Identifying habitat of particular significance for pāua fisheries management

Discussion document

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1. Background

Habitat of particular significance for fisheries management (HPSFM) is referred to under section 9(c) of the Fisheries Act 1996 (the Act):

> *"9 Environmental principles –*
>
> *All persons exercising or performing functions, duties, or powers under this Act, in relation to the utilisation of fisheries resources or ensuring sustainability, shall take into account the following environmental principles:*
>
> *… (c) habitat of particular significance for fisheries management should be protected"*

This is a general consideration that decision makers must take into account when achieving the purpose of the Act, which is "to provide for the utilisation of fisheries resources while ensuring sustainability". The Act does not define HPSFM, nor does Fisheries New Zealand (FNZ) have a working policy definition of HPSFM and there is currently no precedent for how HPSFM should be applied in practice. The fishing industry is developing an industry strategy for how HPSFM could be applied from an industry management perspective (draft strategy appended).

2. Purpose

The Pāua Industry Council Ltd. is developing its own strategy for how HPSFM can be applied in practice for the sustainable utilisation of pāua fisheries resources. The purpose of this discussion document is to outline the key considerations seen as relevant for HPSFM application and to propose how these considerations can be integrated into a framework for how HPSFM for pāua can be identified. This document does not intend to define HPSFM specifically, as definitions may vary depending on the management context within which it is applied (e.g., by FNZ, customary, commercial). However, the framework proposed attempts to allow for the incorporation of principles of importance to different management sectors.

This document outlines:

- Considerations for identifying HPSFM for pāua
- Critical habitats for pāua fisheries
- Threats to pāua habitats
- Proposed framework for HPSFM for pāua classification
- Key points for further discussion

3. Considerations for identifying HPSFM for pāua

Matters that are relevant to identifying HPSFM generally are:[1]

- Habitat can be defined as 'the place or type of area in which an organism naturally occurs';
- Marine species may have specific habitat requirements at different life history stages, for example, for spawning, early juvenile growth and adult feeding. Therefore, HPSFM may be defined in relation to specific life history stages;
- The Magnuson-Stevens Fishery Conservation and Management Act (USA) defines 'essential fish habitat' (EFH) to mean: '*those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity*'. Essential fish habitat is not necessarily the same thing as HPSFM but it provides a useful starting point;
- Unlike EFH, New Zealand's legislation refers to habitats of particular significance for ***fisheries management*** – i.e., this may include habitats:
    - That are being actively managed in order to enhance the utilisation and/or sustainability of fisheries resources; or
    - Where failure to provide for their explicit management is likely to result in failure to provide for the utilisation of fisheries resources while ensuring sustainability;
- HPSFM should therefore be identified in a manner and at a scale that is relevant and useful for fisheries management purposes;
- It follows that HPSFM for a species will differ depending on the management approach for the species or area (and who the fisheries manager is). For instance, a fisheries plan that sets out measures for commercial harvesting activity may result in identification of HPSFM that differ from HPSFM that are identified for the purposes of customary management within a mātaitai reserve; and
- Habitats of ***particular significance*** means those that are worth notice, special, not ordinary and of considerable effect (not negligible) for fisheries management. It does <u>not</u> mean all habitat of a particular species, and it does <u>not</u> necessarily mean areas with high catch rates for a species.
- The principle that HPSFM should be ***protected*** requires consideration of threats to HPSFM. Although the purpose of the Act defines ensuring sustainability as "avoiding, remedying, or mitigating any adverse effects *of fishing* on the aquatic environment", section 9(c) simply states that HPSFM "must be protected", with no reference to effects of fishing. It can therefore read that the principle in s9(c) applies to protection from all potential environmental threats, not just effects of fishing.

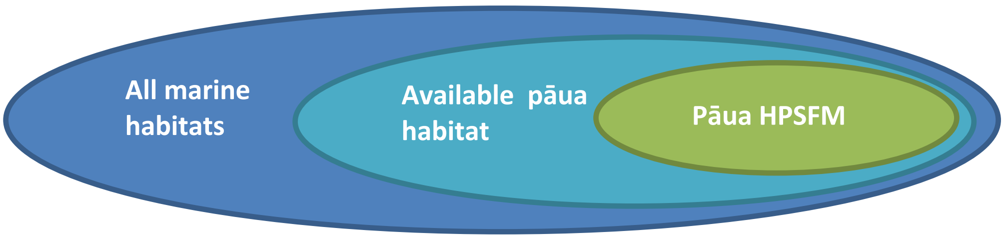
An area that is identified as HPSFM can then be protected, as follows:

[1] Points in this paragraph adapted from Ministry of Fisheries (2001), Front-end policy definitions.

- If the habitat is threatened by fishing activity, then the fishing activity can be managed under the Fisheries Act;
- If the habitat is threatened by other activity (e.g., environmental threats), then the threat can be managed under other legislation (primarily the Resource Management Act).

4. Critical pāua habitats for pāua fisheries

Habitats of Particular Significance for Fisheries Management (HPSFM) for pāua are a subset of all available pāua habitat:



The first step in identifying HPSFM for pāua is to describe and identify general pāua habitat requirements, for each significant stage of the pāua lifecycle (Figure 1) using information from scientific literature and observation. Pāua may also be found in other habitat types that are not readily observed or studied, which may not be described here.

The following outlines the key stages of the pāua life cycle, and where relevant, describes the habitat requirement associated with each life stage. Key life cycle stages for pāua are described under similar headings used for the descriptions habitats and areas of particular significance for fin-fish in Morrison et al (2014).

a. Adult Spawning

Most pāua reach maturity after about 3 years at approximately 80mm in shell length, but maturity can occur sooner in fast-growing populations (McShane and Naylor 1992). Maturity generally corresponds with their emergence from cryptic juvenile habitats to more exposed habitats (explained below pg. 4), where they aggregate for spawning.

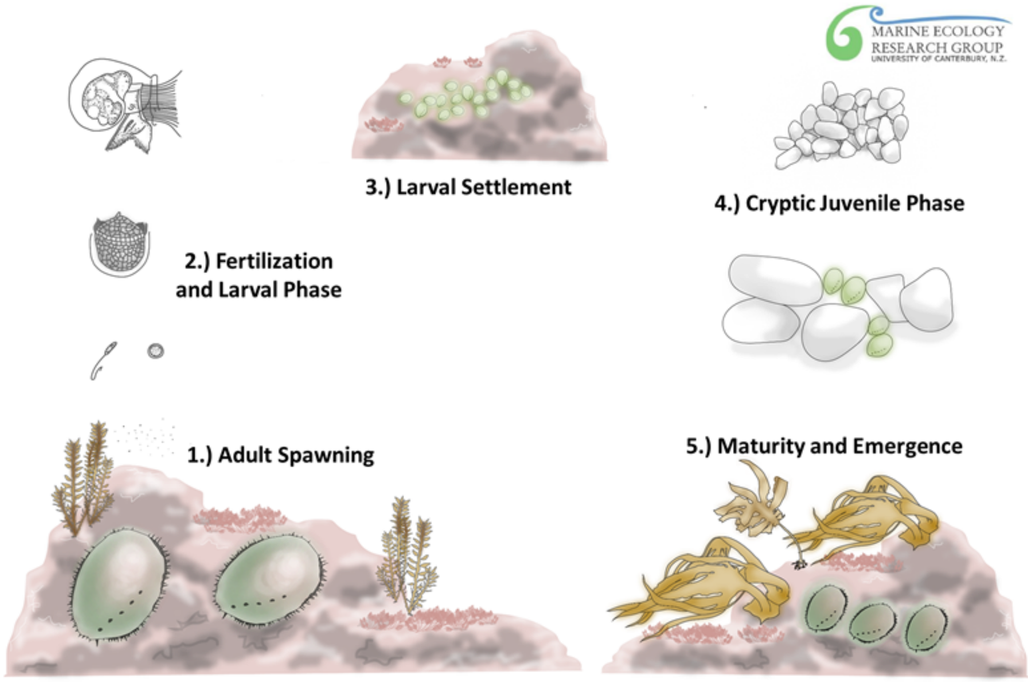


Figure 1: Simplified pāua life cycle denoting key stages (Courtesy, Marine Ecology Research Group – University of Canterbury).

Pāua are broadcast spawners with mature adults synchronously releasing gametes into the water column where external fertilisation of eggs occurs (Hooker and Creese 1995). Spawning is believed to occur 1-2 times a year in pāua, with spawning events being regularly observed in early spring (Radon pers. comm. 2012), and autumn (Poore 1973d). Spawning events are believed to be initiated by environmental cues such as storm events and large swells (Poore 1973d). Pāua mature at approximately 80mm in shell length, which generally corresponds with the time at which they emerge from cryptic juvenile habitats to more exposed habitats. Spawning success largely depends on proximity of mature pāua, which increases the likelihood of fertilisation (Babcock and Keesing 1999), and 'spawning aggregations' of adults are often observed. Good fertilisation rates are important because pāua will experience very high mortality as larvae and into the settlement and juvenile phases.

Habitat requirement

Pāua spawning requires rocky reef habitats in 0-15m depth that allow for aggregation of large numbers of pāua in close proximity. Open platform or boulder type habitats are more likely to accommodate large pāua aggregations. Habitats in areas more exposed to swells may be more likely to experience environmental cues that initiate spawning (e.g., large swells during storm events).

b. Fertilisation and larval phase

Successfully fertilised pāua eggs are negatively buoyant for the first 12 hours until development into the trocophore and veliger larval stages (Tong and Moss 1992, Stephens et al 2006). Preliminary larval phases in pāua last for 4-8 days, during which larvae can actively swim at speeds of 1-3mms^{-1}. Larvae are lecithotrophic (non-feeding), and do not require eternal food sources prior to settlement. Between days 5 and 9 days post-fertilisation, competent larvae are able to settle, but may temporarily delay settlement until appropriate substrate is encountered (Tong and Moss 1992). Due to the relatively short larval phase and poor mobility of larvae, larval dispersal distance depends on the point of dispersal, local coastal topography, and local hydrodynamic conditions (Stephens et al 2006). While modelling has shown the potential for dispersal of pāua larvae up to 80km, distances of up to 200m are predicted to be most likely (Stephens et al 2006). This suggests that pāua recruitment is generally quite localised at scales of 100s of meters (Naylor pers comm. 2019).

Habitat requirement

Key habitat for pāua larvae is near-shore coastal waters, with proximity to suitable settlement habitat being important for long-term survival into juvenile life stages (discussed next). Pāua larvae are susceptible to mortality if temperatures get too high (>20 C), so cooler waters are likely to promote survival. Adult spawning habitats, amongst other factors, will influence larval dispersal. Spawning habitats in exposed areas and near strong tidal flows are more likely to promote dispersal of larvae away from the source populations, and habitats in sheltered areas may promote populations that are more self-seeding. Further, complex crevice and boulder type habitats, and abundance of large macroalgae (e.g., Macrocystis and Durvillaea) may promote the entrainment of larvae and restrict larger-scale dispersal (McShane 1992, Stephens et al 2006).

c. Larval Settlement

Pāua settlement in marine invertebrates is the process where larvae transition from their planktonic larval phases in the water column and land on benthic substrata. This occurs after 5-9 days into the larval phase when veliger larvae drop their swimming structure (velum) and fall onto the substrate (Tong and Moss 1992). Pāua veliger larvae are widely reported to settle preferentially on crustose coralline algae (CCA) due to a GABA-induced chemical cue (Morse 1984, Kawamura et al 1998). Survival through settlement may be adversely affected by fine silt covering available habitat. After settlement, competent larvae start to metamorphose into juvenile pāua which primarily graze on benthic diatoms (Kawamura et al 1998). Recently settled larvae have numerous predators including nereid worms (McShane and Naylor 1995) and cryptic spaces may improve early survival.

Habitat requirement

Boulders and cobbles covered in CCA in the shallow sub tidal (1-3 m depth) zone are the most commonly described settlement habitat for pāua (Schiel 1990, Aquirre and McNaught 2012), although settlement can occur at depths up to 8m. While CCA-covered rocks may be preferred, other types of substrata also enable settlement, and to a lesser extent, pāua can settle into gutter/crevice type habitats. Post settlement survival and growth of pāua has been shown to be significantly greater in deeper (6-8m) compared to shallow (1-2m) habitats, and has been attributed to water movement causing dislodgement and sedimentation causing smothering of post-settlement recruits (McShane and Naylor 1995). Post-settlement pāua inhabit coralline algae habitats for about 8 weeks before seeking out cryptic juvenile habitats (McShane and Naylor 1995). For successful survival and growth into the identifiable juvenile phases (3-80mm), it is important that settlement occurs proximate to cryptic habitats favoured by juveniles.

d. Cryptic Juvenile phase

For the purpose of this description, the juvenile life phase of pāua is defined by when larvae metamorphose into identifiable pāua (approximately 3mm) until they reach maturity (>80 mm) (Tong and Moss 1992). Juvenile pāua inhabit cryptic habitats (described below), where they are more likely to avoid contact with numerous predators, namely wrasse and sea stars. They remain cryptic for approximately 2-3 years until the onset of maturity (70-90mm) after which they emerge and move into more open habitats (McShane and Naylor, 1992). Juvenile pāua typically feed by grazing algal films, and will start to passively feed on drift algae as they approach the size of sexual maturity (Poore, 1972c).

Habitat requirement

It is widely reported that the vast majority of juvenile pāua inhabit cryptic habitats from the intertidal zone to approximately 2 m depth (Wilson and Schiel 1995, Naylor et al 2017), although juvenile can be found at low densities up to 12 m (Gerrity pers. comm. 2021) 'Cryptic' habitats are those where pāua cannot be readily observed without destructively surveying habitats. These habitats are preferred to enhance predator avoidance, in particular from the most common seven-arm sea star *Astrostole scabra* (Aquirre and McNaught 2013). Juvenile pāua habitat is typically described as medium sized boulders, but emergent and adult pāua also commonly observed in exposed gutter and crevice type habitats must also support juveniles to a degree. Cover of algal films and a steady supply of drift algae will improve growth rates and progressions towards maturity.

e. Maturity and Emergence

Here, adult pāua are defined as are those that have emerged from cryptic habitats associated with juveniles and have reached sexual maturity (larger than approximately 80mm), and have emerged from cryptic habitats associated with juveniles. Adult pāua can inhabit a wide range of rocky reef habitats from the intertidal zone to about 15m depth (Poore 1972b). They are largely sedentary in nature, and are unlikely to move far from where they initially ceased migrating after emergence (Schiel and Breen 1991). Adult pāua tend to aggregate together, which improves the likelihood of fertilisation success during spawning (McShane 1995). Pāua can reach a maximum size of 200mm, and growth has been shown to vary considerably both between fisheries management areas (Sainsbury 1982a, Naylor et al 2006) and at scales as little as 100s of meters (McShane and Naylor 1995). Sea temperature has been shown to be the main driver of variability in growth rates, with cooler waters typically promoting faster growth (Naylor et al 2006). However, habitat related factors such as wave exposure and food availability also influence growth (McShane and Naylor 1995). Adult pāua feed passively on drifting seaweeds fragments, the availability of which is influenced by habitat complexity and exposure (Allen et al 2006, Cornwall et al 2009). The specific diet varies depending on locally available algal species, but laboratory studies have shown preference for brown algal over red and green algae.

Habitat requirement

Adult pāua inhabit rocky reef habitats ranging from the intertidal zone down to 15m in depth (Poore 1973d), but are most typically found at depths of 1 to 10m. Higher growth rates (and therefore larger pāua) are typically associated with more complex habitats (large boulder and gutter type habitats) in areas of high wave exposure that promote food availability. Habitats supporting faster growing pāua populations are important for the fishery as they are more likely to support growth past minimum harvest size (MHS), and promote progression of pre-MHS pāua into the fishery after harvest of sized individuals. Fast growing pāua also tend to inhabit areas with diverse macroalgal assemblages, in particular red algae (McCowan, pers. obvs). Sheltered habitats that typically experience less water movement are often associated with slow growing or 'stunted' pāua, where individuals rarely reach minimum harvest sizes. This may be due to density dependent growth as slow growing areas often support very high densities of pāua. This could be related to high settlement success in less energetic environments. Slow growing pāua are often associated with habitats with an abundance of hard brown macroalgal (e.g., *Carpophyllum*).

f. General

It is important to recognize that critical habitats for each stage of the pāua life cycle cannot be considered in isolation, i.e., it cannot just be cryptic juvenile habitats in an area that are important, it is also the habitat in surrounding areas that support the other life cycle stages. While specific habitats (e.g., juvenile) may be identified as being subject to particular threats worthy of protection, descriptions of pāua habitats of particular significance are likely to refer to general areas of multiple habitats, including the water column.

5. Threats to pāua habitats

The primary requirement under s9(c) of the Fisheries Act is that fisheries decision making takes into account that "habitat of particular significance for fisheries management should be protected", but habitats important for sustaining fisheries can threatened by a range of stressors that are not expressly within the jurisdiction of the Fisheries Act. Other threats can be made relevant however through, for example, s66 of the Resource Management Act 1991 which states "..when preparing or changing any regional plan, the regional council shall have regard to – (c) (iii) regulations relating to ensuring sustainability or the conservation, management, or sustainability of fisheries resources …”. This makes it important to consider relevant environmental and other stressors on habitats when classifying pāua habitats of particular significance, as regional council decision making controlling potential threats has the potential to affect critical pāua habitats. Further, s9 of the Fisheries Act specifies ‘environmental principles’, so consideration of environmental stressors on habitat seems intuitive.

The effects of environmental stressors on pāua habitats are summarised in Table 1. The following summarises the major identified threats to pāua (from McCowan, 2020 EAF Review), and describes how critical life stages, and associated habitats and/or stages of the pāua life cycle that can be affected by them (referred to in section 2).

a. Environmental stressors that can affect pāua habitats

i. Sedimentation

In the context of marine environments, sedimentation is the process of particles being deposited on the seafloor. Sedimentation is driven by geology, topography, active tectonics and rainfall (Jones et al 2008). New Zealand’s shallow coastal zone and proximity of anthropogenic activity to coastal areas make sedimentation the most-significant land-based stressor on the marine environment (Jones et al 2008). Sedentary species such as pāua that do not typically move far are particularly susceptible to the effects of sedimentation, and sedimentation has been identified as a threat to all possible pāua habitats and ecosystems (MacDiarmid et al 2012).

There are no published studies investigating the effects of sedimentation on spawning ability in pāua. However, severe sedimentation events that cause complete smothering of animals would prohibit spawning altogether. Sedimentation events that smother available habitat and/or cause dislodgement of pāua will also reduce the reproductive capability of local populations.

Suspended sediments in the water column have been shown have effects on pāua larvae (Philips and Shima 2006). While suspended sediments are not strictly within the definition of sedimentation (the deposition of sediments), they are related processes that have downstream effects on pāua populations, and should be considered a relevant environmental stressor. Experiments that replicated the sediment loads present in Wellington Harbour after heavy rain events showed that increased sediment load can affect development and growth of pāua larvae and lead to increased mortality (Philips and Shima 2006).

Sedimentation has been identified as a key factor influencing recruitment success in pāua (McShane and Naylor 1995, McShane and Naylor 1997). In particular, sedimentation can affect settlement success of veliger larvae by smothering settlement habitats, interfering with the chemical cues (e.g., from crustose coralline algae) that can induce settlement, and by limiting the available surface area for post-settlement grazing (Sainsbury 1982a, Schiel 1992, Kawamura et al 1998). The influence of sediments on post settlement survival and metamorphosis are also well documented in other abalone species (e.g., *H. diversicolor,* Onitsuka et al 2008). While no studies have shown direct effects on juvenile pāua mortality or growth, sedimentation can affect the juvenile life phase by smothering cryptic boulder habitats. This can cause behaviour of juvenile to be modified as they move out from cryptic habitats to avoid smothering, making them more susceptible to predation (e.g., by the seven arm starfish (*Astrostole scabra*)), and dislodgement (Chew et al 2013).

Again, while not strictly sedimentation, suspended sediment in the water column has been shown to have effects on adult pāua by reducing mucus productions, however no effects have been observed on growth or oxygen consumption (respiration) in adult pāua, but potentially reduced respiration in smaller pāua (Raea 2013). Severe sedimentation event have been linked to direct mortality in adult pāua (Sainsbury 1982a, Preece 1998). This is usually due to sudden localised changes in sediment distribution after storm swells , forcing pāua after from preferred substrates or burying them (Sainsbury 1982a). Adult pāua are largely sessile and require clear, flat substrate to attach to live and feed. Severe sedimentation events can reduce the carrying capacity of available habitat which can hinder population rebuild after mortality events (Stanley, pers. comm. 2014). There are numerous anecdotal reports of pāua mortality following sedimentation and storm events, e.g. most recently at Maungamanu, north of Kaikoura in April 2019.

The effects of sedimentation on pāua habitats may be exacerbated in some instances by heavy metal contamination. Heavy metal pollution is recognised as a major threat to marine environments, particularly in areas proximate to industrial activity and urban areas (Gorski and Nugegoda 2006). The accumulation of heavy metals has been observed in many New Zealand shellfish species including pāua (Nielsen and Nathan 1975). Heavy metals have been shown to have adverse effects on *Haliotis rubra* larval and juvenile (Gorski and Nugegoda 2006) survival in laboratory studies, however levels of heavy metals detected in nearshore coastal waters are not usually high enough to have adverse effects. In pāua, field and laboratory studies have been used to examine the effects of heavy metal contamination on pāua following the Rena grounding near Motiti Island. Adverse behavioural (reduced adhesion) and mortality effects were observed in pāua treated with contaminated sediments (McSweeney 2015).

Sedimentation can also affect the abundance of the key macroalgae species used as a food source for pāua. Sedimentation can inhibit the settlement and early development of key species such as *Macrocystis pyrifera* by covering settlement substrates and causing abrasion to newly settled recruits (Schiel et al 2006). Suspended sediments also increase water turbidity, inhibiting light and photosynthetic activity of juveniles and adults (Devinney and Volse 1978, Schiel et al 2006), and sediment that settles on the laminae of adults can inhibit nutrient exchange required for growth (Pirker 2002).

Sedimentation is a potential threat to key habitats required by pāua at all life stages. In particular, habitats proximate to areas with high sediment load, including major rivers with catchments with high intensity agriculture or forestry prone to runoff are most susceptible. These habitats may be more susceptible to the effects of sedimentation in sheltered areas with less wave exposure and/or tidal flows where deposition of sediment happens ore readily. Modelling of sediment deposition near identified habitats of particular significance will be useful in future analyses.

ii. Climate change related stressors

There is an increasing awareness of the effects of climate change on marine ecosystems. Two key considerations with climate change with respect to pāua and their habitats are increasing sea temperatures (and marine heatwaves) and ocean acidification. These processes themselves are difficult if not impossible to mitigate, however there is potential to monitor and manage specific parts of the fisheries containing habitats that are likely to be more vulnerable to their effects, or where their impacts are more readily observed.

Sea temperature

Sea temperature can directly affect many aspects of the pāua life-cycle and behaviour, as well as algal species that help form key habitats. In this context, habitats under threat from changing sea surface temperatures encompasses all available pāua habitats (including the water itself) in areas that are prone to the effects of changing sea temperature.

At early life stages, increased temperature has been shown to increase the speed of larval development in pāua (Tong et al 1992), and juveniles have also been shown to grow faster at higher temperatures (Tong 1982), however this relationship weakens as pāua grow larger (Searle et al 2006). Growth rates in adults are significantly influenced by temperature with growth, and maximum length being larger at cooler temperatures (Naylor et al 2006). Length at maturity has also been shown to increase with cooler temperatures, although this is likely to be due to reduced growth rates after the juvenile phase in cooler water (Naylor et al 2006). Temperature therefore plays an important role in controlling pāua population characteristics across through their range, e.g., pāua are typically only fished from the Wairarapa south where waters are cool enough to promote growth in pāua over 125mm regularly. In red abalone (*H. rufescens*) increasing sea temperature has been shown to restrict growth rates and reproduction (Vilchis et al 2005). Changing sea surface temperatures could therefore potentially restrict the range of pāua, and in particular the range of the fishery where pāua grow over the minimum harvest size. Disease susceptibility in abalone is also linked to increased water temperatures (Vilchis et al 2005, Rogers-Bennett et al 2010), with disease outbreaks in pāua typically associated with water temperatures over 20°C (Diggles and Oliver 2005).

Sea temperature can also affect the abundance and distribution of macroalgae which are critical components in the ecosystems pāua inhabit. For example, temperature plays an important role in the life cycle of *M. pyrifera* as during summer, kelp forest biomass declines in response to nutrient limitation, as nutrient exchange is inhibited by warmer temperatures (Geange, pers. comm. 2014, Vilchis et al 2005, Mabin et al 2019). Temperature therefore has an important role in defining the extent of the range that *M. pyrifera* typically occupies (generally south of Castle Point on the east coast and Kapiti Island on the west coast of the North Island). Increasing temperatures could therefore also restrict the range of key macroalgal species such as, *M. pyrifera,* which could have downstream effects for pāua ecosystems and fisheries. Another important algal species in pāua ecosystems are crustose coralline algae (CCA) which promote larval settlement. In the literature studies report different findings about the effects of temperature on CCA, but a recent meta-analysis concluded that negative impacts are observed on CCA with temperatures above 5.2°C from ambient conditions, as well as 2.0°C below ambient conditions (Cornwall et al 2019). This suggests that CCA have a reasonable level of thermal tolerance that may enable it to withstand effects of warming waters.

Marine heat waves

A related phenomenon to changing sea-surface temperature is marine heat waves. Marine heat waves have been defined as a prolonged discrete anomalously warm water event (Hobday et al 2016). Marine heatwaves are occurring in environments that support pāua ecosystems with increasing frequency and magnitude (Mundy pers. comm. 2019). Episodic, short term extreme events such as marine heatwaves have been observed to cause mortality and recruitment failure in marine species (Samuel et al 2019). There have been anecdotal reports of pāua mortality and starvation associated with marine heatwave events (e.g., on the Chatham Islands (PAU4) in 2019). However, it is difficult to isolate a marine heat wave as the main driver of mortality or starvation in the context of other processes such as sand movement due to storms, and variability in kelp abundances. Pāua have a reasonably high thermal tolerance across their latitudinal range e.g., 20°C in the north to 8°C in the south, however drastic changes in temperatures over short time periods can have adverse effects on physiology (Ragg pers. comm. 2017).

Ocean Acidification

Ocean acidification is the gradual decrease in pH (or increased acidity) of the ocean caused by increasing amounts of atmospheric carbon dioxide. Levels of ocean acidification are affected by temperature, being slightly increased in cooler waters, which are where the most productive pāua fisheries exist. Lowered oceanic pH can have adverse effects on invertebrates that are reliant on carbonate for shell production (such as pāua) (Cunningham et al 2016).

Reduced pH has been shown to effect larval survival and development. This is thought to be caused by a reduced rate of shell deposition, meaning larvae are dependent on energy stores for longer in the veliger stage, thus increasing energetic requirements (Cummings et al 2019). Ocean acidification could also limit pāua recruitment, as it impairs growth in crustose coralline algae (Cornwall et al 2013) thus decreasing suitable settlement habitats and food sources for larvae. While this hasn't been observed specifically in pāua, it has been shown to influence other species (e.g., corals in Webster et al 2013). Ocean acidification has been shown to reduce growth rates in juveniles and while no direct effects have been observed on the survival of adults, it increases shell erosion which can affect growth, and potentially physical condition and respiration rates increasing overall energetic requirements (Cunningham 2013). The effects of long-term ocean acidification could therefore cause a reduction in pāua recruitment, by limiting larval development and juvenile growth, as well as affecting fishery dynamics by decreasing growth rates.

Storm events

There is evidence of increasing frequency of storm events with climate change (Easterling et al 2000). Storm events drive different physical processes that have potential impacts on pāua ecosystems. Reproductive cues in pāua are poorly understood, but it is thought that storm events serve as a cue to induce spawning (Poore 1972d), so increased frequency of storm events may alter the timing and magnitude of spawning events. After fertilization storm events may also affect the survival of larvae and influence the distance of dispersal (Stephens et al 2006), so have the potential to influence population dynamics. Large swells associated with storms can also disrupt juvenile boulder habitats causing mortality at critical life stages and limiting recruitment to the fishery. Large swells have also been observed to dislodge and cause mortality in adult pāua, particularly when associated with high rainfall and sedimentation events. There are several documented cases of this occurring, most recently at Maungamanu north of Kaikoura (April, 2019). This has been explained by sudden localised changes in sediment distribution after storm swells, which forced pāua off preferred substrates or buries them (Sainsbury 1982a).

Storm events can also drive the change in abundance of kelp forests especially when associated with high levels of sedimentation after rainfall events (Pirker 2002). Storm events are associated with heavy rainfall, which is also a driver for increased sedimentation (Glade 2003), potentially amplifying adverse effects on pāua populations and macroalgae described above under sedimentation.

b. Effects of pāua harvesting on habitats

Generally, ecosystem effects of fishing can arise from the methods of fishing (i.e., effects on habitats of the harvesting process), and the functional roles that the target species plays in its ecosystem (i.e., its relationship with predator, prey and competitors) (Anderson et al 2011). Pāua are harvested by free-diving (with the exception of the Chatham Islands where UBA is allowed) and using blunt knife-like tools to prise the animal off the reef. While there may be minimal amounts of damage to habitats caused by the tools, catch bags or anchors, overall impacts are like to be negligible compared to other fishing methods such as dredging and trawling (Anderson et al 2011). In areas where there is high and repetitive fishing pressure, cumulative effects on habitat may be worth controlling.

Table 1 below summarises the potential environmental effects on different stages of the pāua life cycle and corresponding habitats.

Table 1: Summary of potential environmental effects on stages of the pāua life cycle and corresponding habitats

		Life stages and critical habitat				
Threatened habitat		Coastal waters	CCA covered cobbles/boulders in shallow subtidal zone	Cryptic boulder habitats in shallow subtidal zone	Rocky reef habitats from 1-15m	Associated algal species
Life stage supported		Fertilization and larval (and all stages generally)	Settlement	Juvenile to emergent	Spawning adults, juvenile to emergent	Food, habitat forming for all life stages
Environmental stressor	**Sedimentation**	✗	✗	✗	✗	✗
	Increasing sea temperature	✓	?	✓	✗	✗ ?
	Marine heatwaves	✗ ?	?	?	?	✗
	Ocean acidification	✗	✗	✗	✗	✗
	Storm events	✓	✗	✗	✗	✗
	Pollutants/heavy metal runoff	✗	✗	✗	✗	?
	Harvesting related	-	-	-	?	?

✗, ✓, - and ? denote negative, positive, negligible or unknown effect (respectively) on paua habitat and/or life stage

6. Proposed framework for HPSFM for pāua classification

To identify HPSFM for pāua, a classification framework is necessary to distinguish habitats of *particular* significance, from all pāua habitats (i.e., all rocky reef habitats around New Zealand). As outlined in key considerations in section 1, habitats of *particular* significance mean those that are worth notice, special, not ordinary and of considerable effect (not negligible) for fisheries management. Together with key considerations outlined in section 1, key words from section 9 of the Act (shown in bold below) can help define what considerations should be deemed important for classification of all habitats as HPSFM:

> *"9* ***Environmental*** *principles –*
>
> *All persons exercising or performing functions, duties, or powers under this Act, in relation to the* ***utilisation*** *of fisheries resources or ensuring* ***sustainability****, shall take into account the following* ***environmental*** *principles:*
>
> *… (c) habitat of particular significance for* ***fisheries management*** *should be* ***protected****"*

a. Proposed classification criteria for identification of HPSFM for Pāua

The following outlines seven proposed classification criteria for identification of HPSFM for pāua, defines links to key legislative considerations and explanations of their relevance.

- **Habitat is subject to environmental stressors**

Relevance to Section 9: 'environmental', 'protected'

Explanation: Areas with habitats that would benefit from management to mitigate the effects of existing, suspected or anticipated environmental stressors

Information sources:
- Scientific monitoring (e.g., temperature, sediment load)

- Local knowledge and observation
- Forecasting (e.g, marine heatwaves)

- **Habitat is of importance to pāua population regeneration**

Relevance to Section 9: 'sustainability'

Explanation: Areas with habitats that are central to supporting population regeneration in the local area, and within recognised spatial scales relevant to pāua fishery management, e.g., recognised recruitment habitats, recognised spawning aggregations, habitats that promote larval dispersal.

Information sources:
- Dive surveys
- Habitat mapping (e.g., UC habitat classification)
- Local observation
- Matauranga Maori

- **Habitat is of importance to research**

Relevance to Section 9: 'fisheries management', 'sustainability'

Explanation: Areas with habitats that are subject to past, present or future research relevant to pāua, e.g., collection of growth and length at maturity data. Require protection to sustain consistency in data streams informing stock assessment.

Information sources:
- Industry research program locations (e.g, growth tagging locations)
- Other research institutions' research locations (e.g., UC juvenile abundance monitoring point in PAU3N)

- **Habitat is of importance to fisheries management**

Relevance to Section 9: *'fisheries management', 'sustainability'*

Explanation: Areas that are subject to fisheries management initiatives, where habitat protection is critical to successful outcomes.

Information sources:
- Fisheries New Zealand management (eg., fisheries closures)
- Industry management initiatives (e.g., translocation, reseeding)
- PāuaMAC AOPs and Fisheries Plans
- Customary management areas (e.g., rahui)

- **Habitat is of importance to commercial fishery**

Relevance to Section 9: 'fisheries management', 'utilisation'

Explanation: Areas with habitats that are known to consistently produce a high (%) of the TACC for that QMA or management area (stat area or industry agreed zone)

Information sources:
- Commercial catch records (PCELR and ER data)

- Local knowledge

- **Habitat is of importance to customary fishery**

Relevance to Section 9: ‘fisheries management’, ‘utilisation’

Explanation: Areas with habitats that are of high importance to customary fishing utilization.

Information sources:
- Kaitiaki customary take records
- Local knowledge
- Matauranga Maori

- **Habitat is of importance to recreational fishery**

Relevance to Section 9: ‘fisheries management’, ‘utilisation’

Explanation: Areas with habitats that are of high importance to recreational fishing utilization.

Information sources:
- Recreational catch estimates
- Accessibility
- Proximity to large centres
- Local knowledge

b. Proposed framework for classification of pāua habitats of particular significance

The following describes a proposed process for how specific habitats or parts of the fishery could be classified as habitats of *particular* significance.

⇒ Area containing habitat is considered based on its potential relevance to one of the seven categories:
1. Subject to known, suspected or anticipated environmental stressors;
2. Importance in supporting pāua population regeneration, e.g.:
   - Recognised recruitment habitats;
   - Recognised spawning aggregations;
   - Habitat promotes larval dispersal.
3. Subject to current or planned research on pāua and/or associated species (e.g., macroalgae);
4. Subject to current or planned pāua fisheries management initiatives
5. Importance in supporting commercial pāua fisheries;
6. Importance in supporting customary pāua fisheries;
7. Importance in supporting recreational pāua fisheries;

⇒ The considered area containing the habitat is then scored for its importance to each of the categories (see explanation of scores in Table 2 below).

⇒ For each considered area containing the habitat, scores for each category are summed to provide a total score reflecting its overall significance.

⇒ If the overall significance is higher than a pre-determined score, it is classified as a habitat of *particular* significance. It is initially proposed that this number is 10, meaning it is very important with regard to one category, and at least moderately important with regard to three other categories.

NB: it should be considered whether particular categories are weighted higher than others.

This framework could be applied to current areas of interest to have them classified and mapped as habitats of particular significance, and/or could also be applied retrospectively if areas of interest become subject to decision making under the Fisheries Act.

Table 2: Weighting scores for HPSFM for pāua classification

Classification criteria	Weighting score
Subject to environmental stressors	(0) No threat (1) Suspected threat (2) Anticipated threat (3) Known threat
Importance to pāua population regeneration	(0) No pāua present in habitat (1) Pāua present, no recognised critical habitats (2) One recognised critical habitat (3) More than one recognised critical habitat
Importance to research	(0) No research (1) Past research (2) Planned research (3) Current research
Importance to fisheries management	(0) No current management initiative (1) Planned management initiative (2) One management initiative (3) More than one management initiative
Importance to commercial fishery	(0) No commercial catch (1) Low commercial catch (<x%) (2) Moderate commercial catch (%?) (3) High commercial catch (%?)
Importance to customary fishery	(0) No customary catch (1) Low customary catch (frequency?) (2) Moderate customary catch (3) High customary catch
Importance to recreational fishery	(0) No recreational catch (1) Low recreational catch (2) Moderate recreational catch (3) High recreational catch

c. Example application of the proposed framework

The following table shows a working example (mock) of how this framework could be applied in practise for a selection of areas of habitat from different pāua Quota Management Areas (QMAs).

	Area of importance	Tory Channel	Maungamanu	Ascots	Smoky Bay	Turakirae
	QMA	PAU7	PAU3	PAU4	PAU5B	PAU2
	Primary category	Environmental	Customary	Environmental	Research	Commercial
	1. Environmental stressors	3	1	3	0	0
Scoring category	2. Population regeneration	2	2	2	2	3
	3. Research	1	0	3	0	1
	4. Management	0	0	0	2	0
	5. Commercial importance	1	2	3	1	3
	6. Customary importance	2	3	1	0	1
	7. Recreational importance	1	2	0	1	1
	Total Score	**10**	**10**	**12**	**6**	**9**

Under this proposed framework and classification score threshold of 10, Tory Channel, Maungamanu and Ascots would qualify as HPSFM for pāua, whereas Smoky Bay and Turakirae would not.

d. Addressing the issue of scale

It will be important to address the issue of scale with this classification framework. The above areas range in size (approximate coastline length) of hundreds of metres to several kilometres, and it is likely that within an identified 'area' classified as HPSFM for pāua, that specific habitats within the area may attract different classification scores. Therefore, finer scale classification of HPSFM for pāua may be necessary.

This is explained with an additional example (mock – not from actual data) below for Paparoa Point in PAU3. Applying the framework, the general area would be initially considered due to its importance to recreational fishing (car park access), and its importance to research (current post-earthquake abundance monitoring site), and the classification scoring would see it identified as HPSFM for pāua with a score of 11.

	Area of importance	Paparoa Point
	QMA	PAU3
	Primary category	Research, recreational
	1. Environmental stressors	1
Scoring category	2. Population regeneration	3
	3. Research	3
	4. Management	0
	5. Commercial importance	2
	6. Customary importance	0
	7. Recreational importance	2
	Total Score	**11**

However, there are specific parts of the habitat within this area identified as HPSFM for pāua that could carry different scores based on this framework. This is illustrated in Figure 2 below, which shows that within a general area considered HPSFM (scales of 100s of metres), there may only be discrete patches specific habitat (scales of 10s of metres) within the area that qualify as HPSFM for pāua under this framework.

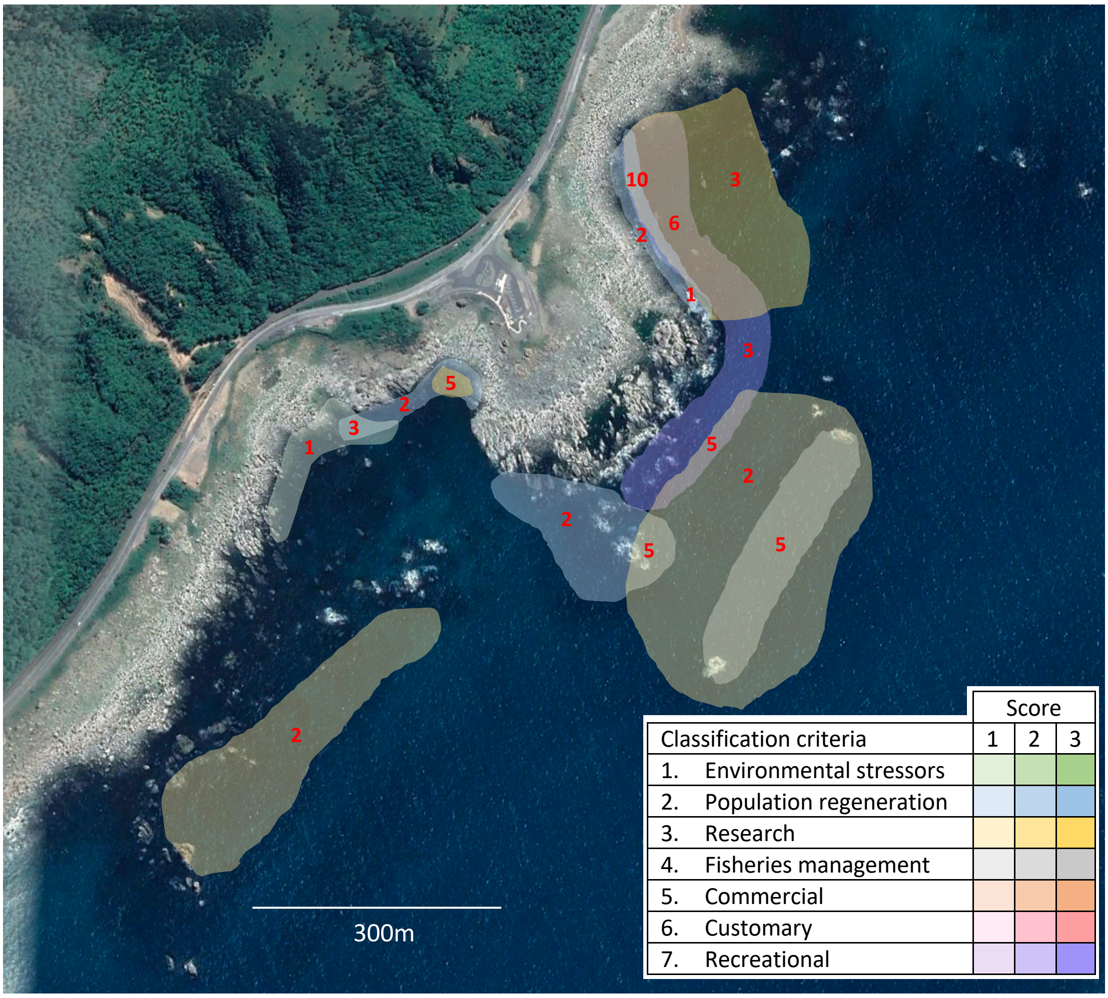


Figure 2. Map of Paparoa Point showing areas of habitat with different classification criteria and weightings. Numbers in red show total weighting score from cumulative criteria weightings for habitat. NB: this is a mock-up, not from actual data.

Ultimately, the scales that are relevant for HPSFM identification need to reflect what is achievable for management and/or protection by decision makers. It is likely that this would need to be determined on a case-by-case basis depending on the threat (type, expected timing, magnitude), and what protection controls are available to decision makers.

7. Key discussion points

- Does the legislative scope of Section 9 of the Act (with consideration of Section 8) extend to cover the need for HPSFM to be protected from all potential environmental effects, not just effect from fishing activity?
- Classification criteria – are these all necessary? Are there other relevant considerations/criteria?
- Classification scoring – should scores for different categories be weighted differently based on their relative perceived importance?
- How should classification scores be decided?
- What is the right score for a habitat to be classified as HPSFM for pāua (proposed as 10)?
- Scale – what scales are relevant for the application of HPSFM classification – area wide vs fine scale? Must reflect that scale the management and/or protection can be applied.
- Is this general framework an acceptable means of identifying HPSFM for paua?

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