2.1 Importance of the Spiny Lobster Fishery

The Jamaican spiny lobster stock is concentrated mainly on the offshore banks and to a lesser extent on the island shelf, with commercially viable quantities found particularly on the Pedro Bank, Morant Bank and Formingas Bank (Figure1) (Haughton & King, 1992). Spiny lobster represents the most economically important fishery resource in the Western Central Atlantic region of the Caribbean (Ehrhardt *et al.*, 2009). It provides employment to over 32,000 fishers across some 25 spiny lobster producing countries with significant annual earnings (Chavez, 2007). As it relates to management, with the exclusion of Florida (USA), Mexico, Cuba and Belize which have relatively well-managed fisheries, the region’s spiny lobster fisheries are largely characterized by an open access, unregulated fisheries regime (Chakalall & Cochrane, 2007; Ehrhardt *et al.*, 2009; WECAFC, 2007). There is also a high level of ‘artisanalization’ which makes monitoring and control difficult (Chakalall & Cochrane, 2007). The resource is considered fully to over-exploited throughout most of the region with even some of the aforementioned well-managed fisheries experiencing decline (Chakalall & Cochrane 2007; WECAFC 2007). Improved pricing due to high demand and decreasing supply has added to the management problem by providing incentives for over-capitalization (Chakalall & Cochrane 2007).

Spiny lobster resource represents an important component of the total landings of the Jamaican commercial fishery. There are six types of lobsters that are found in Jamaican waters however *P. guttatus* and *P. argus* are the only two species that are commercially valuable (Aiken, 1984). A major proportion of the lobsters landed in western Jamaica are from the artisanal fishery and are sold mostly to the tourist industry. However this proportion, to this day, has yet to be quantified (Martin-Murray, 2009). The peak demand for lobsters within the export and tourist industries occurs at the start of the three- month closed season (April - June) period. A large concentration of lobsters is found on the Pedro Bank (Figure 1), which account for about 60% of the total landings in the industrial fishery (Fisheries Division pers. comm. 2014). Lobsters are exported mainly to the United States, Canada, Panama, Netherland Antilles, Cayman Islands and Martinique. The spiny lobster fishery is the second most lucrative export fishery after the queen conch. In 2012, the total production of lobster was estimated to be approximately 350 tons and valued at US$5.65M (FAO, 2014). Landings for lobsters usually peak in March and late September.

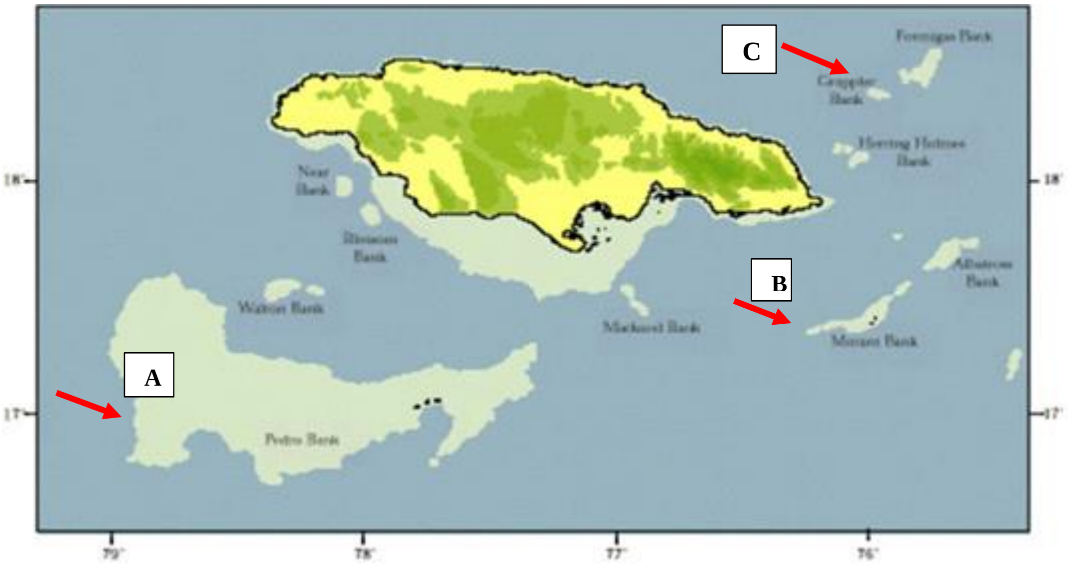

Figure 1: Geographic location of important spiny lobster fishing grounds in Jamaica; A - Pedro Bank, B - Morant Bank, C - Formingas Bank.

2.2 Governance

The Fishing Industry Act of 1975 recommended a minimum size for spiny lobsters (*P. argus*) of 76 mm carapace length (CL). It is illegal to land lobsters below this minimum size or offer such lobsters for sale. Female lobsters with eggs are also protected by this Act. In 2009, a new regulation was introduced during the closed season which prohibits persons or entities from having in their possession any lobster or parts thereof after 21 days of the commencement of the annual closed season (April 1-21). Individuals or entities caught with lobsters found after this period are subject to the seizure of products and prosecution. In addition, no lobsters must be kept alive in any holding device during the closed season. However, in 2014 an amendment was made to this regulation where, upon declaration of the amount of lobster in hand and the establishment of a sanctioned storage facility, individuals or entities may be granted permission to have in bonded storage lobster product within the closed season. Enforcement activities include end-of-season declarations of lobster by the processors and inspections of fish processing plants, hotels, beaches, and restaurants. Further restrictions were placed on the industrial vessels including, limited entry and gear restrictions.

The Ministry of Agriculture and Fisheries, Fisheries Division is the main agency with responsibility for the management, research and policy direction of the fishing industry. Its capacity for effective enforcement is however limited due to constraints on staffing and funding. As a result, the Fisheries Division depends heavily on collaborated multi-agency approaches to fisheries management where partnerships with agencies such as; the marine police, military, other environment and planning agencies of government, as well as non-government organizations, form the framework for management and enforcement within the Fishing Industry. Despite these constraints, the Fisheries Division maintains an active programme including a licensing and registration system, limited monitoring of vessels and catch, in addition to biological monitoring and some research (Morris, 2010). Enforcement activities by the Division encompass the inspection of landings and lobster establishments to ensure compliance with the Closed Season and other regulations.

Despite the existence of this framework, non-compliance remains extremely high due in part to weak linkages among the main arms of management, that is, biological restrictions, enforcement activities and judicial arrangements which are presently too weak to produce an adequate deterrent. Additional challenges include IUU (illegal unreported and unregulated) effort including poaching by foreigners and locals (Morris, 2010).

2.2.1 Spiny Lobster fishery management in Jamaica

The management of the spiny lobster fishery in Jamaica is mostly that of an open access for artisanal fishers and limited entry for industrial fishers (max. 12 entities). The fishery is plagued by a poor system of enforcement due to a lack of resources by the regulatory agency Fisheries Division. Studies have shown that there is a lack of adherence for the current management systems as Gittens (2001) found that there was a reduction in trends of the mean sizes of lobster being caught in addition to a decrease in the lobster abundance on both the south shelf and on the Pedro Bank. Of these catches, 30% of the lobsters landed from the Pedro Bank were below the 50% maturity level thus suggesting recruitment overfishing and low biomass. This is not a recent development as Kelly (2002) in his report stated that in 1975 the Fisheries Division reported 75% of the lobsters landed were immature females and suggested strict management measures should be employed. Whereas CRFM (2009), reported that in 2005 30% of the total lobsters sampled were under the minimum legal size (76 mm carapace length).

The closed season was observed as being less than effective as CRFM (2007) attempted to identify a recruitment index based on data available for both the South Shelf and the Pedro Bank from 1996 to 2006. For the South Shelf, CPUE over the 10 year period showed similar spikes around August. It was suggested that recruitment may be occurring in August, about one month after the closed season but also found that the results were inconsistent and could be due to either sampling errors or an ineffective closed season. The report also looked at trends in mean carapace length to determine recruitment period. It was found that Jamaica's spiny lobster recruitment may occur between the months of February and June, and to a lesser extent, August and September. These results were consistent with those of our neighbour Cuba who has on record over 40 years of data. As a result, the recommendation was made to move the start of the closed season gradually to February; or to designate closed areas during the recruitment period. Other findings included in CRFM (2007) comprise of: a negative effect of some fishing methods, e.g. Hookah, on recruitment; a fluctuating mean carapace length (lowest observed in March and August; highest in September and November); and the need for more economic data and monitoring for the complex lobster fishery.

Overall, the management regime has been unable to adequately control fishing effort or harvests over the years as stated by Morris (2010). He identified that this situation has developed largely due to an underdeveloped management regime and proposed that a rights based fisheries management regime would be more appropriate in addressing many of the problems facing this fishery.

2.3 Biology of Spiny Lobster

The Caribbean spiny lobster, *Panulirus argus*, has a tropical and sub-tropical distribution and a very complex life cycle that includes five phases: adult, egg, larva (phyllosoma), puerulus and juvenile (Figure 2).

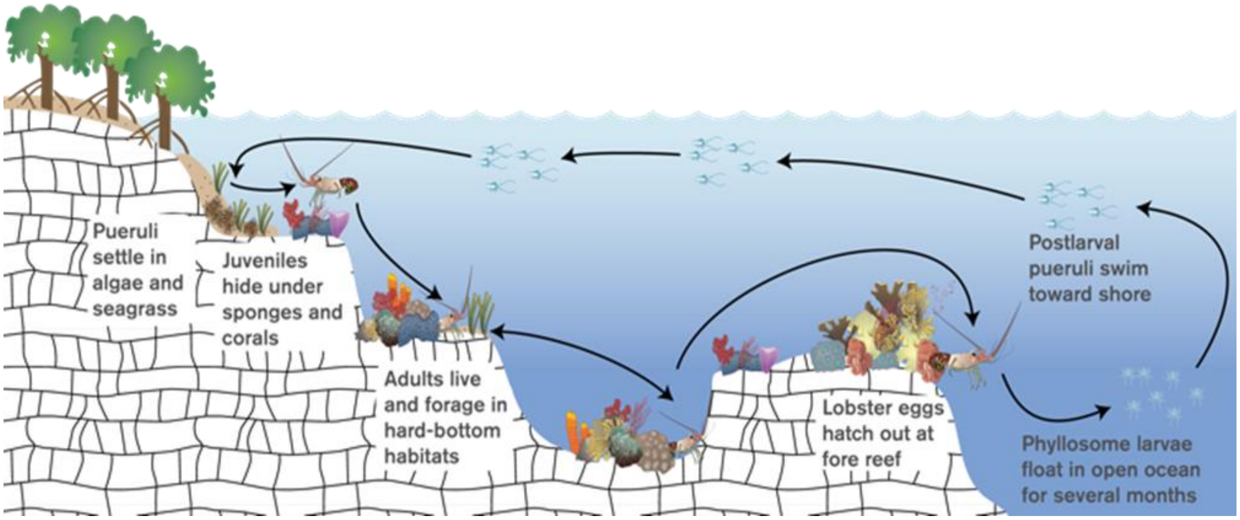

Figure 2: Spiny Lobster life cycle (source: Leahy, 2010).

It is a relatively shallow water dwelling species, preferring sheltered habitats, such as littoral fringes, particularly mangrove and seagrass beds which are inhabited mainly by the post larval and early juvenile stages (Chakalall & Cochrane, 2007). Adults may be found in rocky areas and coral reefs down to at least 100 m (Munro, 1974). Spiny lobsters are distinguished by a rounded carapace, with forward pointing spines, prominent rostral horns and long spiny antennae; young juveniles possess varied body colours ranging from shades of black, brown and purple to shades of red, brown, and light greys in adults (Marx & Herrnkind, 1985).

The spiny lobster is sexually dimorphic with males tending to grow faster with larger and heavier carapaces in addition to lighter and shorter tails (Munro, 1974). Growth averages around 50 mm per year in the first year, but may fall dramatically to an approximate average of 25 mm in subsequent years (Martin-Murray, 2009). Growth and moulting are largely dependent on local environmental conditions such as temperature, as well as population density, and tend to occur more frequently in younger individuals (Marx and Herrnkind, 1985).

Females generally reach first sexual maturity at carapace lengths of 78 to 83 mm. Mating results via deposition of a waxy spermatophoric mass by males upon the sternum of female spiny lobsters (Marx and Herrnkind, 1985). When the female is ready, eggs are passed over the spermatophore for fertilization to occur (Marx and Herrnkind 1985). After fertilization and incubation of approximately 4 weeks, females move to deeper waters to spawn (Munro 1974). Spawning mostly occurs during the period of February to August; however, some spawning occurs all year round (Marx and Herrnkind, 1985; Munro, 1974), usually at temperatures approaching 24ºC (Lyons 1980).

Due to the wide distribution of this species, its high fecundity and reproductive activity, which occur throughout the year, there is a constant supply of larvae dispersed throughout the region (see Table 1). The highest larval densities are reported within the regions of South of Cuba, the entrance to the strait of Yucatan, the east of Belize, north of Honduras, north of Venezuela, in the strait of Florida and in the Viejo Canal of the Bahamas (Alfonso *et al.*, 1991).

Table 1: Peak postlarval settlement periods for locations with spiny lobster (Meggs et al, 2010).

Location	**Peak months of settlement**	**Reference**
Australia	September to January	Phillips 1986
Antigua	February, May September to October & December	Bannerot *et al.* 1987b
Puerto Rico	June – August	Bannerot,1987b
Cuba	May to July & September to November	Cruz *et al.* 1992a
Florida	February to May	Menzies & Kerrigan 1980
Mexico	March to April & September to October	Gutierrez *et al.* 1989
Bahamas	September, November, and February	Afonso & Gruber, 2007
Jamaica	July & October to November	Young, 1993 and Meggs *et al.* 2010

The larvae are planktonic and their development in the Caribbean takes place over a period of 6 to 10 months (Alfonso *et al.*, 1991). After the metamorphosis of the larva (XI stage) to the puerulus stage, with a mean length of 5.6 mm in Carapace Length (range, 4.2 – 6.1 mm CL) and at about 4 to 8 days (Butler & Herrnkind, 1991) migrate towards the coast, with maximum settlement periods during the months of August to December (Cuba, Mexico Caribbean, Jamaica, Antigua, Costa Rica and Bermuda) and February to March (Florida Keys). The puerulus settle on substrates covered with clones of red macroalgae Laurencia spp (Marx & Herrnkind, 1985). After settlement the puerulus mutate into the postpuerulus stage or algal phase, the size ranging from 6.1 to 16.5 mm CL (between 2 and 5 months). The postpuerulus change into the juvenile stage between 8 to 11 days after settlement. Juveniles are recruited to the fisheries between 76.0 and 76.8 mm CL at about 2.0 – 2.8 years (Butler & Herrnkind, 1997).

2.3.1 Pueruli settlement

Many studies have been done on the puerulus life cycle of the spiny lobster by various countries including Jamaica (Young, 1993; and Meggs *et al.*, 2010). Australia however has pioneered studies relating puerulus settlement index to lobster stock recruitment as well as additional studies in relating this relationship to the establishment of a forecasting system for future lobster stocks. Such studies (Linnane *et al.*, 2013) show results which demonstrate that puerulus monitoring is a relatively robust indicator of future fishery performance and can be viewed as an important data source. Similarly, Sammarco *et al*., (1994) state that the level of recruitment to the fishery is indeed related to levels of puerulus settlement. They have used the close relationship between settlement and subsequent catch to develop a method of predicting the annual catch four years in advance. Gardner *et al*., (2001) also utilised puerulus catches on artificial collectors, with monthly measurements aimed at predicting future changes in recruitment to the fishery.

In Jamaica, Young (1993) and Meggs *et al*., (2010) demonstrated a similarity in settlement peaks even though their methods of collection (Witham Collector and GuSi Collector, respectively) were different thus giving rise to varying results, such that the GuSi collector produced higher yields in numbers of puerulus collected on a monthly basis. Both studies however did not correlate settlement to recruits even though the both suggested that settlement information could become paramount in the prediction of catches, seasonality, and locations of lobster fishing.

3 METHODS

3.1 Data Acquisition

3.1.1 Pueruli Settlement

Data on puerulus settlement was collected from 3 sites: Discovery Bay, St. Ann (May 2010 – May 2013), (Figure 3a), Coquar Bay, St. Catherine (August 2009 - December 2013), (Figure 3b) and Bowden, St. Thomas (January 2009 to December 2013), (Figure 3c). Discovery Bay, located along the north coast, was discontinued in 2013 due to extremely poor settlement at the site. The remaining locations are both located along the south coast of Jamaica. The data for these 2 sites was recorded as a 5 year time series of the numbers and types in each collector of the puerulus observed. This data set was stored in MS Excel spreadsheets.

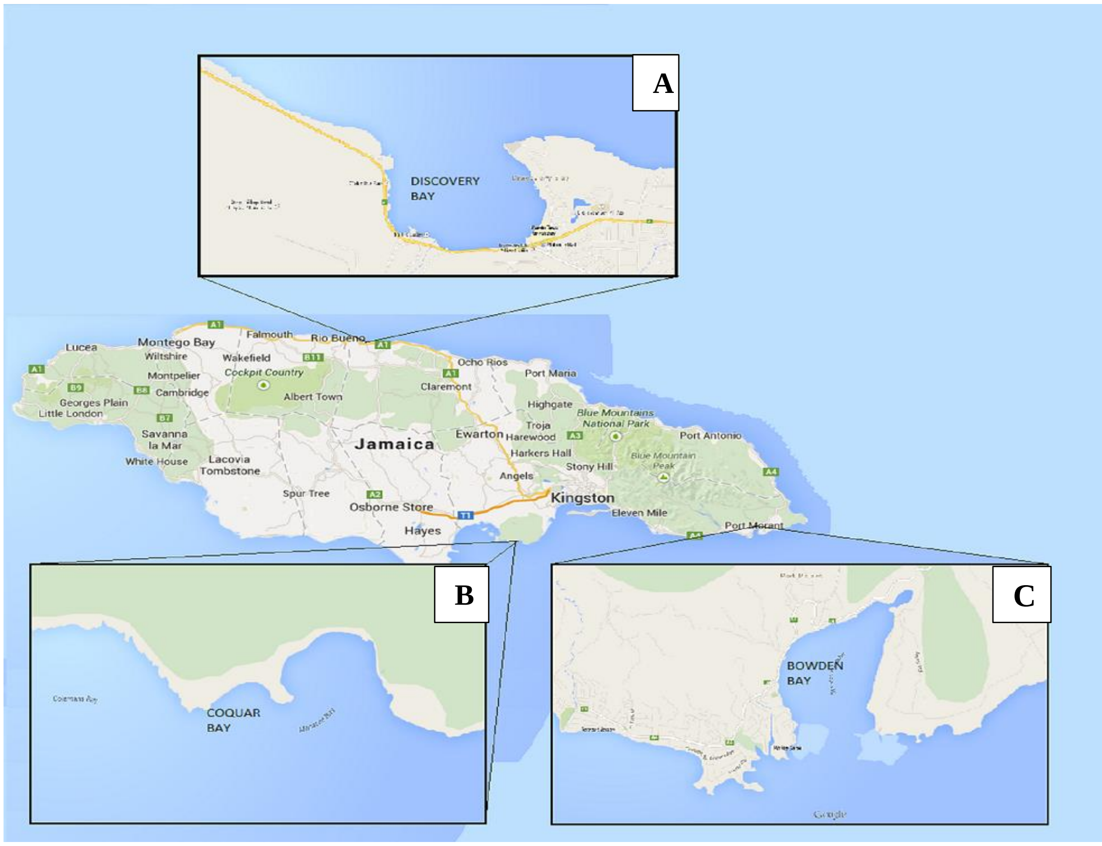

Figure 3: Overview of the collection sites of pueruli settlement stages of the spiny lobster: Discovery Bay (A), Coquar Bay (B) and Bowden Bay (C).

Monitoring of collectors (Figure 4) is done by free diving to release collector from its anchor; a marker buoy is secured to the anchor once the collector has been detached. The collector is then placed on the boat on an area that has been covered with a lightly – coloured material e.g. tarpaulin. The collector is shaken to release the pueruli that reside within it. The shakes consist of three (3) sets of four (4) i.e. one set consists of four shakes that are done within 10 seconds; once a set has been completed the result is tabulated. However, if a puerulus is seen after the final set shake, another set will have to be done to ensure all pueruli have been dislodged from the collector. The collector is then returned to the water where it is re-anchored and the buoy removed.

Figure 4: Modified GuSi collector for pueruli stages of spiny lobster.

3.1.2 Environmental parameters

Data on sea surface temperature (SST), (Figure 5a) and chlorophyll a, (Figure 5b) was gathered from Giovanni – Ocean Color Radiometry Online Visualization and Analysis (GES-DISC, 2015) where monthly data on each parameter for the period 2008-2014 was acquired. From this the area of interest was selected using latitude and longitude readings (W=-80, E=-70; N=20 and S=10, respectively). The parameters of chlorophyll a and SST were selected from the satellite MODIS-Aqua (11 micron day) 9km. A visualization of the above mentioned was created. From this generalization, ASCI files were downloaded for each parameter. ASCI files contain readings of latitude, longitude, and l3m data measured as degree Celsius for temperature and mg/m^3 for chlorophyll a (Acker & Leptoukh, 2007). The mean of both environmental parameters was calculated for each year and was then rounded to 2 degree bins.

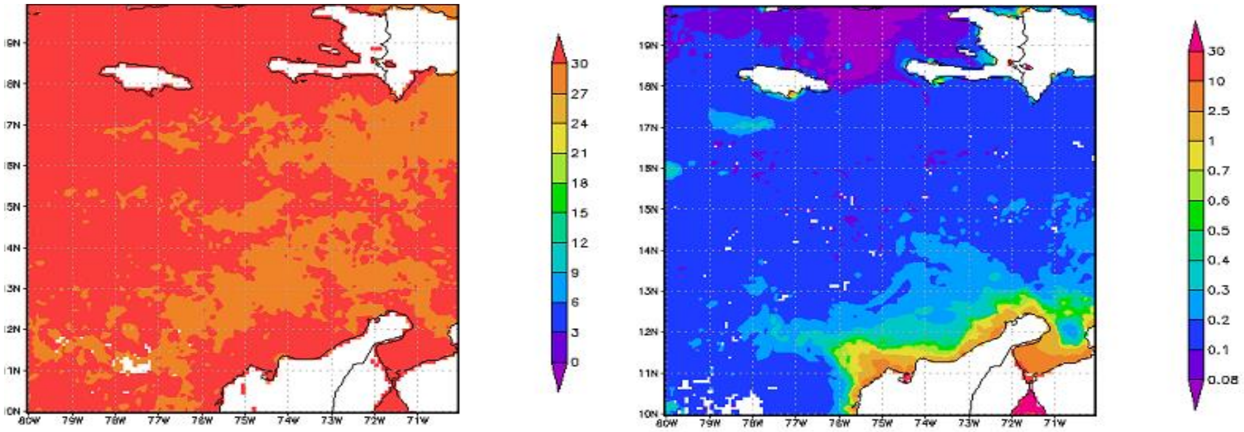

Figure 5: a) Sea Surface Temperature in the Caribbean Sea August 2009, b) Chlorophyll a in the Caribbean Sea August 2009.

3.1.3 Length Frequency

Length frequency data from commercial catches were acquired from the data unit of the Fisheries Division- Ministry of Agriculture and Fisheries of Jamaica. The data set contains information for the period 2005-2012 on date of collection, sex and maturity, tail and carapace lengths in millimetre (mm). The dataset was seen to be incomplete with missing values for both tail and carapace lengths. A conversion factor (c.f.) of 0.565 developed for Jamaica (CRFM, 2009) was used to fill in the missing values.
Maturity stages of female lobsters within this section were defined as follows:

- S = spent (eggs have been released)
- T = tarspot (female with spermatophoric mass on stomach)
- E = female with brown eggs (old)
- D = female with orange eggs (freshly secreted)
- TE = Tarspot with brown eggs
- TD = Tarspot with orange eggs

The ratio of carapace lengths (CL) ≤76mm was calculated for each month within each year for the period.

3.2 Analysis

3.2.1 Pueruli Settlement compared to Environmental Parameters and Collector Sites

Pearson's product moment correlation coefficient test (Crawley, 2007) done in R (R, 2013) was used to estimate the association between the study sites of, Bowden Bay and Coquar Bay as well as with the 2 study sites compared to the means of temperature and chlorophyll a. Time steps/lags were also done to compare three (3) months prior and after to ascertain if a relationship existed between environmental parameters and settlement index of both sites. The significance level of $p \leq 0.05$ was used.

GLMs were used to examine the effects of months and year on environmental parameters (SST and chlorophyll a), the settlement in Bowden Bay and Coquar Bay as well as the ratio of carapace lengths (CL) ≤ 76mm (Crawley, 2007). Gaussian distribution was used for each model. Data for all response variables except the ratio were log_{e} – transformed to stabilize the variance of the residuals. The final models were:

$$log_e(T + 1) = \mu + Yi + Mi \qquad (1)$$

$$log_e(Chl + 1) = \mu + Yi + Mi \qquad (2)$$

$$log_e(P_B + 1) = \mu + Yi + M_i \qquad (3)$$

$$log_e(P_C + 1) = \mu + Y_i + M_i \qquad (4)$$

$$(Pre / Adult) = \mu + Y_i + M_i \qquad (5)$$

Where *T* is the mean SST at the 2^0 bin 14^0 N - 80^0 W; μ is the mean response; Y_i the year effect; M_i the year effect; *Chl* the mean chlorophyll a at the 2^0 bin 14^0 N - 80^0 W; P_B the mean number of pueruli at Bowden Bay; P_C the mean number of pueruli at Coquar Bay; *Pre* the number of lobster with carapace lengths (CL) $\leq$76 mm; and *Adult* the number of lobster above 76 mm CL.

3.2.2 Yield per Recruit

The following von Bertalanffy male growth parameters developed for Cuba (Arce & de Leon, 1997) were used.

Where Linf =185; k =0.23; and t0 =0.44. Natural mortality of M=0.34 was also used with a length-weight relationship from Arce & de Leon (1997) defined as:

$$W = 0.00243 * CL^{2.764} \qquad (6)$$

where, W represents the weight of the lobster (g) and CL is the carapace length (mm).
The simple formula for the yield per recruit, is as follows:

$$Y = \Sigma F * N * W \qquad (7)$$

Where *Y* is yield; *F* the fishing mortality; and *W* the weight of individuals.

The Y/R was calculated on a monthly interval using a defined function within R (R, 2013) incorporating the von Bertalanffy growth parameters, fishing mortality (F) of 0 – 2, M and the length-weight relationship. Selection at age was done with an almost knife-edge selection, with 0.25, 0.5 and 0.75 selection in the months prior to the given age of certain carapace length (70, 76, 93, 103, 120 and 133 mm). Y/R was calculated for varying closed season scenarios using selection of 76 mm CL. Closed seasons were measure by 3 months steps for the entire year. The assumption for this calculation was that spawning occurred in January. The Y/R for the selection at age of the previously mentioned CL was also calculated.

3.2.4 Management Recommendations

A review of literature for the various management practices of leading spiny lobster countries was done. From these papers the best practices of the top spiny lobster countries (Cuba and Australia) were looked at in more detail, and as such, comparisons were made to see how best Jamaica could employ measures utilized by these countries.

4 RESULTS

4.1 Pueruli Settlement

Discovery Bay was not included in the analysis due to exceedingly low results i.e. only 5 months of recorded data (Table 2) reflected settlement over the 4yrs of monitoring.

Table 2: Puerulus settlement in Discovery Bay, northern Jamaica, over the period 2010-2013.

Year	Month	Puerulus	Pigmented Puerulus	Post Puerulus
2010	May			1
	November			28
2011	April			1
2012	May			1
2013	March			1

Bowden Bay showed variable settlement trends occurring over the years with 2012 having the largest settlement pulse and 2014 the lowest (partly due to an incomplete data collection period) (Figure 6). For Coquar Bay the highest settlement year was that of 2010 and the lowest in 2009. This low figure for 2009 is again due in part to the data collection process starting late within this year and not necessarily due to low settlement.

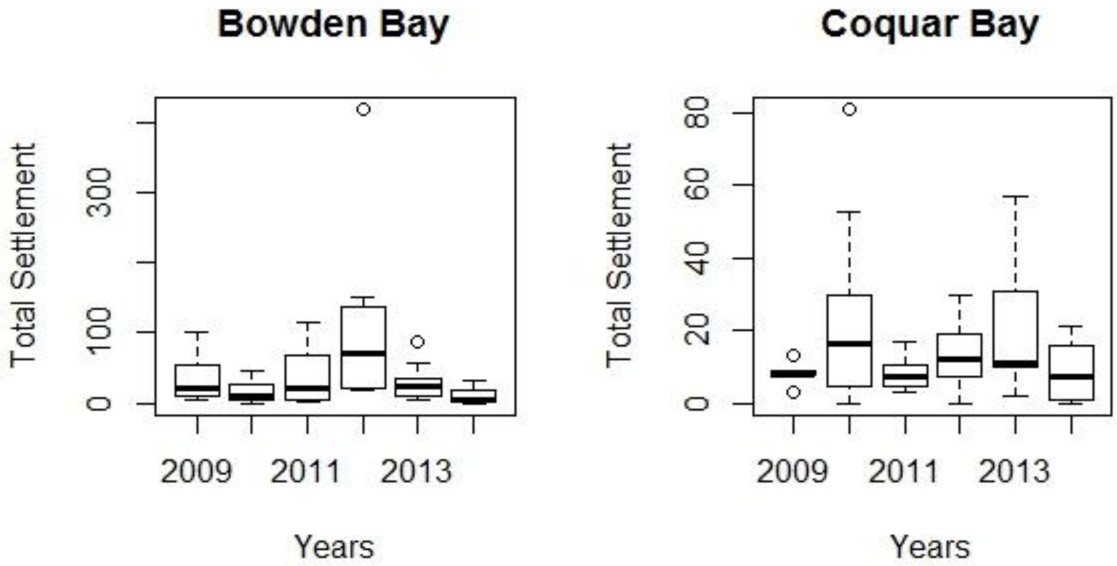

Figure 6: Bowden Bay and Coquar Bay annual pueruli settlement for the period 2009 – 2014.

4.2 Environmental Parameters

An annual variation in sea surface temperature in the regions south of Jamaica could be observed (Figure 7) throughout the time series (2008-2014). The lowest values between 26 - 27 ^{0}C were observed in January – March and the peak was observed in September at ~ 30 ^{0}C. There were also annual variations in chlorophyll a data (Figure 8) but not evident as demonstrated by temperature variations. The values ranged from as low as 0.03 – 0.08 mg/m^3 observed in May – June and peaks > 1.0 mg/m^3 in December – January.

The glm outputs for temperature, 2° bin of 14° N – 80° W, over months (Appendix 4) reflected April to September (Figure 9) showing a gradual increase after which there was a marked decrease from October to January of the following year. Over the seven (7) years (Appendix 4) where it started with two cooler years 2008-2009, followed by two warm years and a somewhat dramatic fall in 2012 and again the warmest year of 2013 and then the warm year of 2014 (Figure 9). In the glm model the effects of month and year were found to be significant (p<0.05).

Chlorophyll a glm outputs for the same area showed that for the factor month (Appendix 3) a decline from January to June (Figure 10) followed by a steady increase in the following months. Over the seven (7) years period (Appendix 3) chlorophyll a is seen to have its lowest year being 2009 followed by an increase to its highest year in 2011 but in subsequent years there was a general decrease (Figure 10). In the glm model the effects of month was found to be significant (p<0.05) however the effect of year was found to be marginally insignificant (p>0.05).
Temperature is negatively correlated (cor = - 0.57) to Chlorophyll a (Figure 11) this was observed for a time lag of 0 to -3.

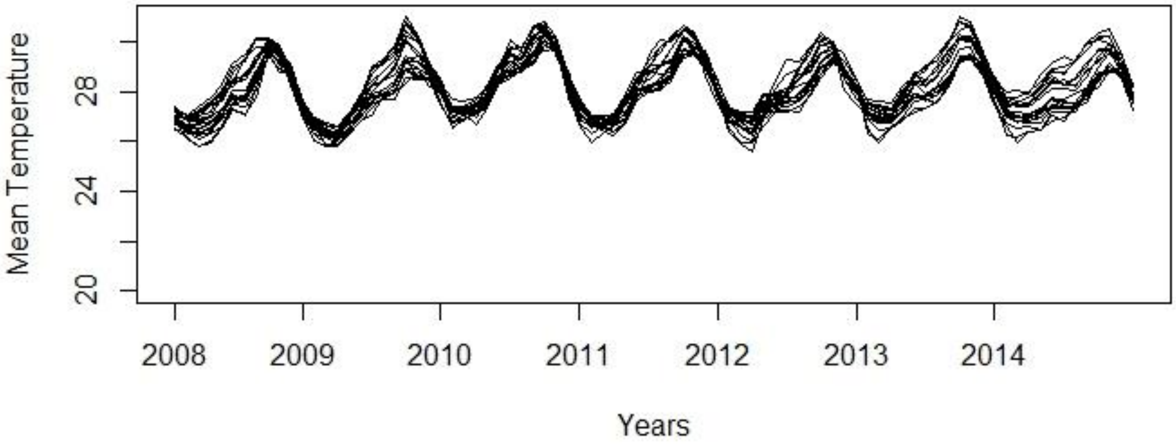

Figure 7: Estimated mean monthly sea surface temperature across all locations (2° bins) for the period 2008-2014.

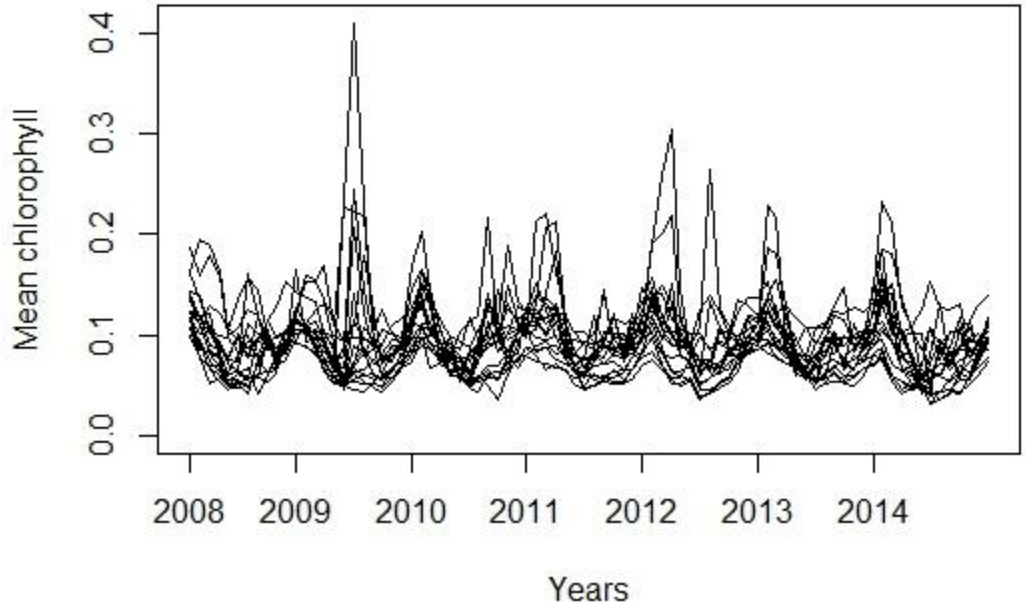

Figure 8: Estimated mean monthly chlorophyll a values across all locations (2° bins) for the period 2008-2014.

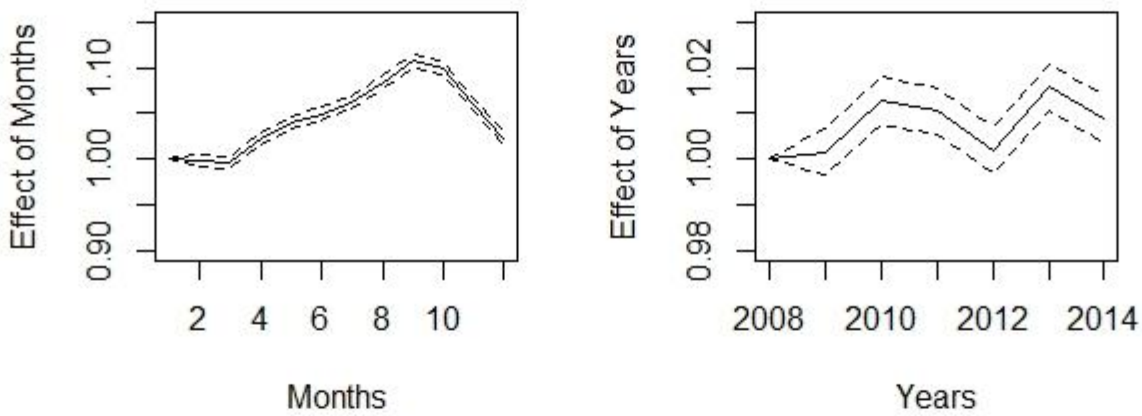

Figure 9: The effect of the factor month and year in a glm model on the mean SST at the 2° bin 14° N – 80° W.

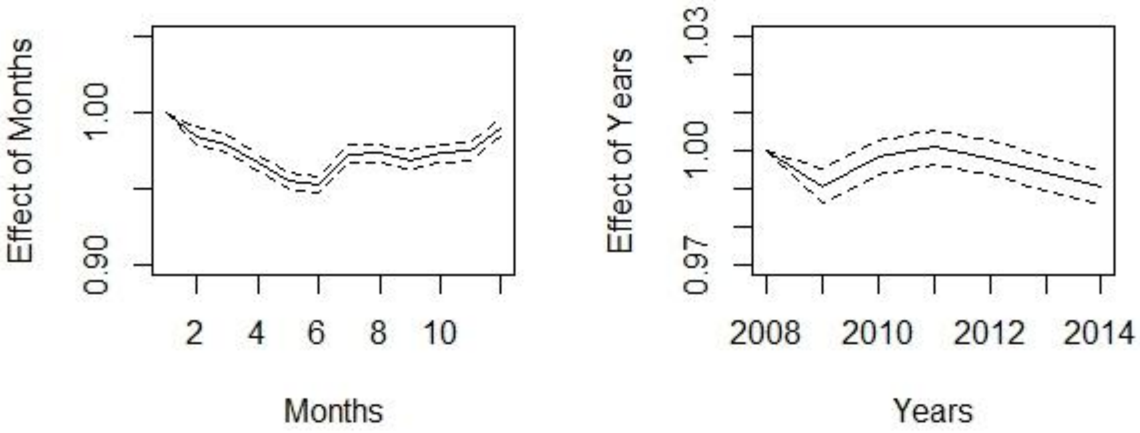

Figure 10: The effect of the factor month and year in a glm model on mean chlorophyll a values at the 2° bin 14° N – 80° W.

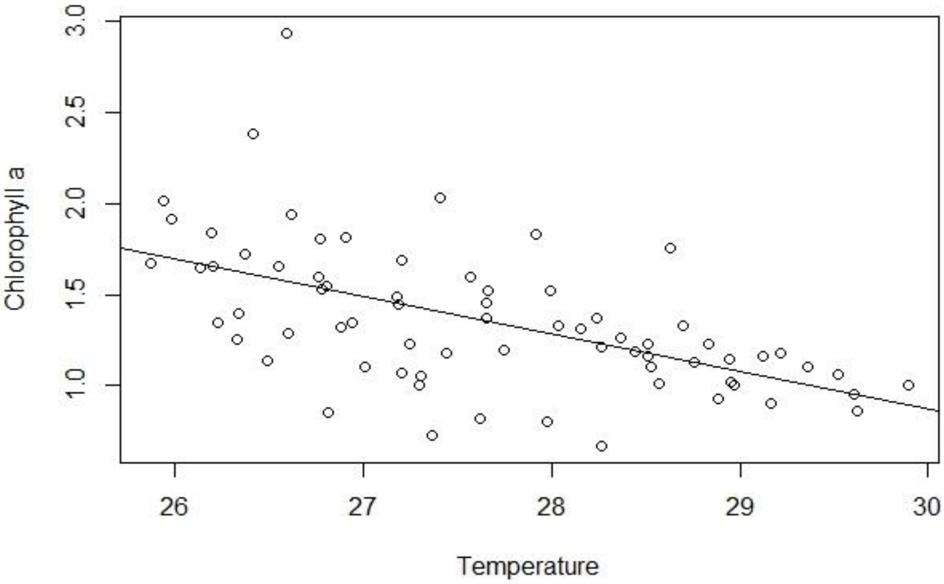

Figure 11: Chlorophyll a against SST 1 month later (time lag of -1) at the location 14° N – 80° W.

4.3 Correlations between pueruli settlement and environment and GLMs

4.3.1 Pueruli Settlement within sites

Pueruli settlement index for Bowden Bay (Figure 12), shows the output of a glm model of the effect of months (Appendix 1) on settlement within the six (6) years (2009-2014). It shows January as month 1 having the highest peak of settlement remaining high until April after which there was a steady decrease. Besides from the marginal increase observed from July to August, settlement does not start increasing significantly until October. It can be seen that settlement starts increasing in October to January of the following year after which there is a steady decline. Settlement over the years (Appendix 1) has been generally low with only 2012 showing a distinct spike in settlement (Figure 12). In the glm model the effects of month and year were found to be significant ($p<0.05$) at a degree of freedom (df) of 11 and 5, respectively.

Coquar Bay unlike Bowden, does not have a pronounced period of settlement over months (Appendix 2). Nevertheless, there was a steady increase in settlement from February to May (Figure 13); further peaks are seen in September and November. Yearly outputs of settlement (Appendix 2) were seen in 2011 whereas 2014 had the least amount of settlement over the six (6) years (Figure 13). The remaining years generally showed similar settlement. In the glm model the effects of month and year were found to be insignificant ($p>0.05$) at a degree of freedom (df) of 11 and 5, respectively. There was no correlation in settlement of pueruli between sites both with and without time lag (1-6 months).

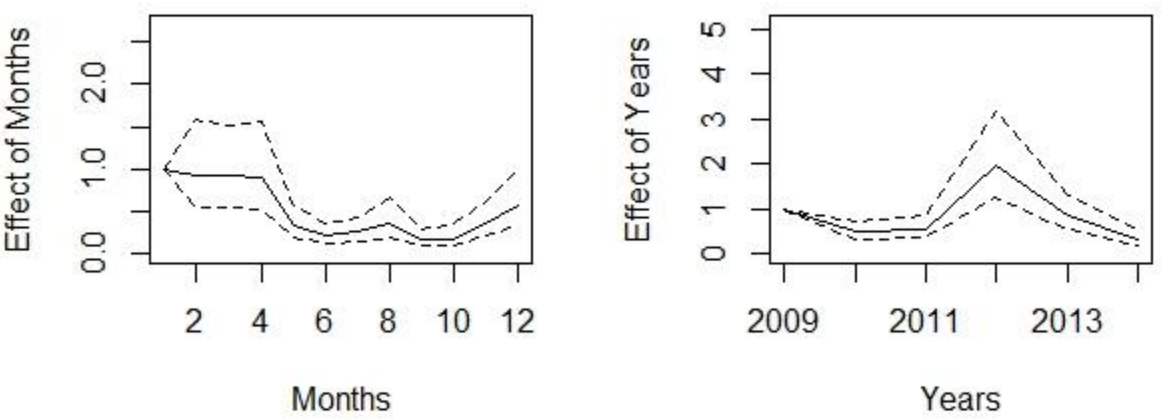

Figure 12: The effect of the factor month and year in a glm model on the settlement of pueruli in Bowden Bay.

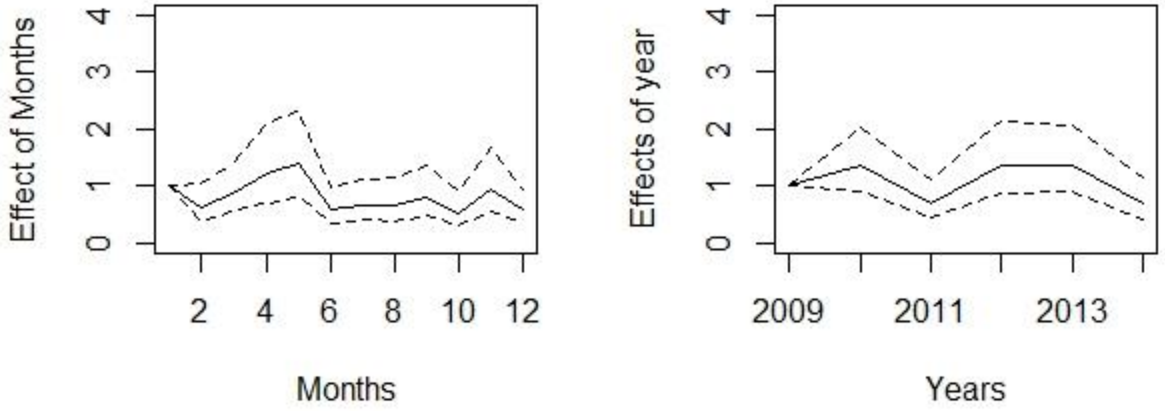

Figure 13: The effect of the factor month and year in a glm model on the settlement of pueruli in Coquar Bay.

4.3.2 Pueruli Settlement and Environmental Parameters

At Bowden Bay there was a significant relationship between settlement as well as both chlorophyll a and temperature (Figure 14). In that there was a seasonal and annual variation seen in the time series. It was observed that Chlorophyll a had a positive relationship at a time lag of -1 and 0 months (i.e. temperature has an effect on chlorophyll a 1 month prior and present) whereas temperature was seen to have a negative effect at time lag 0, 1 and 2 months later, i.e. current month and subsequent 2 months, (Appendix 5-6). Coquar Bay on the other hand demonstrates only a minimal relationship for chlorophyll a however no significant relationship was seen for temperature.

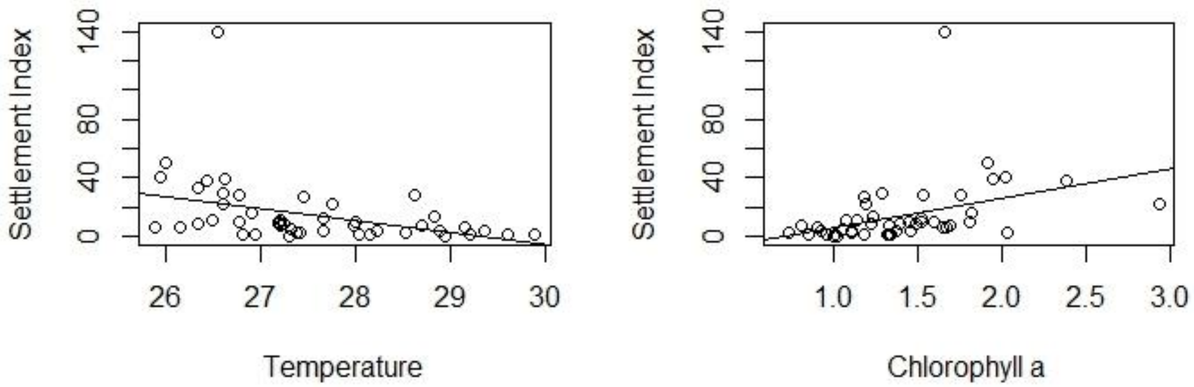

Figure 14: Correlation tests showing the relationship between temperature and chlorophyll a in Bowden Bay for the period 2009-2014.

4.4 Length Frequency of Lobster

The ratio of lobster of CL ≤76mm was generally high August with smaller peaks in December and February (Figure 15). The gap displayed between the months of April to June represent the lobster closed season where no lobster was caught during this period. There was a general decline in CL ≤76mm (Figure 16) over the years (2005-2012).

The ratio of spawning lobsters to total female lobsters was seen to be highest in July followed by September with the lowest ratios observed in December (Figure 17a). The highest ratio of tar spot lobster was seen in January (Figure 18b) however this is misleading as this month had a small sample size and so reflects higher ratios due to this. September and October both reflected the second highest ratios of tar spot lobsters with December having the lowest. Scratched lobsters were observed mostly in November followed by March and July with lowest levels seen in December. It should be noted that the levels of lobsters with eggs will not be a true representation of this stage as it is illegal to catch this stage. With that said the highest ratios were seen in December followed by August and the lowest ratios in March and November.

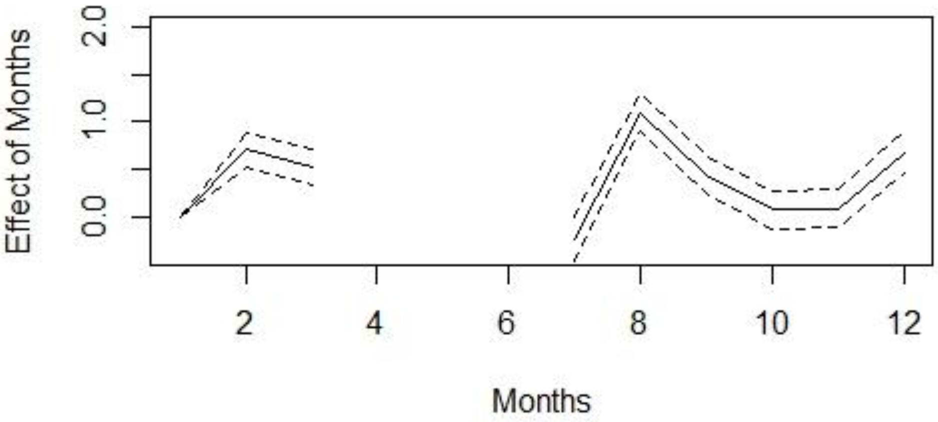

Figure 15: Carapace Lengths (CL ≤76mm) over all months for the period 2005 – 2012.

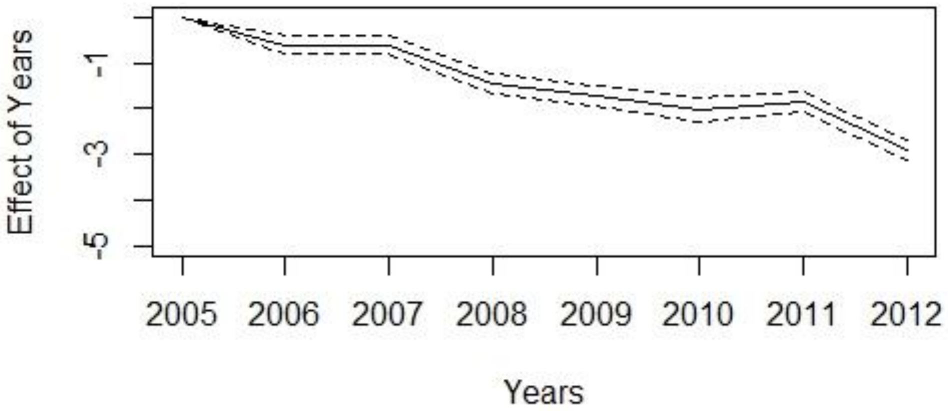

Figure 16: Carapace lengths (CL ≤76mm) over all years for period 2005-2011.

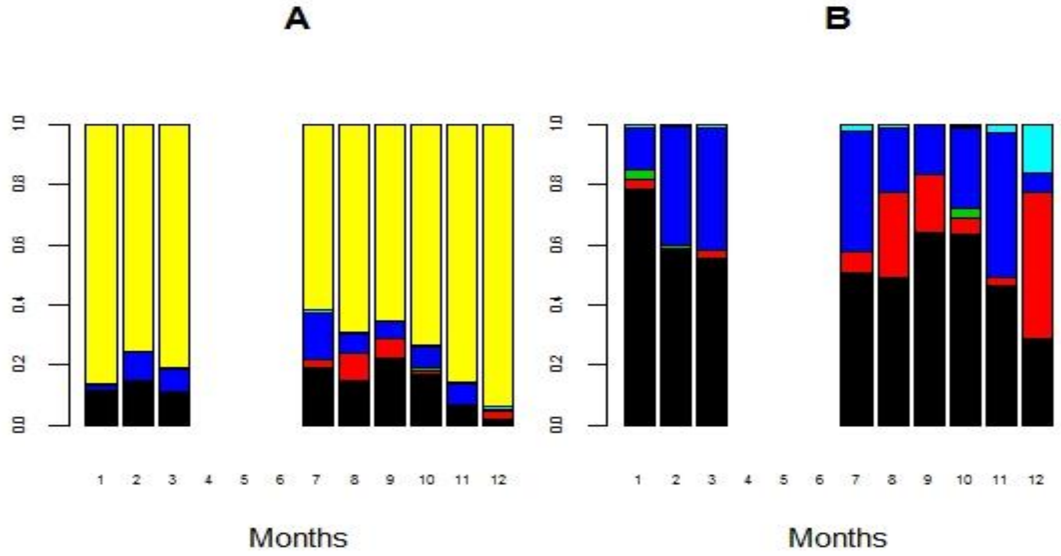

Figure 17: A – Ratio of female spawning stages to all females of the spiny lobster over months for the period 2005-2012. B – Ratio of spawning stages over months for the period 2005-2012. YELLOW= all females, BLACK=tar spot, RED=eggs (orange), GREEN=tar spot with eggs, BLUE=scratched, AQUA=eggs (brown), PINK=tar spot with eggs.

4.5 Yield per Recruit

The closed season that was seen to have the highest apparent yield (Table 3) was in August to October and the lowest in March to June, given that the lobsters are born in January and settle in August and further recruit to the fishery in September - October. The August to October closed season shows that a relatively high yield can be maintained even with increasing fishing effort (Figure 18). The minimum legal size (MLS) with the greatest yield was seen at CL of 120 mm (Figure 19) with a high fishing mortality (F) (Table 3). Though a CL of 120 mm yields the most, the F is too high thereby a more reasonable F seen at a CL of 93 mm would be the recommended MLS.

Table 3: Yields at different closed season periods and at varying minimum legal size.

Closed Season	**Yield (g)**	**MLS (mm)**	**F**	**Yield(g)**
Jan-Mar	203.4467	70	0.48	195.4439
Mar-Jun	202.9102	76	0.56	204.8305
Jun-Aug	206.1545	93	0.91	229.0669
Aug-Oct	**208.4303**	103	1.41	240.8367
Oct-Dec	206.4738	**120**	**2**	**248.4228**
Dec-Feb	204.3048	133	2	230.8346

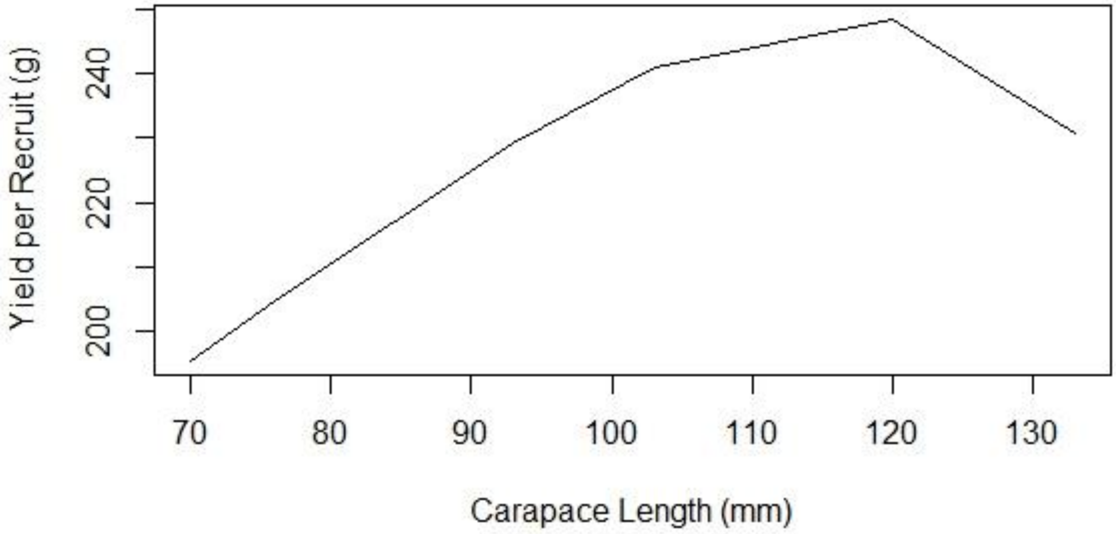

Figure 18: Maximum yield per recruit against minimum allowed landing sizes.

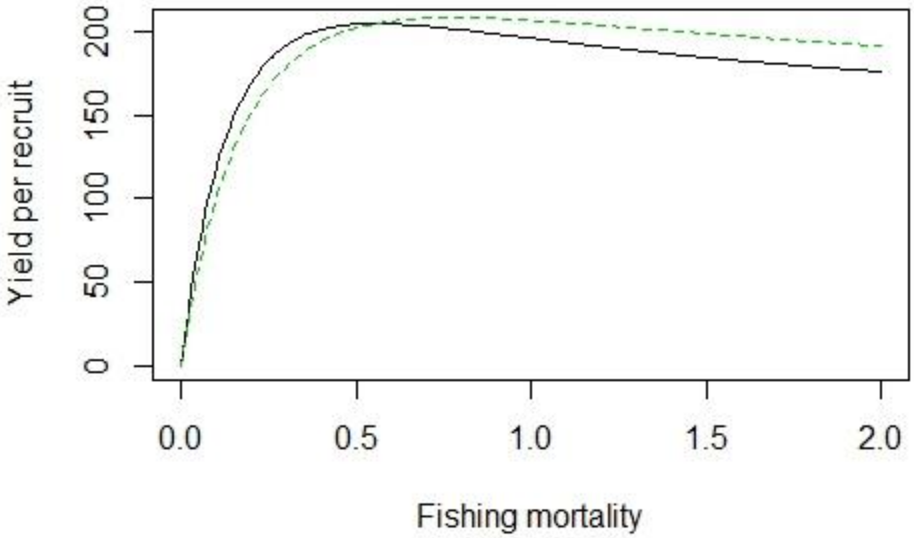

Figure 19: The yield per recruit against fishing mortality at CL of 76mm selection. Closed season in August to October is denoted by the broken line whereas the unbroken line is the effect without closure. Note for closed season F was not corrected (should be less on an annual basis).

4.6 Management Strategies

The management initiatives of 5 countries, including Jamaica, were examined and compared (Table 4). It was found that within the Caribbean region Cuba had the most comprehensive set of management strategies whilst outside of the region Australia had the best management initiatives. Cuba and Australia both practice fishing zone management where licensed fishers are only licensed to catch spiny lobster based on their designated zone. That is, once a fisher has been designated to a zone he is only allowed to fish within this zone for the fishing season. Jamaica on the other hand does not have a total allowable catch (TAC), maximum legal size (MaxLS) nor do they employ any gear restrictions within the artisanal sector, with exception only to the industrial sector. Bahamas is also in a similar position as Jamaica but differs only in that they do not have good monitoring practices of their stock. Antigua and Barbuda has made it illegal to catch spiny lobsters with intact tarspot as well as having a MLS of CL 90mm.

Table 4: Management strategies employed by countries in and outside the Caribbean region.

Strategies	**Bahamas**	**Jamaica**	**Australia**	**Cuba**	**Antigua and Barbuda**
Species	*Panulirus argus*	*Panulirus argus*	*Panulirus cygnus*	*Panulirus argus*	*Panulirus argus*
Close Season	✓	✓	✓	✓	✓
Protected Areas	✓	✓	✓	✓	✓
MLS	✓	✓	✓	✓	✓
MaxLS	x	x	✓	✓	x
TAC	x	x	✓	✓	x
Licenses	✓	✓	✓	✓	✓
Catch Restrictions	✓	✓	✓	✓	✓
Gear Restrictions	✓	✓	✓	✓	✓
Monitoring	x	✓	✓	✓	✓
Special Management Strategies	x	Limited Entry	ITQ Fishing zone management	Fishing zone management	no possession of lobster with intact tar spot
Source	Sealy, 2011	Fishing Industry Act 1975	Brown, 2011	Muñoz-Nuñez, 2009	Horsford, Simon, Archibald, Webber, & Joseph, 2013

5 DISCUSSION

5.1 Pueruli Settlement

5.1.1 Pueruli Settlement within sites

Bowden Bay and Coquar Bay both show variations in their settlement pulses, however only in Bowden Bay were there annual and seasonal variations of settlement, with peaks in the first 4 months of the year.

When compared to other settlement studies it was revealed that Bowden Bay does not reflect an exact match to any one country. However, similarities in aspects of some countries' pulses were seen as is the case with Bahamas and Florida (Table 1); even though Florida's settlement pulse starts in February and ends in May. The settlement peak seen in Cuba is around 3 months later in the year. The Jamaican studies (Meggs *et al.*, 2010 and Young, 1993) did not reflect the peak period seen in Bowden Bay even though both studies were conducted within the same bay area. Both studies time series were quite short in that they were both less than 2yrs, so this may account for any disparities observed. Other studies such as González & Wehrtmann (2011), done in Costa Rica, showed peaks in January and February however they could not explain this as the results were not in keeping with settlement peaks seen around the Caribbean. They did however try to relate such findings to oceanographic events, e.g. storms, occurring far offshore. Although Coquar Bay settlement was found to be statistically insignificant with no clear seasonality, the peaks exhibited were also close to Florida's.

5.1.2 Pueruli Settlement and Environmental Parameters

The positive relationship observed between settlement and chlorophyll a in Bowden Bay, may allude to the possibility that pueruli may be using the periods that produce the highest amounts of chlorophyll in previous months to settle. That is when there is an abundance of food – phytoplankton, for the zooplanktons that are fed on by the larval stage – phyllosomes, may be the causal agent which provides the energy necessary for the phyllosomes to metamorphose into the puerulus which could then settle (Briones-Fourzan *et al*., 2008).

González & Wehrtmann (2011) found that mean sea surface temperatures were not significantly different during their 12 months sampling period and between each of their stations, in Costa Rica. However, sea surface temperature for this study was seen to be negatively correlated to settlement at Bowden Bay. The difference may be due to the usage of only local SST readings for that study whereas this study utilised readings from areas south and to the east of mainland Jamaica (<520km to S and <920km to the E). This is because later phyllosome stages in most palinurid species are most commonly found inhabiting oceanic waters beyond the continental shelf, as much as 1500 km from the coast (Berry, 1974; Serfling & Ford, 1975; Phillips *et al.*, 1979; Booth *et al.*, 1998; in (Jeffs *et al*., 2005). The phyllosome stage of lobster is seen to grow better at lower sea surface temperature of 26^0C (Caputi *et al.*, 2014), which supports why pueruli settlement is seen to increase in "cooler" months for Bowden. Studies done in Australia have found that historically there has been a positive relationship between puerulus settlement and water temperature during the early larval stages, February to April (Caputi *et al*., 2001) although in recent years the relationship has deteriorated resulting in higher water temperature resulting in lower settlement (Caputi *et al.*, 2014). This decline in settlement has been further examined and it was found that SST is not the only factor affecting settlement as there was no increase in settlement when there was a decline in temperature (Caputi *et al.*, 2014). This may mean that even within the Jamaican context that though a negative relationship was seen to be present between SST and settlement it does not equate to it being a causative factor and so further analysis must be done on other parameters in order to ascertain causality.

Both sites in 2012 had their highest level of settlement with temperature of the same year showing its lowest levels over its 7 years' time series. It is unclear as to why this is the case but chlorophyll exhibits its highest concentration in the preceding year, 2011; when looked at more closely it was observed that the latter months of 2011 exhibited their highest chlorophyll concentration which was only a few months prior to settlement in 2012. This may then account for the high settlement levels in 2012.

5.2 Management

5.2.1 Yield per Recruit

Closed seasons are widely used in fisheries management as a control on effort. In short lived species such as prawns, the timing of seasonal closures can influence the mean size at capture and thus the yield of the stock (Somers & Wang, 1997). However, seasonal closures in longer lived species are generally more simplistic, where they serve as a constraint on effort, although there is often an attempt to link the closed period to an annual pattern of aggregation or reproduction (Gardner & Frusher, 2000). Most lobster fisheries incorporate seasonal closures of some kind (Phillips *et al.*, 1994) and these can be timed around the periods when females are carrying eggs, or when molting occurs. Countries with closed seasons such as Australia (females = 1 June – 15 November, males = 15 September to 15 November), Cuba (February – May), and Jamaica (April – June) have definitely put this measure into practice. However, whereas other countries such as Cuba and Australia have a sampling scheme within their closed seasons Jamaica does not. As it stands there is no data on the spiny lobster within the closed season within Jamaica. This is quite troublesome as a holistic management plan cannot be done due to this gap. As such a sampling scheme needs to be developed within this period so that data can be gathered to have a more complete understanding of the spawning stock.

Jamaica's current closed season appears to have a small effect on maximum yield though it encapsulates the time at which recruitment to the fishery (CL 76 mm) is to be happening. Jamaica was found to have a relatively high fishing effort (Martin-Murray, 2009) due to this it seems to make sense to have a closed season as this would help to reduce the fishing pressure placed on the lobster stock. At high fishing mortality a slightly higher yield is attained with closed season separate from the benefits of protecting the spawning stock mentioned above. The current MLS of CL 76 mm does not give as great a yield as a CL of 93 mm. Jamaica has the option for a potential range of MLS that would be geared at increasing yield that is from CL 76 mm -120 mm . However a MLS greater than 93 mm CL requires high levels of fishing mortality to attain maximum yield thereby it would be more feasible to set a MLS around 93 mm CL.

5.2.2 Length Frequency

The maturity stage of tar spot spiny lobsters is currently legal to catch within the Jamaican lobster fishery. This is a deleterious practice as the tar spot lobster indicates that mating has occurred and that the female is mature (developed ovaries). By making it illegal/prohibited to catch tar spot lobster the Jamaican lobster fishery would in effect be proactively protecting the ‘berried’ or egg lobsters thereby increasing the level of larval recruitment within the meta-lobster larval stock of the Caribbean. Since a female will release 600 - 1200 eggs per gram body weight (Munro, 1974) the logical conclusion may be that, the larger the female lobster the more eggs it will release. So millions of potential recruits are being lost due to the legality in catching tar spot lobsters and since the larval stock is considered a shared stock (Kough *et al.*, 2013), Jamaica is thereby limiting the recruiting potential of countries that benefit from its spawning stock.

Considering that Jamaica now has a 5 years’ time series on its pueruli settlement pattern aspects of lobster recruitment to the fishery can then be calculated and later tested. That is, since the highest settlement peak within the Bowden Bay study site was observed in January to April then certain assumptions can be made and then tested through further studies. Therefore a puerulus once settled, was spawned 7 months before and will take 10 months (age = 17 months) to enter the nursery area, then a further 8 months (age = 25 months) to recruit to the fishing zone and 8 more to recruit to the fishery at 76 mm CL (age = 33 months) (Arce & de Leon, 1997). Bearing these figures in mind it can then be said that a puerulus settling in January - April was spawned in June – September of the previous year, will then recruit to the nursery habitats in November - February 10 months later, then to the fishing zone in July – October, 8 months later and finally to the fishery March - June. It would appear that recruitment to the fishery may be taking place during the closed season based on this calculation. This requires further investigation to determine the accuracy of this information.

Lobsters with CL ≤ 76 mm was found to be most abundant in August. Considering the potential recruitment in July – October, as mentioned previously, it could be assumed that this may actually be a reflection of this calculation however data is missing to clarify this information. Additionally, recent trends in decreasing ration below CL of 76 mm could either be caused from less recruitment in recent years or that management efforts through enforcement or education could be working (illegal to catch lobsters with CL < 76 mm). However, it has been this researcher’s experience that fishers tend to hide the smaller sized lobsters that they have caught and only produce the legal sized lobsters to be measured on data collection trips. It is actions such as these which give rise to skewed results within the dataset which rely solely on fishery dependent information.

5.2.3 Management Initiatives

Australia and Cuba have been both toted as having the best managed lobster fisheries in the world (Department of Fisheries (2011) and Muñoz-Nuñez (2009), respectively) with Australia seen as the most sustainable. Cuba has been reporting a general decreasing trend in recruitment, which can be related to a decrease in spawning stock biomass (Fadragas, 2005). As such it can be concluded that even with the best management strategies, a sustainable harvest strategy does not guarantee that a managed stock will always be at its highest possible yield. Australia on the other hand found that their pueruli settlement was seen to have been decreasing since 2006 - 2012 and as a result measures such as increasing egg production through a reduction in the harvest rate of lobsters and protection of lobsters located in sensitive spawning areas through closed seasons as well as a reduction in maximum female sizes were employed (Caputi *et al*., 2014). All these practises have helped to limit the impact on the stock.

Jamaica has strategies in place to protect the spawning stock, juvenile lobsters as well as measures geared at controlling effort, at least at the industrial level through a limited entry system. However, there are no harvest controls or studies geared at shoring up the current management strategies. Overall Jamaica's management strategies are not in a dire state. Nonetheless strategies such as fishing zone management, prohibition of catching tar spot lobsters, and holistic sampling schemes within fishing grounds, landing sites, closed season and closed areas can be employed. These strategies are possible to achieve although they require strong political will and decisive action on the part of the regulatory agency to effect a more efficient lobster fishery. If these strategies are to be employed, then a rights based fisheries management regime as proposed by Morris (2010) may in fact be the way to address the short falls in the lobster fishery in order to make it a more efficient one.

6 CONCLUSIONS AND RECOMMENDATIONS

Jamaica through Bowden has a clear settlement peak in January until April with a smaller peak observed in August. From this a potential recruitment peak is seen in March to June. The current closed season needs to be investigated in order to fill the gap left in the data set. Higher yield would be maintained by increasing the current minimum legal size.
The recommendations are then:

- A continuation of the pueruli monitoring program so that future analysis can be done to relate settlement to recruitment
- Establishment of additional monitoring sites around Jamaica. Coquar Bay did not show a clear pattern of settlement and so did not provide a good comparative analysis between sites.
- Conduct a fishery independent survey at least 3-4 times annually with special emphasis placed on monitoring within the closed season.
- Prohibit the catching of tar spot lobster to increase fecundity of the stock.
- Increase minimum legal size of spiny lobster to around CL 93mm.

ACKNOWLEDGEMENTS

I would like to extend my gratitude to the staff of the UNU-FTP: Dr. Tumi Tómasson, Þór Ásgeirsson, Mary Frances Davidson and Sigríður Ingvarsdóttir. The opportunity that you have afforded me has been a truly edifying experience and for that I am immensely grateful.

I would also like to thank my supervisor Dr. Jónas P. Jónasson for his time, effort and expertise that he most generously gave throughout the duration of my project. I salute you sir.

Finally, I would like to thank my family: my husband, David Panton, and my son, D. P. Panton, for their never ending support and encouragement; my sister, Krystal Cooke, whose eye for details was always an asset to the completion of this project; and to my fellow-mates who were my family away from family.

Thank you all so much for everything.

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APPENDIX

Appendix 1: Glm results for years and months in Bowden Bay for the period 2009-2014.

Coefficients	Estimate	Std.Error	t value	Pr (> |t|)	Significance (p<0.05)
Intercept	3.259	0.4683	6.959	0	*
factor(year)2010	-0.7364	0.4303	-1.7112	0.0974	
factor(year)2011	-0.5917	0.4456	-1.3279	0.1942	
factor(year)2012	0.6836	0.4731	1.445	0.1588	
factor(year)2013	-0.163	0.4367	-0.3733	0.7115	
factor(year)2014	-1.2113	0.5822	-2.0804	0.0461	*
factor(month)2	-0.0871	0.5425	-0.1605	0.8736	
factor(month)3	-0.0879	0.5065	-0.1736	0.8633	
factor(month)4	-0.1167	0.5578	-0.2092	0.8357	
factor(month)5	-1.1298	0.5582	-2.0241	0.0519	
factor(month)6	-1.5811	0.5582	-2.8325	0.0082	*
factor(month)7	-1.3661	0.5173	-2.6407	0.013	*
factor(month)8	-1.0141	0.5953	-1.7033	0.0988	
factor(month)9	-1.8579	0.5951	-3.122	0.004	*
factor(month)10	-1.7492	0.688	-2.5423	0.0164	*
factor(month)11	-1.0279	0.5414	-1.8985	0.0673	
factor(month)12	-0.5476	0.5414	-1.0114	0.3199	

Appendix 2: Glm results for years and months in Coquar Bay for the period 2009-2014.

Coefficients	Estimate	Std.Error	t value	Pr (> |t|)	Significance (p<0.05)
Intercept	1.5832	0.5197	3.046	0.0048	*
factor(year)2010	0.3055	0.4037	0.7568	0.4551	
factor(year)2011	-0.3466	0.4639	-0.7471	0.4608	
factor(year)2012	0.3186	0.4394	0.7251	0.474	
factor(year)2013	0.3129	0.4079	0.7671	0.449	
factor(year)2014	-0.3674	0.5027	-0.731	0.4705	
factor(month)2	-0.4537	0.5038	-0.9006	0.375	
factor(month)3	-0.1383	0.4718	-0.2932	0.7714	
factor(month)4	0.2073	0.5384	0.385	0.7029	
factor(month)5	0.3377	0.5015	0.6734	0.5058	
factor(month)6	-0.5211	0.5007	-1.0406	0.3064	
factor(month)7	-0.4022	0.5015	-0.8019	0.4289	
factor(month)8	-0.4031	0.562	-0.7172	0.4788	
factor(month)9	-0.2007	0.5196	-0.3862	0.7021	
factor(month)10	-0.6194	0.5196	-1.192	0.2426	
factor(month)11	-0.0474	0.562	-0.0843	0.9334	
factor(month)12	-0.525	0.4846	-1.0833	0.2873	

Appendix 3: Chlorophyll a Glm results for years and months for the period 2009-2014.

Coefficients	Estimate	Std.Error	t value	Pr (> |t|)	Significance (p<0.05)
Intercept	0.1118	0.0051	21.876	< 2e-16	*
factor(year)2010	-0.0094	0.0045	-2.0928	0.0402	*
factor(year)2011	-0.0018	0.0045	-0.4084	0.6843	
factor(year)2012	0.0009	0.0045	0.2016	0.8409	
factor(year)2013	-0.0021	0.0045	-0.4684	0.6411	
factor(year)2014	-0.006	0.0045	-1.3382	0.1854	
factor(month)2	-0.0157	0.0059	-2.6577	0.0099	*
factor(month)3	-0.021	0.0059	-3.5544	7.00E-04	*
factor(month)4	-0.0335	0.0059	-5.6816	0	*
factor(month)5	-0.0458	0.0059	-7.7561	0	*
factor(month)6	-0.0487	0.0059	-8.2593	0	*
factor(month)7	-0.0276	0.0059	-4.6794	0	*
factor(month)8	-0.0274	0.0059	-4.6391	0	*
factor(month)9	-0.0316	0.0059	-5.3617	0	*
factor(month)10	-0.027	0.0059	-4.584	0	*
factor(month)11	-0.0258	0.0059	-4.3664	0	*
factor(month)12	-0.0104	0.0059	-1.7627	0.0826	

Appendix 4: Temperature Glm results for years and months for the period 2009-2014.

Coefficients	Estimate	Std.Error	t value	Pr (> |t|)	Significance (p<0.05)
Intercept	3.3283	0.0058	578.648	< 2e-16	*
factor(year)2010	0.0017	0.0051	0.3267	0.7449	*
factor(year)2011	0.0127	0.0051	2.4969	0.015	*
factor(year)2012	0.0104	0.0051	2.0456	0.0448	
factor(year)2013	0.002	0.0051	0.389	0.6986	*
factor(year)2014	0.0156	0.0051	3.0726	0.0031	
factor(month)2	0.0089	0.0051	1.7555	0.0838	
factor(month)3	-0.0037	0.0066	-0.5563	0.5799	
factor(month)4	0.0226	0.0066	3.4008	0.0011	*
factor(month)5	0.0395	0.0066	5.9513	0	*
factor(month)6	0.0484	0.0066	7.2873	0	*
factor(month)7	0.0606	0.0066	9.1216	0	*
factor(month)8	0.0811	0.0066	12.2132	0	*
factor(month)9	0.102	0.0066	15.3547	0	*
factor(month)10	0.0947	0.0066	14.2624	0	*
factor(month)11	0.0578	0.0066	8.699	0	*
factor(month)12	0.0232	0.0066	3.4872	9.00E-04	*

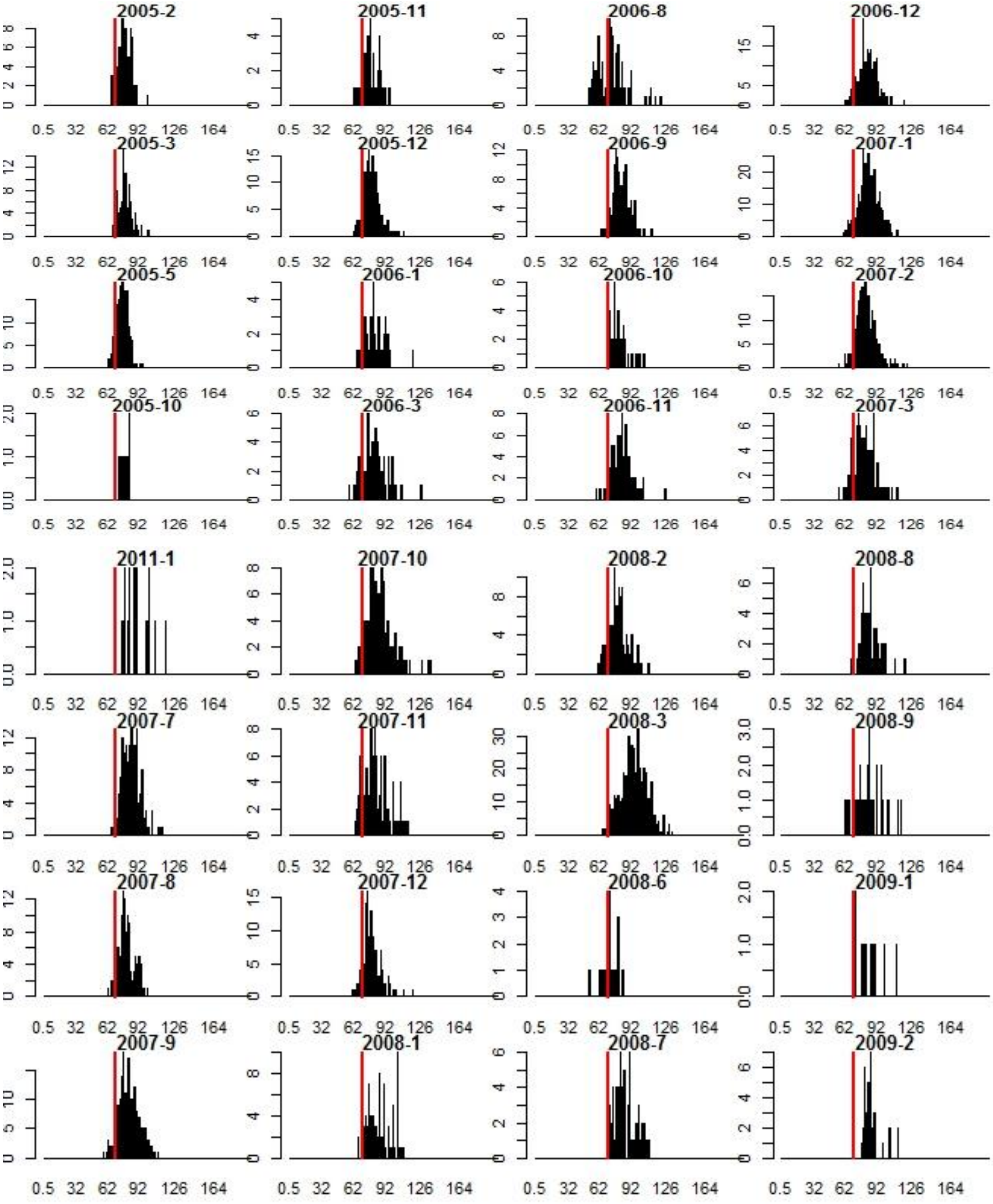
Appendix 5: showing correlation tests done for collections sites, Bowden Bay and Coquar Bay compared to chlorophyll a for time steps of 3 months prior and 3 months later. Highlighted values are significant (P<0.05).

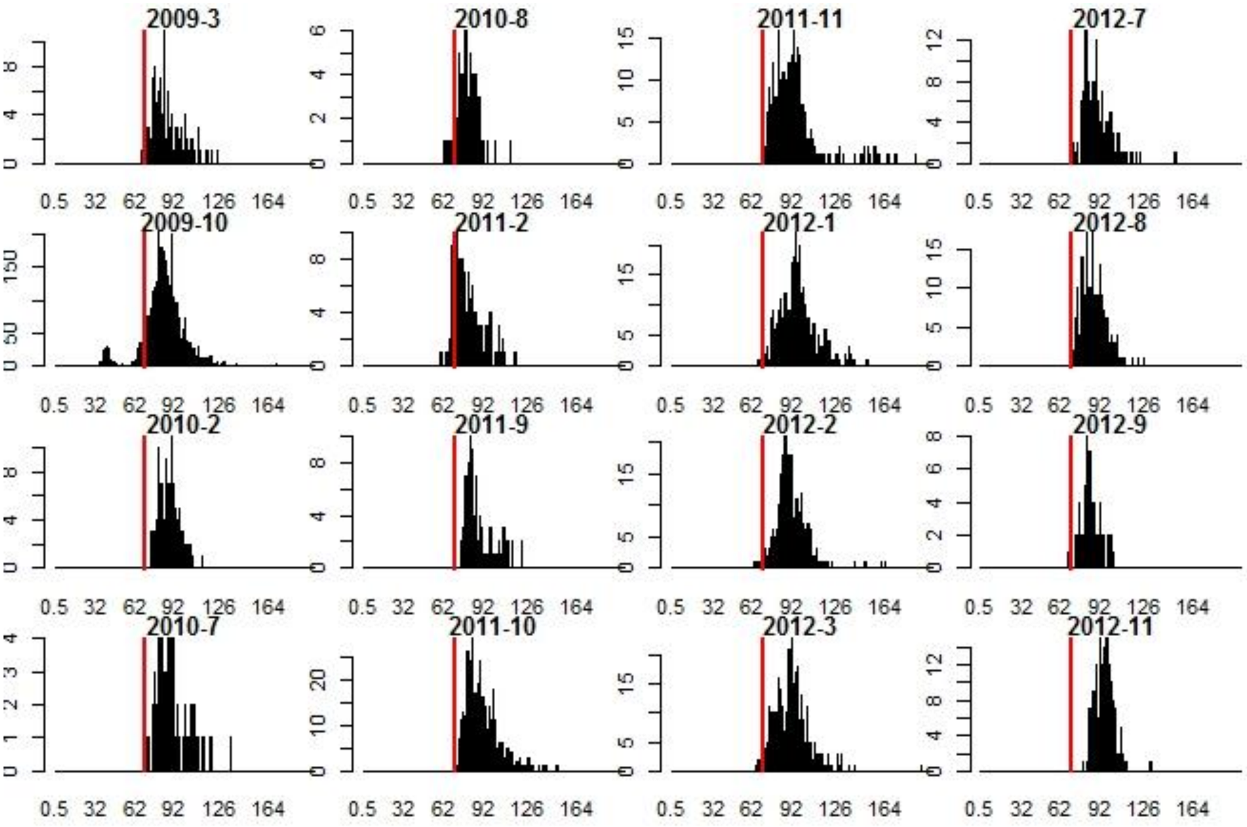
	Bowden							Coquar Bay						
Location	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
14-72	-0.15	0.12	0.25	0.34	0.37	0.35	-0.02	0.08	0.09	-0.12	0.00	-0.08	0.09	0.09
14-74	-0.20	0.07	0.34	0.54	0.39	0.27	-0.05	0.11	0.00	-0.07	-0.07	-0.06	0.01	0.06
14-76	-0.08	0.15	0.49	0.33	0.24	0.09	-0.13	0.07	-0.01	-0.01	-0.13	0.03	-0.09	0.09
14-78	0.16	0.19	0.33	0.52	0.21	-0.01	-0.27	0.12	0.06	-0.02	-0.17	-0.10	-0.02	-0.10
14-80	0.28	0.23	0.30	0.46	0.22	-0.03	-0.14	0.13	0.10	0.01	-0.08	-0.09	-0.10	-0.16
16-72	0.00	0.14	0.11	0.25	0.16	-0.11	-0.08	-0.04	-0.07	-0.10	-0.13	-0.08	0.05	0.08
16-74	-0.06	0.12	0.24	0.31	0.14	0.18	-0.19	0.07	-0.08	-0.01	0.12	-0.05	-0.04	0.11
16-76	-0.04	0.12	0.34	0.35	0.15	0.13	-0.19	0.04	-0.01	0.13	0.09	-0.05	-0.17	0.05
16-78	0.06	0.15	0.43	0.42	0.19	0.03	-0.14	-0.02	0.02	0.11	0.08	-0.10	-0.11	-0.08
16-80	0.13	0.34	0.45	0.52	0.16	-0.03	-0.21	-0.01	-0.05	0.08	0.03	-0.18	-0.16	-0.16
18-70	-0.11	0.04	0.04	0.03	-0.10	-0.17	-0.18	-0.12	-0.20	-0.07	-0.12	-0.10	0.04	-0.03
18-72	0.09	0.32	0.32	0.27	0.10	0.04	-0.09	0.00	-0.16	-0.07	-0.02	-0.05	-0.11	-0.15
18-74	0.19	0.18	0.27	0.31	0.06	-0.11	-0.20	0.07	-0.17	-0.06	0.06	-0.11	-0.12	0.06
18-76	0.06	0.17	0.34	0.37	0.08	-0.06	-0.18	0.08	0.03	0.05	0.06	-0.03	-0.05	0.01
18-78	0.12	0.11	0.23	0.30	0.04	-0.16	-0.25	0.05	-0.05	0.05	0.11	-0.05	0.04	-0.10
18-80	0.11	0.27	0.34	0.49	0.22	-0.08	-0.25	0.05	0.02	0.05	0.15	-0.03	0.03	-0.15
20-74	0.14	0.15	0.22	0.24	0.09	-0.15	-0.18	-0.06	-0.13	-0.06	0.08	-0.13	-0.06	-0.08
20-76	0.06	0.11	0.19	0.22	0.06	-0.14	-0.29	0.08	-0.04	0.04	0.08	0.00	0.01	0.01
20-78	0.06	0.19	0.33	0.37	0.20	-0.08	-0.27	0.18	0.05	0.01	0.12	-0.05	-0.10	-0.11
20-80	0.13	0.20	0.34	0.40	0.18	-0.13	-0.29	0.12	0.10	0.05	0.13	-0.02	0.06	-0.06

Appendix 6: showing correlation tests done for collections sites, Bowden Bay and Coquar Bay compared to temperature for time steps of 3 months prior and 3 months later. Highlighted values are significant (P<0.05).

	Bowden							**Coquar Bay**						
Location	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**
14-72	0.27	0.05	-0.18	-0.39	-0.45	-0.39	-0.26	-0.06	-0.01	0.00	0.02	0.05	0.00	0.00
14-74	0.26	0.04	-0.21	-0.42	-0.46	-0.40	-0.22	-0.09	-0.02	0.03	0.01	0.05	0.04	0.00
14-76	0.24	0.05	-0.19	-0.37	-0.42	-0.36	-0.22	-0.09	-0.02	0.05	0.02	0.06	0.03	0.00
14-78	0.21	0.03	-0.19	-0.37	-0.41	-0.37	-0.21	-0.09	-0.01	0.06	0.03	0.09	0.04	0.02
14-80	0.20	0.00	-0.21	-0.36	-0.40	-0.37	-0.20	-0.06	-0.06	0.08	0.06	0.11	0.04	0.06
16-72	0.25	0.02	-0.22	-0.41	-0.42	-0.37	-0.25	-0.05	0.00	0.05	0.04	0.10	0.06	0.01
16-74	0.24	0.03	-0.21	-0.39	-0.42	-0.37	-0.23	-0.07	-0.03	0.02	0.04	0.10	0.04	0.01
16-76	0.23	0.02	-0.20	-0.36	-0.39	-0.36	-0.22	-0.05	-0.03	0.02	0.00	0.09	0.08	0.01
16-78	0.22	0.03	-0.21	-0.37	-0.38	-0.34	-0.20	0.00	-0.01	0.03	0.04	0.09	0.06	0.04
16-80	0.23	0.00	-0.22	-0.36	-0.36	-0.33	-0.17	0.01	-0.03	0.05	0.04	0.10	0.01	0.07
18-70	0.17	-0.03	-0.25	-0.43	-0.43	-0.35	-0.20	0.00	0.05	0.04	0.05	0.08	0.04	0.00
18-72	0.18	0.00	-0.24	-0.43	-0.41	-0.33	-0.22	-0.03	0.02	0.02	0.04	0.05	0.02	0.00
18-74	0.17	0.00	-0.25	-0.41	-0.41	-0.33	-0.23	-0.01	-0.01	-0.01	0.02	0.05	0.02	0.04
18-76	0.16	-0.03	-0.27	-0.41	-0.40	-0.32	-0.22	0.02	-0.01	0.00	0.01	0.06	0.02	0.01
18-78	0.16	-0.06	-0.28	-0.38	-0.35	-0.29	-0.19	0.03	-0.01	0.01	0.02	0.05	-0.03	0.03
18-80	0.16	-0.08	-0.30	-0.37	-0.35	-0.30	-0.18	0.05	-0.02	0.01	-0.01	0.06	-0.05	0.03
20-74	0.08	-0.11	-0.32	-0.41	-0.40	-0.30	-0.18	0.01	-0.05	0.00	0.00	0.04	-0.01	0.01
20-76	0.08	-0.10	-0.33	-0.43	-0.38	-0.30	-0.20	0.02	-0.03	0.01	0.01	0.03	-0.02	0.01
20-78	0.11	-0.11	-0.29	-0.39	-0.36	-0.29	-0.18	0.02	-0.04	0.00	-0.02	0.03	-0.04	0.01
20-80	0.11	-0.16	-0.31	-0.38	-0.35	-0.29	-0.18	0.04	-0.06	-0.02	-0.04	0.02	-0.07	0.02

Appendix 7: Length frequencies for all months for the period 2005-2011, CL of ≤76mm is denoted with a red line.

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