REPORT NO. 2519

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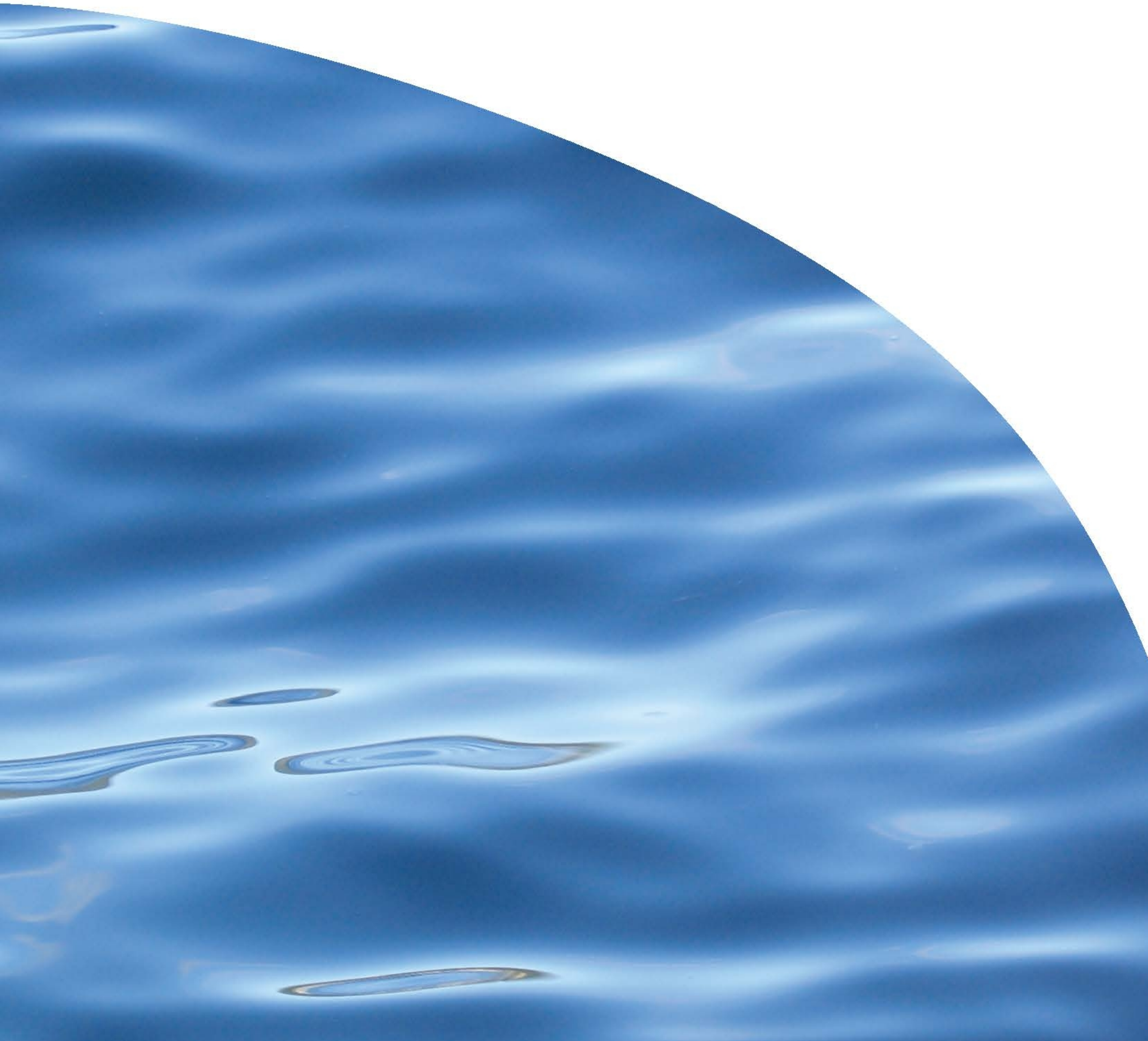

REVIEW OF GREENSHELL MUSSEL (GSM), *PERNA CANALICULUS,* SPAT-FALLS IN THE BAY OF PLENTY REGION

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EXECUTIVE SUMMARY

This report provides a desktop review of existing information on spat-fall occurrences and the likely factors leading to Greenshell Mussel (GSM) spat-fall in the Bay of Plenty. Due to a paucity of hard data on the occurrence of GSM spat in the Bay of Plenty, the focus was placed on oceanographic variables, including water currents, water temperature and chlorophyll-a, as indicators of potential sites of increased spat concentration. Higher concentrations of GSM spat are often associated with large scale oceanographic eddies that form behind land masses, and in areas of higher food concentration.

Using oceanographic and environmental variables, three sites were identified as possible spat catching sites for further investigation (Figure 1). These sites include: a site inshore of Mayor Island, an offshore site between Whakatane and Te Puke, and the corners of the existing Opotiki Offshore Marine Farm site. Further in-situ research on spat fall concentrations is recommended in the Bay to establish the distribution and seasonality of GSM spat fall.

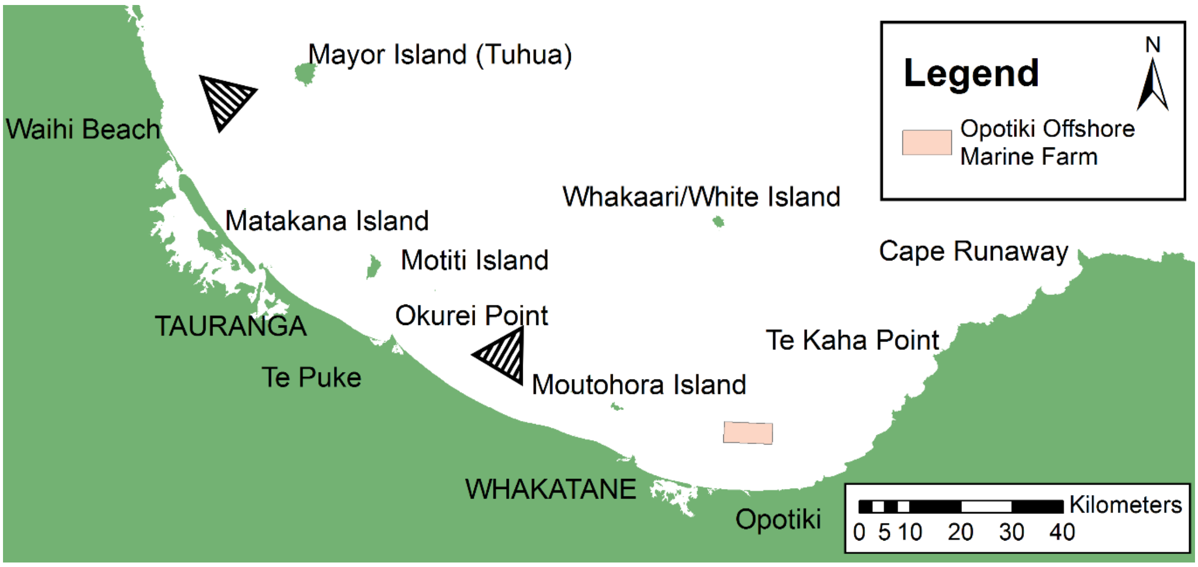

Figure 1. Suggested areas for investigating green shell mussel spat-fall (shaded triangles and the corners of the Opotiki Offshore Marine Farm) within the Bay of Plenty.

TABLE OF CONTENTS

LIST OF FIGURES

1. INTRODUCTION

Cawthron was asked to provide a desktop review of existing information to:

1. Identify knowledge of Greenshell Mussel (GSM) spat-fall occurrences in the Bay of Plenty
2. Using oceanographic variables identify potential areas of higher GSM spat concentration in the Bay of Plenty.

When requesting information or asking residents of the Bay of Plenty if they had noted spat fall, the answer was invariably 'no'. Locals indicated where the adult mussels are, or were, but spat settlement was not something that the local populace had noticed. In addition, most environmental studies in the region have concentrated on general marine ecology and not mussel spat. Other than at existing aquaculture sites, there has been little or no data of GSM spat-fall in the region.

Due to the paucity of information on historic spat-fall in the Bay of Plenty region, this report uses information on mussel larval behaviour, data from known spat-falls on existing mussel farms, and available environmental information to identify possible periods and areas of GSM spat fall. It is stressed, however, that further in-situ research on GMS spat-fall and on-going environmental monitoring will be required to increase the certainty and reliability of these predictions.

2. SPAT SETTLEMENT

2.1. Mussel larvae

The behaviours of GSM larvae in the water column are complex, due in part to a long larval duration of up to six weeks, and the potential for swimming behaviour to influence their distribution as they grow. In their early stages mussel larvae are assumed to be essentially pelagic particles, with their distribution within the water column dictated by the water currents around them (McQuaid & Phillips 2000). As larvae develop, their ability to control their direction increases and it is assumed that larvae undertake vertical migration in response to various cues such as food availability (Bayne 1976), tides (Garland & Zimmer 2002; Shanks & Brink 2005; Knights *et al.* 2006) and environmentally driven behaviours (Garland & Zimmer 2002; Shanks & Brink 2005). A study of *Mytilus galloprovincialis* spat in South Africa, however, found no evidence of vertical migration, and settlement of larvae was successfully predicted using wind and surface current data alone (McQuaid & Phillips 2000).

The arrival of GSM larvae to the shore as pediveligers (late stage larvae) and early stage spat is further complicated by mucus drifting (Lane *et al.* 1985), and secondary settlement on seaweed (Alfaro & Jeffs 2002). Through these passive transport mechanisms, their distribution is also controlled by water currents. Furthermore, because the period of time from spawning through the larval to early spat stages and settlement can be as long as six weeks (Jenkins 1979), the distances travelled by spat can be considerable.

Concentrations of mussel spat are, therefore, influenced by food availability (Gardner 2000), water currents, and upwelling/downwelling events (McQuaid & Phillips 2000), temperature (Flaws 1975), and salinity (Hickman 1991), and these variables are in turn influenced by season, tides and geography.

2.2. Mussel spat settlement

The factors affecting the settlement of GSM spat[1] are better understood than the distributions of mussel larvae in the wild. Settlement of GSM spat can occur from the surface to 30m depth (K. Heasman pers. obs.), but does not preferentially settle near the surface or deeper in the water column (Meredyth-Young & Jenkins 1978; Alfaro & Jeffs 2003). GMS spat settlement is influenced by water current speed (Hayden & Woods 2011), tides (Knights *et al.* 2006), chemical cues (Alfaro *et al.* 2006; Gribben *et al.* 2011), rope types (Karayucel *et al.* 2002; Sharma 2003; Filgueira *et al.* 2007; Karayucel *et al.* 2009; Gribben *et al.* 2011), and food concentrations (Gardner 2000; Helson & Gardner 2007).

Based on the information gained during the Cawthron Open Ocean Aquaculture (OOA) research program from 2006 to 2008, the peak period for GSM spat settlement at Opotiki was found to be from September to February (K.Heasman pers. Obs.). Some GSM spat were seen in July and August in 2007, but in low abundance. At the Opotiki site, GMS spat settled on mooring lines that extended from the surface to the seabed at 28m depth.

The factors responsible for the retention of mussel spat post-settlement were considered outside the scope of this document and are not discussed.

[1] In this document, mussel spat refers to mussel juveniles ranging in size from 350µm (i.e. immediately post settlement) to 4mm.

3. POTENTIAL INFLUENCES OF SPAT DISTRIBUTION

A review of the potential environmental influences on spat distribution has not previously been undertaken in the Bay of Plenty region. This desktop assessment provides information that may be useful for determining potential GSM spat transport routes during the larval pelagic period and possible sites of spat concentration.

3.1. Water currents

Water currents are likely to distribute mussel larvae across the Bay of Plenty and the prevailing currents have been the subject of studies by various organisations including Environment Bay of Plenty, Cawthron Institute, Waikato University and NIWA. A comprehensive study by Longdill (2008) used physical measurements and numerical modelling approaches to gain an understanding of the water currents in the Bay of Plenty region. A consistent theme from Longdill (2008), and other published research, was that the water currents in the Bay are influenced by a number of local (i.e. wind, tide and river influences) and regional forcing factors (i.e. shelf currents).

3.1.1. Regional currents

At the wider scale of the Bay, regional forcing creates water currents due to interactions between the East Auckland Current (EAUC) and the resulting East Cape Eddy (ECE) (Figure 1). Longdill (2008) noted that several studies have detected weak south easterly flows with surface currents of about 14 cm/s in outer oceanic areas of the Bay of Plenty (Ridgway N. & M. 1986; Stanton B.R. *et al.* 1997; Tilburg C.E. *et al.* 2001). There does, however, appear to be a separation between coastal shelf water and oceanic waters off the Bay of Plenty. This delineation of shelf and oceanic water has been observed in other studies (Gibbs & Knight 2001); (Park S 1998; Park & Longdill 2006), but occasional intrusions of oceanic waters onto the shelf were also observed. These occasional intrusions are likely to be related to wind-driven upwelled water such as that observed off-shore from Pukehina (Longdill 2008).

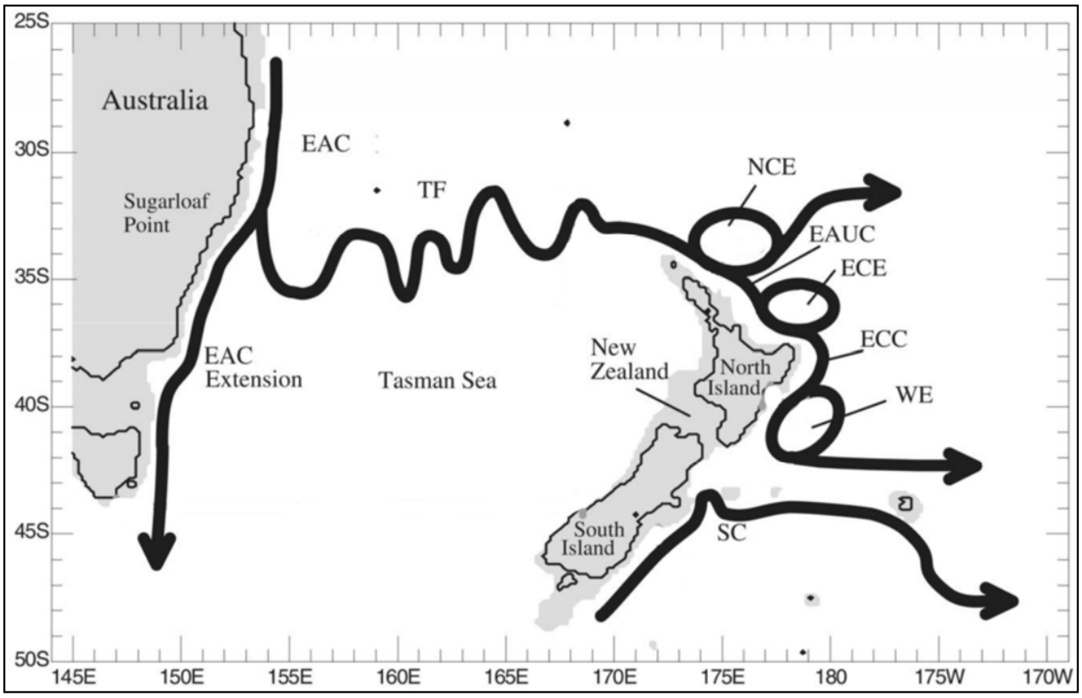

Figure 2. Approximate positions of the East Australian current (EAC), Tasman Front (TF), North Cape Eddy (NCE), East Auckland Current (EAUC), East Cape Eddy (ECE), East Cape Current (ECC), Wairarapa Eddy (WE), and the Southland Current (SC) structures surrounding New Zealand (Source: Longdill 2008; Tilburg et al. 2001).

3.1.2. Local Currents

Cawthron studies during the 2000's showed that during periods of low wind, tidal currents tend to dominate in the Bay of Plenty region (Heasman *et al.* 2009) although there was generally some regional flow influence from the East Auckland Current (Ridgway & Greig 1986). The tidal currents were, however, overwhelmed and dominated by storm or wind induced currents. In general, the water currents near the Opotiki offshore mussel farm were West South West to East North East ((Heasman *et al.* 2009).

3.2. Wind

In terms of wind forcing, Bell and Goring (Bell R & Goring D 1998) used almost a decade of modelled weather forecast data to identify that offshore winds (i.e. north-easterly) predominate in the region, and that winds were greatest in autumn/winter (May to June) and were at a minimum in summer months (January to February). Consequently, it could be expected that north-easterly surface currents would be associated with the prevailing wind directions.

3.3. Tides

With the semi-diurnal tide of 1 to 3 meters, tidal forcing is typical of coastal New Zealand regions. Overall, measured and model simulations suggest that tidal shelf currents in the Bay of Plenty region are in the range of 5 to 20 cm/s, but the residual movement of the tidal component over the shelf edge is negligible and non-tidal flows (e.g. wind or density-driven water currents) are substantially faster than tidally generated flows (Longdill 2008).

3.4. Oceanographic Overview

Whilst regional geostrophic flows dominate the deeper oceanic waters of the outer Bay of Plenty, the water currents of greatest importance to GSM spat concentration occur in inshore waters. Inshore waters are likely to be associated with wild mussel beds and, therefore, greater spat abundance.

In between the East Auckland Current and the inshore waters, there appears to be a westerly current traveling from East Cape to Mayor Island (Figure 3). A map of the residual water currents in the region, from a validated model (Longdill 2008), for a 2 year modelled period, suggests that a complex array of currents are likely in the region (Figure 3).

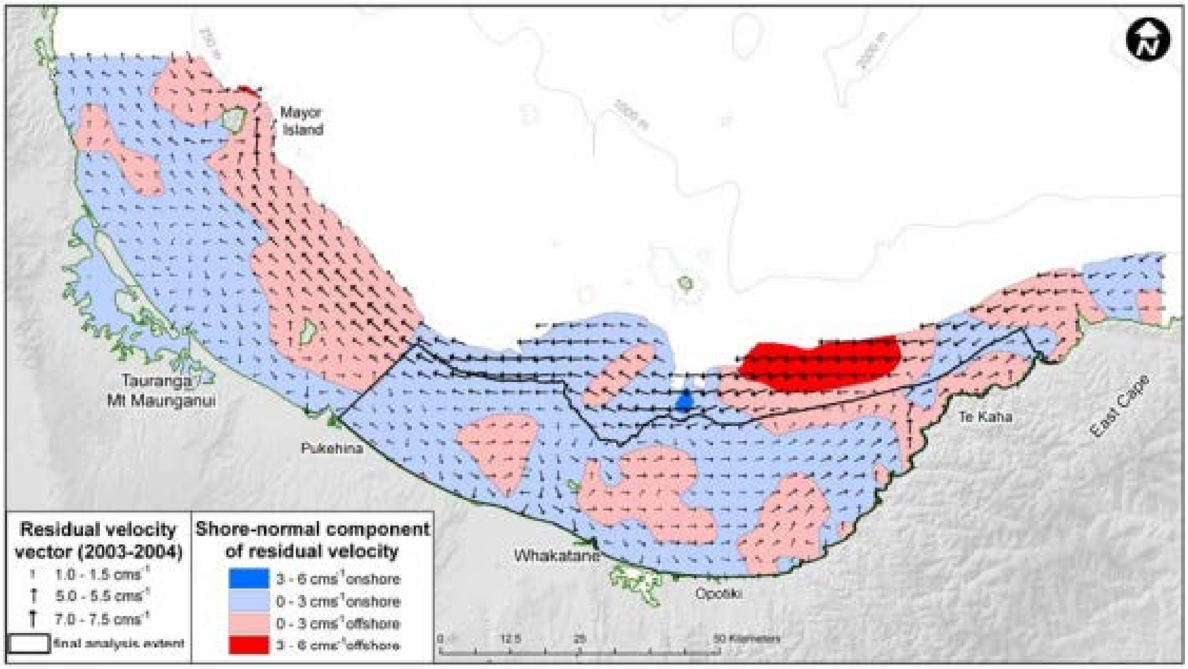

Figure 3. Residual shelf surface velocities (5 to 25 m) from a calibrated numerical model developed by Longdill (2008). Note: 50km scale shown in the figure. Source: Longdill (2008)

The strongest residual surface flows (~7cm/s) were modelled by Longdill (2008) to be near to the 250m depth contour and stretched from the region of the East Cape to

Mayor Island. It is possible that mussel larvae derived from East Cape would be carried by these currents and settle at opportune sites within the Bay such as near White Island and Mayor Island. Inshore of the shelf edge, in the region to the west of Pukehina, the net transport tends to become weaker (~5 cm/s) and heads in a westerly direction. There are local eddies generated in the coastal waters from north west of Opotiki through to north western Whakatane, and another eddy can be observed north of Pukehina extending to the area off Tauranga. Due to their likely ability to concentrate mussel larvae, these eddies are suggested as potential focal points for future spat concentration studies.

Short-term wind-driven currents, for example during storm events, can cause short-term variability in currents. However, the presence of consistent net wind forcing and outer geostrophic flows suggests that the presented net flow (i.e. Figure 3) is a reasonable approximation of net year round circulation. We therefore assume that the net currents presented by Longdill (2008; Figure 3.3) are likely to dominate dispersal of mussel larvae/spat during their pelagic stages in the Bay.

Assuming passive transport (i.e. no net directed larval swimming behaviour), mussel larvae from mussel beds located in the area between Pukehine and Te Kaha are likely to be entrained and concentrated within local inshore eddy structures (Figure 3). Consequently, any future study of spat concentrations would benefit from being situated in these areas.

4. OTHER ENVIRONMENTAL PARAMETERS

4.1. Temperature and thermocline development

Water temperatures in the Bay of Plenty range from 13^{0}C to 24^{0}C (Grieg *et al.* 1988; Heasman *et al.* 2009). A thermocline can develop during the January to May high pressure events, which can have temperature differences of up to 5^{0}C between the surface and 25m depth (Heasman *et al.* 2009). However, during periods of high wind or storm activity the water column becomes well mixed. Average sea surface temperatures, derived from NIWA for the period 1993 to 2004 and compiled by Longdill (2008), indicate that an area of cool water upwelling occurs off Pukehina and a warmer tongue of water extends from Opotiki, past Te Kaha and around East Cape. Due to their influence on the water column environment and any larvae entrained within it, these features should also be considered in future studies of GSM spat concentration.

4.2. Chlorophyll-a

Chlorophyll-a is a measure of a common pigment associated with microscopic algae, phytoplankton, that form a food source for mussels and mussel spat. Higher concentrations of chlorophyll are generally associated with higher concentrations of phytoplankton.

Studies during Cawthron's work in 2007/2008 at the Opotiki offshore mussel farm site (Heasman *et al.* 2009), showed a peak in Chlorophyll-a levels through August/September when waters were well mixed. A period of thermocline development when warmer water lies over deeper water was seen during late January to April 2008. This was associated with lower Chlorophyll-a levels at the surface than at 25m. This is a common phenomenon in coastal waters of New Zealand in summer and is generally associated with a reduction in nutrients (generally nitrogen) in the surface waters. If surface waters are typically lower in chlorophyll a than deeper water during the summer period, this suggests that if mussel larvae are able to control their vertical position they may favour deeper waters during this period.

In addition, the cooler upwelled waters identified by Longdill (2008) off Pukehina, are possibly more productive than the warmer waters observed off Te Kaha, which could also influence GSM larvae concentrations. Consequently, if larvae were able to concentrate in the bay they may favour the eastern side of the bay near to Pukehina.

4.3. Other information on Known Spat-fall events

A review of data and anecdotal evidence found a paucity of information regarding GSM spat settlement and concentrations in the Bay of Plenty region. There are records of adult GSM populations and some historic populations which have now disappeared, but in general mussel spat-fall has not been recorded. To this end the only records that considered GSM spat were from the Cawthron study at the Opotiki offshore aquaculture farm site (Heasman *et al.* 2009; Figure 4.) and observations by regional council staff (Park, S. pers. com.).

5. SUMMARY OF SPAT-FALL INFORMATION

Given the anecdotal evidence, published and unpublished literature the following statements can be made regarding predictions of GSM spat concentrations in the Bay of Plenty region:

- The source of mussel spat within the Bay of Plenty region is not well known. Low densities of adult GSM are found on rocks, reefs, estuaries and islands throughout the Bay of Plenty.
- The only recorded spat fall peaked between September and February on the offshore mussel farm site at Opotiki.
- No variation of spat settlement relative to depth has been observed in the region, but may occur due to localised environmental influences.
- Water currents, which are the main transporters of mussel larvae, tend to be from South West to North East in the coastal (>100m depth) region of the Bay.
- There are two main water current eddies in the Bay, which have potential to concentrate mussel larvae: one eddy is off Matata and the other off the Bowentown inlet of Tauranga harbour.
- The greatest annual levels of chlorophyll-a (surface) are observed off Matata/Pukehina and the lowest off Te Kaha.

Through this desktop review, we have identified areas with higher chlorophyll-a levels and eddies which may concentrate pelagic GSM larvae. The area west of Whakatane on the ocean side of Elephant rock (near Moutohora (Whale) Island; Figure 4.), appears to have the greatest potential for future in-situ study of spat fall. This area has a mean annual chlorophyll-a level that is higher than the rest of the Bay and is also an area where water tends to circulate within a nearshore eddy.

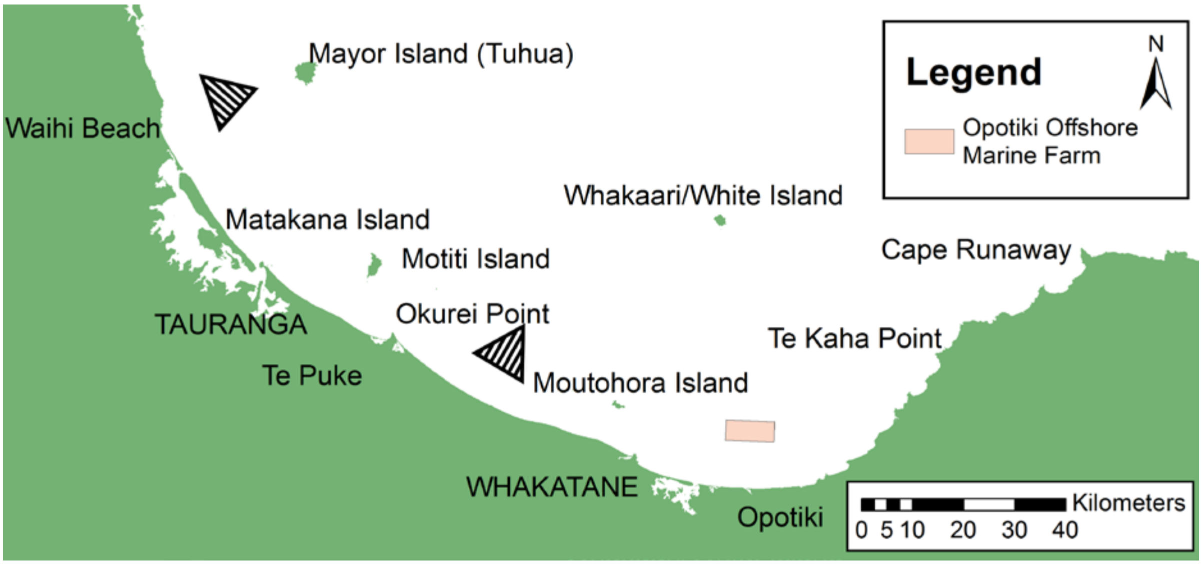

Figure 4. Suggested areas for investigating green shell mussel spat-fall (shaded triangles and the corners of the Opotiki Offshore Marine Farm) within the Bay of Plenty..

The existing mussel farm off Opotiki is close to the eastern edge of an eddy located offshore from Whakatane and chlorophyll-a levels also appear to be greater (although marginally) on the western edge of the farm. Consequently, the corners of the farm (particularly the south western corner) are also suggested as a potential sites for future spat fall investigation (Figure 4.).

6. RECCOMENDATIONS FOR FUTURE RESEARCH ON MUSSEL SPAT DISTRIBUTIONS

Based on the limited information available the following suggestions for future investigation into GSM spat concentrations can be made. However, it must be stressed that because of limited information available; the following suggestions are based largely on opinion and experience rather than data.

6.1. The mussel farm site

The Opotiki offshore mussel farm zones cover a large expanse of water (3700 ha). Generalised information presented prior to this section suggests that settlement of spat could be found across the whole area. We predict that the south western corner of the farming zones may have better spat-falls (Figure 4.), in order to test this, a research program should be established to determine if local differences in GSM spat-fall within the farm area are present.

If a pilot study was undertaken, it is recommended that spat collection ropes should be positioned at each corner of the farm and checked regularly to establish: 1) when the peak periods of spat settlement occur; and 2) the depths that the spat are settling. Comparing the data from the four corners of the farm may also give some indication as to the direction of spat delivery by the water currents.

6.2. Other potential sites

There are two sites outside the farming area which are suggested as potential sites for further investigation of GSM spat concentrations.

The first is between Whakatane and Te Puke, approximately 10 to 14km off the beach near to Moutohora (Whale) Island (Figure 4.). This area appears to be comparatively rich in water column nutrients, and has a general inshore eddy which may concentrate spat.

The second potential site is located further west between Mayor Island and the Waihi Beach, 12km to 16km from the coast (Figure 4.). This area benefits from a variety of inshore current structures which have the potential to deliver and concentrate GSM spat. Due to the distances between the Eastern and Western sites, the site in the western Bay of Plenty (i.e. Mayor Island/Waihi) may access a source of GSM spat that is not available to the existing Opotiki mussel farm. It may also tap into spat sources that are not only different to the eastern region of the Bay, but may also have a varied spat catching period.

Sampling at both Western Bay of Plenty and Eastern Bay of Plenty sites is recommended and would provide information on the seasonality of spat across the bay. Sampling at two locations may also provide information on the origin of spat through data on the depth, direction and timing of spat delivery by water currents.

6.3. Suggested sampling methodology

In order to sample spat concentrations at sites that would provide the most information on potential east-east and north-south gradients, a spat catching triangle is suggested for all locations. The triangle would comprise two spat collection lines parallel to the coast at least 10km apart, and contain one site 10km seaward, but equidistant from each of the two sites parallel to the shore (Figure 4.). Such a triangular sampling would provide information on the depth and occurrence of GSM settlement over time, and would also reflect the direction of delivery and possible origin of spat.

Care should also be taken to avoid placing spat catching lines in the vicinity of reefs and outcrops. These can be sources of fouling organisms, which are best avoided to reduce fouling on lines. Consideration of this factor has also been included in our recommendations for potential investigation areas (Figure 4.).

7. ACKNOWLEDGEMENTS

Environment Bay of Plenty

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