USING LOCAL AND SCIENTIFIC PERSPECTIVES TO UNDERSTAND FACTORS AFFECTING THE DISTRIBUTION OF INVASIVE GREEN CRAB (*CARCINUS MAENAS* L.)

by

Jessica Ann Cosham

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Abstract

Environmental management is becoming more informed through the use of less conventional knowledge sources to understand environmental systems. Following this realization, our study accesses both local and scientific knowledge to improve understanding of which environmental factors drive local-scale distribution of an invasive species, the European Green Crab (*Carcinus maenas* L.). It also attempts to understand how *C. maenas* behaviour might differ in the South Shore area of Nova Scotia, Canada. We synthesized scientific knowledge through an extensive literature review, while interviewing local South Shore fishermen who have experience with *C. maenas*. While several environmental factors are delineated, our research also notes internal (i.e. age, sex, moult phase) and temporal (i.e. seasonal, tidal, diel) variables that affect local distribution patterns. Local knowledge of this species is still developing, however it may play a significant role in understanding the local distributions and movements of this species, especially as knowledge develops.

List of Abbreviations and Symbols Used

°C	Celsius
%	Percent
‰	Parts per thousand
~	Approximately
<	Greater than
>	Less than
A	Adult studies
B	Both age classes (adult and juvenile) combined
AG	Agonistic interactions
BIN	Negative biotic interactions
BIP	Positive biotic interactions
BT	Bottom type
cl	Carapace length
cm^2	Square centimeter
CPUE	Catch per unit effort
cw	Carapace width
DO	Dissolved oxygen
DP	Depth
FO	Food source
Fm	Fathoms
GP	Geography
h	Hour
I	Invasive population
Ind.	Individuals
J	Juvenile studies
LWS	Low water spring tide
MLLW	Mean lower low water
MR	Mixed origin (UK, Australia etc.)
MTL	Mid tide level
N	Northern European origin
NN	Non-invading population (when used after ‘N’ or ‘S’, e.g. ‘NN’ or ‘SN’)
m^2	Square meter
mm^2	Square millimetre
msssr	Midway through the night
sl	Shell length
ss	Sunset
sr	Sunrise
S	Southern European origin
SA	Salinity
SH	Shelter
Sig	Significant
SWNS	Southwest Nova Scotia
TP	Temperature
UK	United Kingdom
USD	United States dollars
VG	Vegetation
WM	Water movement / flow

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Chapter 1: Introduction

1.1 Invasive Species, Local and Scientific Knowledge and Environmental Management

With increased globalization, we are experiencing an upsurge in the spread of non-native organisms. Invasive species are of global concern; they are associated with many impacts ranging from out-competition and consumption of native species, disruption of trophic systems and overall ecosystem engineering, to the co-introduction of parasites that pose a threat to other native species (Rudnick, Chan & Resh 2005, Williams, Floyd & Rossong 2006, Karatayev, Boltovskoy, Padilla *et al.* 2007, Shinji, 2009, Wahl, Wolfe, Santucci *et al.* 2011, Arbetman, Meeus, Morales *et al.* 2013). The projected costs of their impacts in Canada alone rise well into the billions of dollars (Colautti, Bailey, van Overdijk *et al.* 2006). Once introduced to a new region, successful invasive species often spread rapidly and are difficult to control (*e.g.* Minchin, Lucy & Sullivan 2002). A prime example of a successful, widely recognized aquatic invasive species on Canada's coasts is the European Green Crab, *Carcinus maenas* (L) (for a review of this species see Klassen & Locke 2007). It is associated with a range of environmental and economic impacts, and while it has been present on Atlantic Canada's South Shore for decades, recent events have allowed this species to increase its range and magnitude of negative effects, and reach more northerly latitudes. Research has highlighted the potential threats this species poses to North American coastal ecosystems and economies, such as negative impacts on commercial fisheries and ecologically significant species such as eelgrass (*Zostera*) (*e.g.* Davis, Short & Burdick 1998, Locke & Klassen 2007, Malyshev & Quijon 2011, Mach & Chan 2013). Ensuring that densities of this species are kept (or reduced to) below ecologically and economically destructive thresholds is crucial. By extension, reducing or limiting populations through sustainable trapping practices is important.

While an ample body of knowledge exists concerning *C. maenas*, much is dated and the majority is conducted from regions outside of the South Shore of Nova Scotia. Within this region, an admixture of two genetically distinct clades of *C. maenas* has resulted from multiple invasion events. The results of this admixture on this species' distribution and behaviour within invaded areas are therefore poorly known, although they may be inferred from the results of scientific research conducted elsewhere (e.g. Aagaard, Warman & Depledge 1995). At the same time, in our area of concern on the Atlantic Coast, a developing body of local knowledge may help expand and reinforce our understanding of *C. maenas* behaviour along the South Shore.

Environmental management has typically relied on scientifically-produced information as the go-to for understanding the world around us. As described by Raymond *et al*. (2010), scientific knowledge relies largely on a formalized, systematic process with emphasis on qualities such as reliability and validity to create a clearly, explicitly (*i.e*. numerically, categorically or graphically) stated product. Such characteristics make scientific information easier to assess and transfer between users. Consequently there is often aversion to knowledge sources that do not follow similar procedures or possess the characteristics of traditional scientific approaches (*i.e.* non-scientific knowledge), as there is concern that the conclusions they produce will not draw upon the same rigour or meet the same standards (Mackinson & Nøttestad 1998). The format in which some knowledge is communicated may differ also, and thus assessment and integration of these knowledge sources may be challenging if they cannot be articulated in a similar manner.

That being said, the scientific community is quick to admit uncertainty (Mackinson & Nøttestad 1998) and when it comes to environmental management, integration of other knowledge sources may help address the shortcomings of traditional scientific approaches. For example, the rigorous and tedious nature of scientific research is useful in achieving higher certainty around the nature of information collected. It is often limited in spatial extent and resolution, however, and unless collected previously (*i.e.* for other projects) it may be challenging to observe past trends in data. Some information is costly and impractical to collect, especially in a world of budget and time limitations (e.g. Gilchrist, Mallory & Merkel 2005, Hermoso, Kennard & Linke 2013). Furthermore, some local stakeholders may be hesitant to trust scientific knowledge (*i.e.* if there is a poor personal history with managing bodies or perceived agendas of contributing scientists) when it is used to back new regulations in a region (Weeks & Packard 1997).

Traditional scientific approaches are not the only knowledge resource available. Experiential knowledge that is often associated with local, traditional or indigenous knowledge holders has also been recognized for its role in environmental management. This ranges from understanding historic trends in population sizes and distributions to prioritizing areas for conservation efforts, to management of marine protected areas (Balram, Dragićević, & Meredith 2004, Gass & Wilson 2005, Gerhardinger, Godoy & Jones 2009).

In this manuscript, we implement both local and scientific knowledge to elucidate which environmental factors drive local scale distribution of an invasive species, the

European green Crab (*Carcinus maenas* L.). This crustacean has been of growing concern in the Canadian Maritimes in recent years, and there has been a substantial push for its control as it causes significant economic and ecological impacts. In order to better understand the factors driving its inshore, local-scale distribution, we collected local harvester knowledge along the South Shore, as well as a wider body of literature containing scientific information on *C. maenas*. In this thesis, these are used to identify the factors each knowledge source supports in shaping this species' local distribution. The primary objective is to improve understanding of *C. maenas* distributions for future management purposes (*e.g.* planning more efficient removal strategies for population reduction, ecosystem restoration or a targeted fishery). However, we also demonstrate how local knowledge of this crustacean (though relatively new) may contribute to improved understanding and management effectiveness, and provide further general insight into the role of local knowledge in environmental management.

1.1.1. What is Local Knowledge, and Why is it Important?

While local knowledge is often confused with other sources of experiential learning, it can be distinguished as the understanding produced through an individual's direct exposure and experience within an environment (for examples see Raymond *et al.* 2010)**.** While *local* knowledge may be developed within a community, it doesn't usually include knowledge passed down through generations, as with *traditional* knowledge. Local knowledge is usually greatest with aspects of the environment that the individual has direct investment in or interaction with (*i.e.*. species that are hunted, fished or foraged); such understanding usually affects a resource user's success with their livelihood (Olsson & Folke 2001, Gilchrist *et al.* 2005, Murray, Neis & Johnsen 2006, Garcia-Quijano 2007). The detailed and locally relevant nature of such knowledge makes it of great potential value to research. Furthermore, local knowledge may help elicit both spatial and temporal patterns and interactions and site-specific nuances, which may not be as easily detected using traditional scientific methods (Poizat & Baran 1997).

Local knowledge has already been implemented in natural resource management and conservation research (*e.g.* marine protected areas planning, ecological monitoring and restoration) and recognition of its potential is on the rise. It can contribute to existing datasets or provide information in areas where data is scarce: to assist with stock assessment**,** to cross-check information, to generate more detailed understanding of environmental phenomena, and to identify on changes in the environment (Breeze 1997, Poizat & Baran 1997, Neis *et al*. 1999, Olsson & Folke 2001, Huntington, Suydam & Rosenberg 2004, Aswani & Lauer 2006, Garcia-Quijano 2007, Raymond *et al*. 2010). Furthermore, integration of local knowledge and values to facilitate local environmental and resource management decisions may garner greater community acceptance of plans (Weeks & Packard 1997).

1.1.2. Limitations of Local Knowledge

There are nonetheless concerns over the implementation of local knowledge in research. Despite signs of progress and in many cases a demand for greater consideration of local knowledge in management, there remains a debate over the reliability of local knowledge given its qualitative, anecdotal, and potentially biased nature (Poizat & Baran 2007, Griffin 2009). Davis & Ruddle (2010) addressed this issue, conceding that while local knowledge has its merits in research, the knowledge provided is often not tested or challenged to confirm its validity. As with any information, use of local knowledge without recognition of its limitations (*e.g.* applying information at inappropriate scales from that at which it was collected) may produce poor results, and will only serve to discredit its validity for use in future projects. Conversely, as noted by Gilchrist *et al.* (2005), knowledge may be seen as more credible if it stands up to scrutiny**.**

The question of how to integrate knowledge sources (which often stem from unique epistemologies and backgrounds), is also a common issue (*e.g.* Balram *et al.* 2004, Close & Hall 2006). The respective limitations of both local and scientific knowledge warrant exploration, as these may compromise the quality of any conclusions. If knowledge sources bear complementary strengths and weaknesses, they may be implemented in such a way as to minimize uncertainty and maximize understanding**.**

1.2. Species Distribution and Relevance to Management

1.2.1. Local Knowledge and Use in Distribution Models

One recognized use of local knowledge is to understand wildlife population dynamics and changes in species distributions. Predictions of habitat suitability, species occurrence and response to major influences such as climate change, as well as understanding of the factors driving these events, are often developed using computer-based species distribution models (SDMs) (Dambach & Rödder 2011, Gogol-Prokurat 2011, Aguirre-Gutiérrez *et al.* 2013, Patterson 2014). These may be created from existing data or primary surveys, however local knowledge has also found its ‘niche’ in contributing to these. Local experts may provide information on species occurrence and abundance within geographic regions, or help elicit the factors shaping such distributions (Leon 2009, Anadón, Giménez & Ballestar 2010, Patterson 2014). The results of these models may be used in planning and management of fishing activities, conservation strategies, as well as resources for combatting invasive species (*e.g*. Baxter & Possingham 2011, Chang, Sun, Chen *et al.* 2012, López-Arévalo *et al.* 2011). The latter of these, management of invasive species, we explore in this manuscript.

1.2.2. Application to Management of an Invasive Species – a Case Study

C. maenas, is a pan-global marine invasive crustacean that is listed among the 100 World's Worst Invasive Alien Species (Lowe, Browne, Boudjelas *et al.* 2000). *C. maenas* has appeared in Africa, Australia, and on both coasts of the Americas. This species acts as an ecological engineer to invaded regions, and has been known for causing significant environmental and economic damage (Carlton, Cohen & Fountain 1995, Carlton & Cohen 2003, Locke & Klassen 2007). *C. maenas* is a generalist predator with a strong preference for bivalves and it predates upon a number of commercial species ranging from soft shell clams (*Mya arenaria)*, quahogs (*Mercenaria mercenaria)*, oysters (*Crassostrea gigas*), and blue mussels (*Mytilus edulis*) to flounder and (*Pseudopleuronectes americanus*), even lobster (Dare, Davies & Edwards 1983, Grosholz & Ruiz 1995, Floyd & Williams 2004, Miron, Audet, Landry *et al*. 2005, Taylor 2005, Baeta, Cabral, Marques *et al*. 2006, Rossong, Williams, Comeau *et al*. 2006). Ecological disturbances caused by *C. maenas* include destruction of *Zostera*, displacement of and competition with native species, and cascading indirect impacts depleting migratory bird populations (Seymour, Miller & Garbary 2002, Malyshev & Quijon 2011).

Estimated figures for future impacts of *C. maenas* are equally grim. In California, loss of revenue for the commercial shellfish industry was placed at $1 to $44 million USD per annum from *C. maenas* predation (Mach & Chan 2013). In Atlantic Canada, a tentative estimate of $1 million per annum has been made for the Gulf of St. Lawrence from bivalve and aquaculture losses (Locke & Klassen 2007). While these are highly speculative and variable estimates, they reflect a grave spread of potential outcomes. *C. maenas* is believed to invade using a variety of vectors, primarily ballast water, which is responsible for the introduction of many invasive species. In the past, *C. maenas* has also invaded through hull fouling (attaching themselves to the undersides of a ship or hiding among other fouling organisms), or by occupying bored holes and dry ballast in wooden ships. Preventing successive invasions is difficult, and *C. maenas* has appeared sporadically along the East Coast of North America (Carlton & Cohen 2003, Darling, Bagley, Roman *et al*. 2008, Blakeselee *et al*. 2010). In Nova Scotia, this species was first documented through verbal accounts in the 1950s and now occupies the majority of sheltered waters and estuaries along the provincial coastline (Audet *et al*. 2003).

On the Atlantic coast of North America, *C. maenas* colonization was previously limited to latitudes not much further north than Halifax, Nova Scotia due to environmental constraints (larval stages are thought to be sensitive to colder northern temperatures) or other geographic barriers (such as a lack of sufficient retention zones, meaning that larvae could not successfully disperse far enough northward to colonize the next-nearest suitable habitats) (Berrill 1982, Pringle, Blakeslee, Byers *et al*. 2011). It is believed that, until the 1980's, the *C. maenas* populations of North America had all originated from southern European populations. A second invasion of *C. maenas*, this one originating from the northern populations of Europe, is believed to have occurred in the 1980's and preceded a rapid colonization of the rest of Nova Scotia. It has been suggested that these crabs are more tolerant to cold, which may have facilitated their expansion along with as an observed lengthening of seasonal activity (Audet *et al*. 2003, Roman 2006, Ure, Chisholm & Kehler 2010). These populations have also displayed more aggressive foraging and competitive behaviours that may pose additional threats to local ecosystems and fisheries (Rossong *et al*., 2011). Furthermore, since their arrival, this population of *C. maenas* has mixed with populations from the first invasion, creating a region of genetic admixing. This admixture has spread outwards from Southwest Nova Scotia (SWNS), and its influence has now been detected both further north and south along the Atlantic coast (Pringle *et al*. 2011, Blakeslee *et al.* 2010). Considering the recent discovery of this event, little research has been conducted concerning the behaviours of this population of *C. maenas*, and consequently it is uncertain whether its distributions and behaviour in inshore embayments may differ from those of other clades.

While most management plans for this species suggest that complete eradication of *C. maenas* is improbable, trapping is thought to be an effective means of mitigation in partially-enclosed systems and is under consideration with various management plans (Walton 2000, National System for the Prevention and Management of Marine Pest Incursions 2009, Grosholz 2011). Trapping has already shown moderate success in some invaded regions, such as Little Port Joli Estuary, a Parks Canada-managed estuarine system along the South Shore of Nova Scotia. Over the course of half a decade, intensive trapping efforts were able to reduce population numbers to below target densities (16 crabs/trap) in this ecosystem; while some green crabs are still present, numbers are now being kept in check with a more limited trapping strategy (McCarthy, *personal communication*, 2015). Such efforts also highlighted the disproportionate distribution of *C. maenas* to some areas of the estuary, areas which were subsequently targeted when attempting to reduce the population. Improved understanding of the local temporal and spatial factors driving *C. maenas* distribution as observed in this example, especially as they pertain to the *C. maenas* clade along the South Shore, may be beneficial to future monitoring and restoration plans in the area. They may also benefit any *C. maenas* fisheries planning by helping create more informed and effective harvest strategies. Furthermore, as the admixture front spreads further along the Western Atlantic shore board, understanding of how local *C. maenas* populations may change behaviourally may be useful in structuring these various management plans.

Local knowledge has been only occasionally solicited in other Maritime-based studies of *C. maenas* (*e.g.* Tremblay *et al*. 2006). Despite this, fishermen along the Nova Scotia shoreline have voiced concern around *C. maenas* populations, and while most fisheries occur offshore from where *C. maenas* are a concern, there are some potential knowledge sources regarding the local distribution of this species. These include inshore harvesters that experience *C. maenas* as a by-catch species, as well as those that have been involved in removal efforts for a number of years (for example those involved in the removal efforts at Little Port Joli) and, more recently, a bait fishery for *C. maenas.* Thus, local knowledge may provide insights into the nature of local *C. maenas* distributions.

A substantial body of literature already addresses the factors shaping *C. maenas* distribution in local scale regions, although these are mostly derived from other geographic areas (*i.e.* at different latitudes along the same coast, or different coasts altogether) and many only focus on a subset of environmental variables. Nonetheless these works highlight the factors that have been most commonly attributed (from a scientific perspective) as local determinants of *C. maenas* distributions. By comparing the conclusions of these local and scientific knowledge sources, we may elucidate those factors that are most prevalent among each, and common to both, as well as eliciting the benefits and limitations of each knowledge source as they apply to *C. maenas* management (Griffin 2009).

1.3. ***Research and Objectives***

In this manuscript we identify key factors that characterize *C. maenas* populations in their spatial and temporal local-scale distributions, using local and scientific knowledge resources such as expert consultation and literature review. We then compare the responses elicited by these knowledge sources to identify where they converge or conflict, highlighting any relative strengths or weaknesses of each in the process.

Through this research, we answer the following questions: what are the major factors characterizing *C. maenas* distributions, from scientific and local knowledge perspectives; and do responses to these factors potentially differ in South Shore populations from other clades? The findings provide a set of recognized environmental factors and recommendations that may inform *C. maenas* management, monitoring and restoration strategies and fishing activities, particularly in the South Shore area.

The majority of this manuscript is written as a series of publications, contained within the following three chapters. The first (Chapter 2) focuses on summarizing the current scientific knowledge of factors affecting *C. maenas* distribution at the local scale, with particular emphasis on their applicability to modelling; Chapter 3 addresses the same question from a local knowledge-based perspective, using information provided by local *C. maenas* harvesters based along the South Shore of Nova Scotia; and Chapter 4 compares and contrasts the results of the two preceding chapters, emphasizing the relative strengths and limitations of each major knowledge source. While care is taken to reduce the amount of overlap between areas, there are inevitably some redundancies as the background and methods sections are repeated in the three consecutive chapters. The final chapter (5) provides synthesis discussion and conclusions that integrate across the publications/chapters, reflecting back to the research objectives and questions.

Chapter 2: Local-Scale Environmental Factors of European Green Crab (*Carcinus maenas*) Distributions for Modeling and Management Applications

Jessica Cosham[1], Karen Beazley[1], Chris McCarthy[2]

1. School for Resource and Environmental Studies, Dalhousie University, 6100 University Ave, PO BOX 15000, Halifax, Nova Scotia, Canada, B3H 4R2
2. Kejimkujik National Park & NHS, Mainland Nova Scotia Field Unit, Maitland Bridge, NS. B0T 1B0

Abstract

Environmental factors determine the habitat selection, use, and ultimately the distributions of species at various spatial scales. Understanding of the factors driving distributions can ultimately help predict areas of higher species occurrence. In this study we reviewed publications and other reputable documents to evaluate the most conspicuous factors shaping local-scale distributions of a globally invasive species, the European green crab (*Carcinus maenas*). We compared these studies to determine differences across life stages (juvenile and adult), clade origins, as well as the influence of internal and temporal factors. Factors such as depth, biotic interactions, vegetation, presence of shelter and salinity were important, although the relevance of these varied between juvenile and adult stages. The importance of environmental factors varied somewhat by clade also; and internal factors, such as size, sex and moult stage, and temporal interactions such as seasonal, tidal and diel variations played a role in distributions. The implications of these findings are discussed with respect to their utility in species management, and limitations are noted.

***Publication pending submission to Environmental Reviews**

Keywords: habitat, species distributions, green crab, *Carcinus maenas,* modelling, environmental factors

2.1 Introduction

Habitat quality and availability are recognized determinants of population success (Hodgson, Moilanen, Wintle *et al.* 2011). Habitat comprises the sum of areas where a species completes activities necessary for life, and ties in closely with the niche concept, the sum of resources and environmental conditions (including biotic interactions) that permit an individual's survival and reproduction (Whittaker, Levin & Root 1973, Krausman 1997). By this logic, habitat is represented demographically, and (while there are a number of associated caveats) higher population densities can act as an indicator for habitat quality (Van Horne 1983). Therefore, quality habitat may by extension be considered a proxy for areas with high harvesting potential, for instance for invested managers of a commercial species (*e.g.* Chang *et al.* 2012) or targeted removals of an invasive species.

Habitat selection is a hierarchical process that occurs at a variety of spatial scales, with different factors taken into account at each (Hutto 1985). At regional or global scales, important variables typically include climatic factors such as latitudinal temperature and precipitation that delineate the absolute limit of a species' range (Blach-Overgaard, Svenning, Dransfield *et al.* 2010, Compton, Leathwick & Inglis 2010). At finer scales, resource availability and biotic interactions more often influence habitat selection, although there is some contention over this (Chuine 2010, Wisz *et al.* 2013). This compliments the concept of habitat use, the division of resources for different activities such as foraging, spawning, protection or other necessary life tasks (Litvatis *et al.* as cited in Krausman 1997). The influences that different factors exert on populations vary with the temporal and spatial scale under consideration (Specziár, György & Erős

2013, Svensson, Jonsson & Lindegarth 2013). Collectively, these mechanisms drive the spatial and temporal distribution of species.

Within broad-scale areas where invasion and establishment of a non-native species has occurred, understanding forces that drive species distribution at a finer scale is beneficial to predicting species distribution. In modelling and management applications, this may also include consideration of which biologically relevant factors can be most readily monitored or mapped. There is a disjoint often noted between variables that are biologically relevant and those that are ultimately employed in distribution models, due to the challenges associated with collecting data for and modelling more complex factors (*i.e.* biotic interactions between antagonistic species) (Snickars *et al.* 2014). The response of species to environmental factors often results in distributions varying in both time and space, including seasonal, diel and tidal movements, and may further differ depending on "internal" population factors, such as the sex and phenological condition (e.g. spawning or moulting) of individuals within a population (*e.g.* Silva, Hawkins, Boaventura *et al.* 2010, Dambach & Rödder 2011, Dalmau, Ferret, Ruiz la Torre *et al.* 2013, Martin *et al.* 2013).

The European green crab, *Carcinus maenas,* poses such an example. This invasive crustacean is both an ecological and economic threat to many regions along the Northwest Atlantic Coast. For example, eelgrass (*Zostera marina*) and commercial bivalves such as softshell clam (*Mya arenaria*) and blue mussel (*Mytilus edulis*) are among the species predated by *C. maenas* (Davis *et al.* 1998, Miron, Landry, & MacNair 2002). As a consequence of such natural process impacts, there is a push for monitoring and management of *C. maenas*. Manual removal is currently the most pragmatic means of control, and improved understanding of their local-scale distributions may be useful to maximize trapping efficiency. While models have been constructed to address habitat-related concerns around *C. maenas*, these primarily involve invasion risk and potential economic or ecological impacts (Colnar & Landis 2007, U.S. Environmental Protection Agency 2008, Grosholz, Lovell, Besedin *et al.* 2011) and focus less on the factors driving distributions within invaded habitats. Increased understanding of their distribution at lower densities and pre-invasion may help increase the effectiveness of management activities such as control and /or planning for commercial fisheries.

Consequently, in this review, we provide a comprehensive synthesis and evaluation of existing literature on biotic and abiotic drivers of local scale habitat distribution of *C. maenas*. We compile a comprehensive listing of key environmental drivers previously identified as determinants of *C. maenas* distribution, hierarchically arranged by (1) the most established support and (2) practical use as monitoring tools. We also highlight key considerations for understanding distribution at this scale, important to modelling and other management applications. These results can help inform strategies for monitoring and control, such as determining effective locations for traps, as well as highlighting areas warranting further research.

2.2 Methods

Our study follows a methodology similar to that of Snickars *et al.* (2014), who conducted a review prioritizing regional predictor variables for fish, macroinvertebrate and macrovegetation distributions in the Baltic Sea. We conducted an exhaustive review of the literature, involving 1) an initial scan of online databases (key search engines included Google Scholar, Worldcat, and Web of Science; see Appendix A, Table A1 for a list of search keywords) and 2) a review of literature provided by key informants including government documents and published journal articles. The review was primarily limited to peer-reviewed journal publications, however theses and government research reports were also included. For example, Parks Canada State of the Park Reports, personal archives belonging to the primary author, as well as recommendations of related articles from online scientific databases such as ScienceDirect were used to find further resources. We initially selected articles by scanning for relevant titles; abstracts were reviewed to filter ineligible papers (documents not meeting the criteria outlined below). We sought further papers using a pearl-growing method from the works cited sections of current articles. All relevant articles were saved and stored in Mendeley reference manager as PDFs for later reference and access; in the case of hard documents, photocopies were made for easy access.

Articles were considered that involved: 1) one or more experiments concerning green crab, either as the sole focus or as one of multiple species studied, however containing results explicit to green crab; 2) a field or lab-based study that focused on relationships between environmental factors and green crab distribution, including considerations for ontogenetic, phenological, temporal or clade-based influences (at the local scale); or, 3) testing a relationship with a high potential for influencing distribution of green crab in the field.

Conversely, articles were excluded if they: 1) only presented model simulations of green crab distribution or movement without any field or laboratory observations; 2) addressed behaviour according to factors that do not present potential implications for spatial distribution or use; 3) focused solely on locomotor activity patterns with respect to environmental influences (*i.e.,* they did not consider directional responses to environmental factors); or, 4) didn't address adult or juvenile stage green crabs (*i.e.,* studies focusing on larval stages). Studies related to habitat complexity (*i.e.,* with respect to vegetation) were also not included. No restrictions were placed on the geographic location and research/publication date for studies, however these were noted in order to clarify the clade of *C. maenas* most likely being addressed in the study.

Biotic interactions, such as with food resources, are rarely studied in terms of green crab distribution, however biotic interactions have frequently been recognized in the literature as factors likely to influence distributions (Wisz *et al.* 2013, Snickars *et al.* 2014). They are also widely accepted as a key facet in the realized niche model which underpins species distributions, and are thus a key consideration in this study. These interactions involve food sources (prey), predation, competition or parasitism. Adequate food resources are integral to survival, reproduction and persistence of a given population; conversely, competition for resources or predation may have negative implications for fitness, and have implications for the occupation of an otherwise suitable habitat (see, for example, McLoughlin, Morris, Fortin *et al.* 2010, and all of their reviewed citations). For such reasons we explored studies concerning specific food source preferences of these species, as the prevalence and demographic of a prey species is likely to affect the distribution of the predator. This was inferred from studies using results from experiments concerning, for example: 1) predation on prey species in open versus exclusion enclosures; 2) predation intensity in cages with prey and green crab; and, 3) predation ability on prey species of varying relative sizes. We also included studies investigating direct instances of predation and competition among individuals, where episodes of avoidance, displacement or mortality were considered to be significant interactions, and records describing co-inhabitance of species without significant displacement or mortality were considered non-significant interactions. These included both lab and field studies; the former addresses the potential for antagonistic interactions and their outcome, whereas the latter illustrates whether such interactions might be expected to occur in the field due to niche overlap. While interactions with different species within a single study were considered as individual records, records with generalized interactions for all species (for instance, a significant effect of size on predation rates occurring across all prey species) were noted as a single record.

2.2.1. *Data Collection (Types, Criteria)*

The focus of the review is centered on abiotic and biotic environmental factors associated with local scale spatial distribution. In consideration of the research purpose, the review also noted: 1) spatial scale indicated in the study (because the study focuses on effects at a local scale, only results comparing local variation were considered, even if the study also studied effects at other scales); 2) temporal scale (fluctuations on a daily or seasonal scale); 3) the age classes considered (most studies explicitly stated whether juvenile and adult specimens were sampled; otherwise this was inferred if carapace sizes were mentioned, with juveniles usually classed as individuals at or under 30-35 mm carapace width) or differing distribution according to phenology and sex of individual crabs studied; and 4) the geographic origin of the crabs studied, as there have been some suggestions of behavioural differences occurring between allopatric populations (Rossong *et al.* 2011, Haarr & Rochette 2012). Geographic origin was roughly categorized according to Roman & Palumbi (2004) and Brian, Fernandes, Ladle *et al.*

(2006) who previously identified four distinct native populations in Europe (Fig. 2.1). Some studies were omitted where descriptive observations were too general to elicit specific factors or language barriers prevented proper understanding of articles.

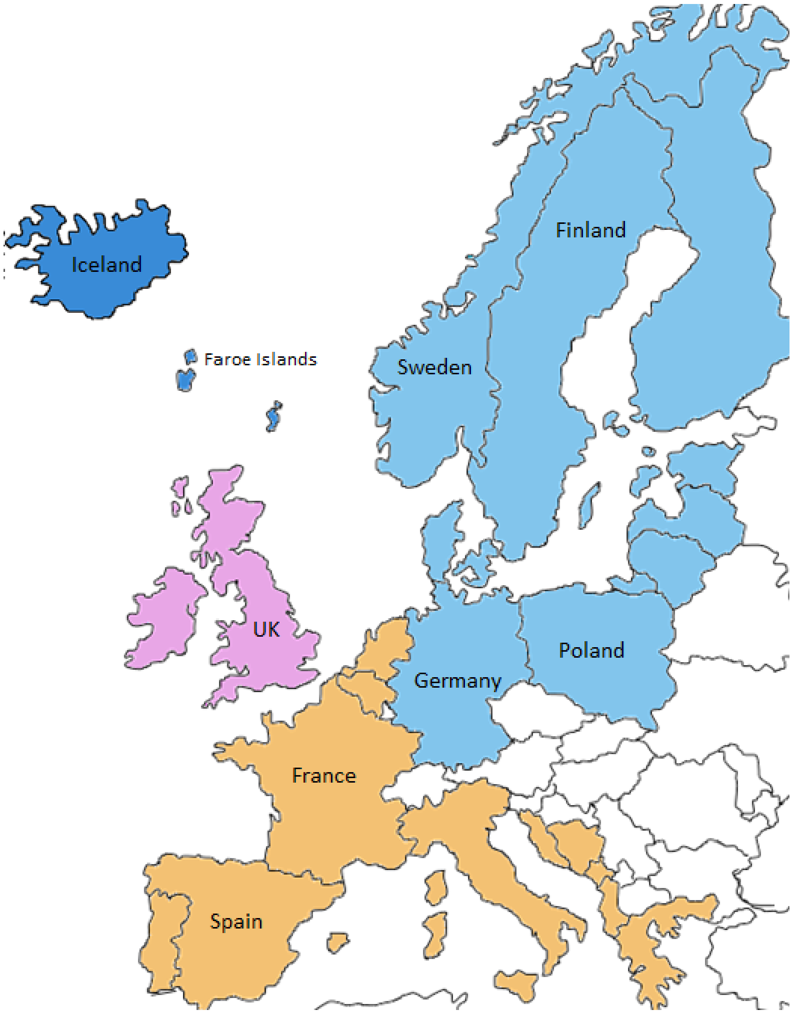

Figure 2.1: Map of Western Europe. The greatest divisions of native *C. maenas* clades exist between Iceland/Faroe Islands (deep blue) and the rest of continental Europe; a smaller division exists at regions south of (orange) and north of (light blue) Germany. The UK (mauve) appears to contain individuals from both sides of the Germanic division, although primarily bears similarities to Western European (orange) populations and overall shows little genetic diversity across the island. *C. aestuarii* regions are also indicated (orange).

(Map adapted from Google Maps 2014, with clade divisions according to Roman & Palumbi (2004) and Brian, Fernandes, Ladle *et al.* (2006)).

Additional factors were identified and incorporated into a Microsoft Excel spreadsheet to be used in contextualizing and synthesizing results. This spreadsheet quantifies the key factors observed, the number of studies concerning each factor, as well as the number of individual records (as one study may produce several records concerning different factors or observing factors which illustrate both main and interaction effects) supporting or refuting each factor. Records were pooled, regardless of age category, and separated into adult and juvenile records. While adult and juvenile studies were compared separately, some studies excluded information concerning carapace sizes and therefore were considered to be relevant for all age classes (these studies were excluded from the juvenile and adult analyses, however were included in the pooled analysis). We used a separate evaluation of adult and juvenile studies to determine whether different factors govern different life stages, as many crustacean species demonstrate demographic shifts to different habitats (Pallas, Garcia-Calvo, Corgos *et al.* 2006, Andrade *et al.* 2014).

Documents often compared multiple experiments, geographic populations, as well as lab and field tests. The decision-making framework for managing these studies is outlined in Table A2 (Appendix A), and includes consideration of studies conducted with more than one *C. maenas* clade, documents with multiple distinct studies (*i.e.* different researchers), single studies with multiple experiments, as well as single studies with multiple statistical outputs.

2.2.2. *Synthesis and Analysis*

All data were managed using Microsoft Excel software. Multiple criteria were used in our analysis; these include the percentage of studies concerning a given factor as well as the number of studies supporting a factor, either with observational support or statistical confidence. Records involving statistical support were pooled with observational records and also considered separately. Records of factors having no effect or non-significant (ns) effects were included. To evaluate whether the effect of a factor differed by region, or between age classes, consistency of these records in the literature between adult and juvenile studies, across geographic populations, and so forth was noted. The number of records noting demographic or phenological influence on the effect of a factor, as well as temporal interactions, was also considered. The environment where research was conducted (lab studies versus water bodies) was also noted. All factors were quantified for inclusion in a comparative analysis. General qualities of each factor (for example, the specific 'type' of bottom most often emphasized as important) were also noted as accurately as possible. The complete summary of these data, as well as the codes used within, can be found in Appendices B, C and D.

2.3. ***Results***

This section describes the key results of this analysis. A general description of the revealed body of literature first provides a picture of the origins and types of data supporting the results. The most prevalent abiotic and biotic environmental factors associated with local scale spatial distribution of *C. maenas* as found in the literature is then presented. These are compared by age class, geographic origin and interactions, and lead into a description of the internal and temporal factors noted.

2.3.1. Studies of Environmental Factors

A total of 71 studies (63 published research articles, six government reports, one book chapter and one graduate thesis) were selected for full review. The majority of studies contributed multiple records (unique observations of factors). Eleven factors were elicited, and fall into the following 5 categories (adapted from Snickars *et al* 2014): 1) bottom topography, including i) depth (considering movements within the tidal column, onshore exposure and sub tidal preferences) and ii) shelter (focusing on use of stones and discarded shells or mussel beds in lab or field settings); 2) biotic features, including, i) vegetation (including algae and macroalgal growth), ii) food source (fauna actively predated on in lab or field observations), and iii) agonistics (including competition with, avoidance of, displacement or predation by other species); 3) hydrography, including i) salinity (either preferences for a set salinity or tolerance to salinity changes), ii) temperature, iii) dissolved oxygen and iv) water pH, 4) exposure, including i) flow (including current and wave exposure), and 5) substrate, including i) bottom type (primary sediment type, *i.e.* mud or sand). Of these studies, 26 involved *C. maenas* of mixed native origins, 20 involved northern European populations, and 25 involved southern European populations (one study involved populations from invasive samples that originated from all three regions (Haarr & Rochette 2012)). Studies entailed field work from 1958 to 2012, the majority (over 70%) of which were conducted within the last 20 years. Thirty-four of the studies were conducted in Europe, 3 in Australia and 34 in North America.

2.3.2. Records - General Trends

Water depth, including location in the tidal column, was a frequently acknowledged factor for both juveniles and adults (in 13% and 22% of studies, respectively) as was agonistic interactions (in 20% and 24% of studies, respectively). In the combined analysis (*i.e.* studies not detailing size class), water depth (19%) was considerably exceeded by agonistic interactions (33%). Agonistic interactions were also more often supported statistically (Table 2.1). No studies found a non-significant effect of depth on *C. maenas* distributions.

Highest *C. maenas* densities occurred from six meters of depth up to the shoreline, and varied according to age class, moult phase, sex, season, tidal phase and the time of day/night (see Appendix E for further details). Agonistic interactions occurred with a number of species and ranged from displacement to predation and mortality; the outcome was dependant on the species as well as size class. In some cases, some species were found to not interact negatively at all (*e.g.* Breen & Metaxas 2009).

Adult and juvenile studies varied somewhat in their emphases. Depth and agonistic interactions ranked highly in both adult and juvenile analyses. For juveniles, vegetation and shelter were also important, whereas for adults this was replaced by salinity and food source (Table 2.1). Vegetation and shelter included discarded shells, live mussel beds (namely for juveniles), rocks, *Zostera*, kelp, algae and rockweed. Preferred salinity ranged from 22-35‰, with red crabs (usually close to moult) preferring more saline conditions. *C. maenas* were found to use a wide range of food sources; again these were dependant on the species, and predation rates by *C. maenas* often depended on prey size.

Records concerning biotic interactions were most often conducted in a laboratory setting. Agonistic interactions had both a high number of statistically significant records as well as the highest number of non-significant records (either where *C. maenas* was shown to not compete with or to avoid agonistics, or was shown to produce significant mortality rates to an agonistic).

Noted less frequently in the literature were pH, dissolved oxygen, bottom type, flow and temperature, although this may have been in part due to a bias in the interests of the scientific community. Dissolved oxygen only appeared to have an impact on crabs late in the moult cycle (red crabs), and bottom type use ranged from mud, silt and sand to cobble. Temperature was found to primarily affect the depth at which *C. maenas* was found. Flow was inconsistent: while in some cases *C. maenas* was found at higher densities in areas with a current, they were aversive to direct wave exposure and also common in low-flow sites when foraging.

A) All studies	Depth	Shelter	Vegetation	Food Source	Agonistics	Salinity	pH	DO	Temperature	Flow	Bottom Type
Number of Studies	**13**	**10**	**14**	**19**	**23**	**12**	**1**	**5**	**10**	**3**	**6**
% Studies Observing	**18**	**14**	**20**	**27**	**32**	**17**	**1**	**7**	**14**	**4**	**8**
P < 0.005	6	5	3	11	11	1	0	1	1	1	1
0.005 < p < 0.05	8	5	4	10	10	2	0	0	2	2	0
Descriptive support	36	5	7	6	8	5	0	2	6	1	5
Discussed support	0	0	2	0	2	3	0	0	0	0	0
Non-Significant (p > 0.05) or refuting support	**0**	**0**	**0**	**3**	**15**	**1**	**1**	**2**	**5**	**1**	**0**
Total Records (interactions)	**13 (37)**	**3 (12)**	**10 (6)**	**7 (23)**	**39 (7)**	**7 (5)**	**1 (0)**	**2 (3)**	**4 (8)**	**2 (3)**	**2 (4)**
Total Statistically Significant Records (interactions)	**6 (8)**	**2 (8)**	**5 (2)**	**5 (16)**	**13 (10)**	**1 (2)**	**0 (0)**	**0 (1)**	**1 (2)**	**1 (2)**	**1 (0)**

B) Juvenile Studies	Depth	Shelter	Vegetation	Food Source	Agonistics	Salinity	pH	DO	Temperature	Flow	Bottom Type
Number of Studies	**4**	**6**	**8**	**3**	**6**	**0**	**0**	**0**	**1**	**0**	**0**
% Studies Observing	**14**	**21**	**29**	**11**	**21**	**0**	**0**	**0**	**4**	**0**	**0**
P < 0.005	1	1	1	1	0	0	0	0	0	0	0
0.005 < p < 0.05	1	3	3	2	5	0	0	0	0	0	0
Descriptive support	2	3	3	0	0	0	0	0	1	0	0
Discussed support	0	0	1	0	0	0	0	0	0	0	0
Non-Significant (p > 0.05) or refuting support	**0**	**0**	**0**	**0**	**2**	**0**	**0**	**0**	**0**	**0**	**0**
Total Records (interactions)	**0 (4)**	**3 (10)**	**4 (4)**	**1 (2)**	**4 (3)**	**0**	**0**	**0**	**0 (1)**	**0**	**0**
Total Statistically Significant Records (interactions)	**0 (1)**	**2 (5)**	**3 (1)**	**1 (0)**	**2 (3)**	**0 (0)**	**0 (0)**	**0 (0)**	**0**	**0 (0)**	**0**

C) Adult Studies	Depth	Shelter	Vegetation	Food Source	Agonistics	Salinity	pH	DO	Temperature	Flow	Bottom Type
Number of Studies	**13**	**1**	**1**	**13**	**14**	**10**	**0**	**2**	**3**	**1**	**2**
% Studies Observing	**22**	**2**	**2**	**22**	**23**	**17**	**0**	**3**	**5**	**2**	**3**
P < 0.005	3	1	0	9	8	1	0	1	1	1	0
0.005 < p < 0.05	3	1	0	8	5	2	0	0	0	2	0
Descriptive support	14	0	1	3	3	3	0	0	1	0	2
Discussed support	0	0	0	0	2	3	0	0	0	0	0
Non-Significant (p > 0.05) or refuting support	**0**	**0**	**0**	**3**	**9**	**1**	**0**	**1**	**1**	**1**	**0**
Total Records (interactions)	**7 (13)**	**0 (2)**	**1 (0)**	**5 (18)**	**25 (2)**	**5 (5)**	**0**	**1 (1)**	**1 (2)**	**1 (3)**	**1 (1)**
Total Statistically Significant Records (interactions)	**2 (4)**	**0 (2)**	**0 (0)**	**4 (13)**	**11 (2)**	**1 (2)**	**0 (0)**	**0 (1)**	**0 (1)**	**1 (2)**	**0 (0)**

Table 2.1: Comparisons of the number of studies and records reporting descriptive or statistically significant (either $0.005 < p < 0.05$ or $p < 0.005$) evidence of factors posing an effect on *C. maenas* distribution in local-scale studies. Numbers are shown for **A)** all age classes, and solely **B)** juvenile or **C)** adult records. Records with interactions with temporal, phenological, ontogenetic or biotic factors are noted in brackets. DO = Dissolved Oxygen. Dividing lines group factors into five broader categories (see section 2.3.1).

2.3.3. *Interactions*

Interactions with demographic and temporal variables were noted in 54% of records, and were found to impact virtually all environmental factors. Of the studies observed, depth demonstrated the broadest range of interactions with carapace width, color, sex as well as circadian, tidal and seasonal temporal influences (Table 2.2). Temperature changes affecting distribution were frequently (at least 63% of supporting records) associated with shifts in season. The outcome of biotic interactions (food sources as well as agonistic interactions) were frequently dependant on size disparities between predator and prey or agonistic pairs. Salinity preferences were often affected by sex or carapace color, although this support was primarily restricted to adult specimens. Dissolved oxygen was only found to substantially affect *C maenas* distributions when carapace color was taken into account. Overall the primary interaction effect was carapace size, or age, while depth was the factor most broadly dependent on demographic and temporal interactions.

It is important to note that interactions were only noted if they were found to affect an environmental factor on multiple occasions; if an interaction effect occurred fewer than three times in the literature (or in the case of factors with fewer than three records, if the interaction didn't occur with every record), the interaction effect was not noted.

Table 2.2: Prevalence of main interacting factors (internal, temporal, phenological) affecting main environmental factors observed in this study. An 'x' indicates where a factor was found to interact with a main factor in more than two records, with either (B) both adult and juvenile, as well as age-nondescript populations, (A) with adult crabs, or (J) with juvenile crabs. Dividing lines group factors into five broader categories (see section 2.3.1).

Interactions	**CW**			**Sex**			**Color**			**Time (season)**			**Time (tide)**			**Time (circadian)**		
Factor	B	A	J	B	A	J	B	A	J	B	A	J	B	A	J	B	A	J
# Depth	x	x	x	x	x		x	x		x			x	x			x	
# Shelter	x		x															
# Vegetation	x		x															
# Food	x	x	x															
# Agonistics	x	x	x															
# Salinity				x	x		x	x										
# Temperature			x	x						x								
# pH																		
# Dissolved Oxygen							x	x										
# Flow																		
# Bottom Type	x			x														

2.3.4. Variation by Clade / Region

The relative distribution of records for environmental factors and significant effects differed between geographically separated regions (Fig. 2.2 A, C). This may partly be due to the imbalance in total studies collected between these locations. In general, studies in areas with mixed clades of crabs (UK, Australia, parts of North America) placed the most emphasis on depth, whereas those with populations of southern (mainly native regions) and mixed clades placed more emphasis on agonistic interactions than did those with northern clades. It is worth noting that the majority of studies concerning food sources originated from invaded regions, whereas vegetation studies were emphasized in native regions. When considering distribution of factors by clade origin, no substantial differences were noted.

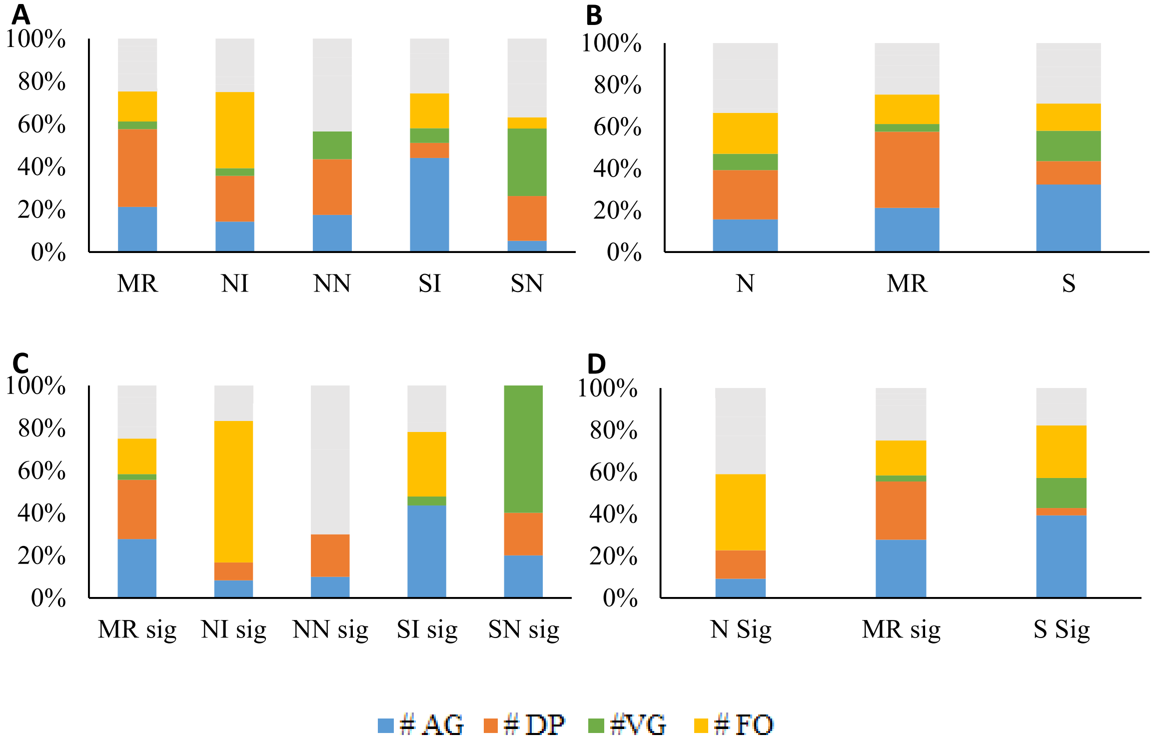

Figure 2.2: Percent (%) of records addressing the effects of environmental factors in populations of *C. maenas* of Northern European (N), Southern European (S) and Mixed origin (MR). Comparisons were made between A) Invasive (I) and Native (N) populations. Comparisons were also made B) looking solely at origin. Records only providing statistically significant support for factors (C and D) were also compared. Factors highlighted include Agonistic interactions (AG), Vegetation (VG), Depth (DP) and Food (FO). Other factors are grouped and not discussed (grey area).

2.4 Discussion

The results indicate the complexity of interactions occurring for *C. maenas* populations at a fine scale. Overall water depth and agonistic interactions demonstrated the greatest influence on *C. maenas* distributions for all age classes in the studies examined. For juveniles, vegetation and presence of shelter-related structures, such as stones or shells were more influential on distributions. For adults, salinity and food source were more frequently indicated, although salinity showed more significant records than food sources. Water chemistry factors (pH, dissolved oxygen), water flow or wave exposure, bottom type and water temperature showed the least support in both demographic divisions. Changes in depth preference were frequently associated with temporal fluctuations and individual size. Regional divisions also showed some differences, with more support for food-based factors in areas with invasive populations. Different clades showed variable degrees of support between the relative presence of depth, agonistic factors or food-based factors.

Many of the factors described in this review were relatable to other local-scale models for *C. maenas*, with some differences. Most models have been constructed at local or regional scales with the intent of inferring invasion risk of *C. maenas* to local shorelines (Colnar & Landis 2007, U.S. Environmental Protection Agency 2008, Grosholz *et al.* 2011). Where our review is concerned with areas where *C. maenas* has already invaded, our focus is directed at understanding within-population distributions, and therefore many of the weighing factors in other studies (*i.e.* distance to adjacent invaded regions) are irrelevant to the focus of our study. Furthermore it may be anticipated that the relative weights of some of these factors also differ with the scales under consideration - where other studies have been constructed to consider suitability of estuaries and inshore spaces as a whole, our review concerns factors as they vary within these spaces.

While this study found the majority of records emphasizing depth and biotic interactions in *C. maenas* distributions, these were also associated with many interactions and additional considerations. Preference for a specific depth was often influenced by season, which is arguably a factor of annual water temperature changes; in several studies evidence supported that *C. maenas* migrates inshore with warmer seasons and to deeper areas with colder temperatures (*e.g.* Atkinson & Parsons 1973, Sharp *et al*. 2003). Long-term seasonal movements are intermingled with short-term temporal shifts with tide as well as circadian rhythm of crab activities, with different depth preferences and greater activity at night (see for example Aagaard *et al.* 1995, Ansell, Comely & Robb 1999). The power of these effects is further broken down into preferences according to sex, moult stage (sometimes indicated by carapace color) and ontogeny, as each of these demonstrates different habitat requirements and tolerances. Therefore, while depth may exert strong influences on distribution and be more readily monitored, the exact effects are intermingled with other factors. Exactly how these interaction effects will impact the distribution of *C. maenas* when conducting removals (*i.e*. when setting traps) may warrant consideration. As far as modelling is concerned, the accuracy of model predictions (*i.e.* where higher densities of *C. maenas* may be found) may be compromised if temporal or internal population interactions (such as depth preference during summer versus winter) are not taken into account.

Temporal fluctuations in species distributions are well recognized in the literature; consequently, the need to account for spatio-temporal shifts of species in models has been noted. For example, D'Heygere, Goethals, Dedecker *et al.* (2003) demonstrated the utility of modelling spatiotemporal relations to understand migratory dynamics. Caixia, Xinjun, Feng *et al.* (2014) illustrated not only the utility of temporal considerations, but how considering the proper temporal scale in modelling (week, fortnight, month) may affect model performance. These are often necessary to account for changes in distribution related to temporal movements, such as seasonal migration. With respect to management activities, tidal fluctuations in *C. maenas* distributions are unlikely to take precedence as most trap soak periods (outside of a research context, these usually last 24 hours) exceed the span of a single tidal cycle, however this may play a role in optimal setting sites for areas displaying severe tidal fluctuations. Seasonal fluctuations may also be important in tracking *C. maenas* movements to greater depths.

In addition to the main effects considered from these environmental factors, many studies also noted demographic and temporal influences as well as interactions between environmental factors. Demographic habitat segregation is common among crustaceans; Andrade *et al*. (2014) noted age-related habitat differences in the redfinger rubble crab (*Eriphia gongaria*), and demographic differences in blue crab (*Callinectes sapidus*) and other Brachyurans (Pardieck, Orth, Diaz *et al.* 1999, Pallas *et al.* 2006). In many species it is common for juveniles to segregate into regions with more available shelter or different substrate types or vegetation. There is even some evidence of sex-mediated distribution of American lobsters (*Homarus americanus*) at the local scale according to temperature differences (Jury & Watson 2013). Such differences are associated with life-stage or sex-related requirements, as different environmental risks and benefits are experienced by these individuals. While the majority of species distribution models aim to explain species distribution (current, potential or future) primarily taking into account environmental factors, demographic and density-based influences (also referred to as internal factors, as opposed to environmental conditions and biotic interactions which are external) are often not considered (Planque, Loots, Petitgas *et al.* 2011). These factors can exert a strong influence on local abundance levels (Loots, Vaz, Planque *et al*. 2011), and their omission may have consequences for model performance at finer scales. While models that can account for multiple demographic or phenological situations simultaneously are rare, it isn't unheard of to address different age classes or phenological events using separate models. Biotic interactions and other factors may be accounted for using certain models, although there are a number of challenges acknowledged with these (Loots *et al.* 2011, Brummer, Maxwell, Higgs *et al.* 2013, Wisz *et al.* 2013, and all citations included). Planque *et al*. (2011) suggests a multi-model approach to better understand which factors exert the greatest effects. While our study noted the presence of many internal effects, only a few (sex, size, phenology) were consistently acknowledged among environmental factors.

The outcome of biotic interactions (competition, predation and food sources), for instance, are highly associated with size differences of competing pairs (predator and prey, or between agonistics). Species-specific outcomes are important also, whereas this study only addressed general support of agonistic interactions; this may require consideration to better formulate the outcomes of biotic interactions depending on the regional variation in fauna. While *C. maenas* was frequently the victor in agonistic interactions, it was also found to be outcompeted or to not interact agonistically with other species at all, which may be due to a combination of heterospecific and demographic (*e.g.* size) factors. Agonistic interactions have been observed more apt to occur when a sharing of microhabitat habitat and resources increases likelihood of direct competition (Schoener 1983). Understanding the factors characterizing species' respective niches, as well as where overlap occurs between separate species' niches, may make prediction of biotic interactions in the field challenging. This has been widely commented on in the literature, although the necessity of incorporating biotic interactions to improve model performance has also been noted, especially at high population densities (Mitchell 2005, de Araújo, Marcondes-Machado & Costa 2014, Snickars *et al.* 2014). Unfortunately, as a large portion of the studies collected for biotic interactions were lab-derived, these may mask the actual occurrence and nature of niche overlap between interacting species, as well as effects of other environmental gradients and qualities on such overlap in the field.

One consideration for studies of biotic interactions concerning food sources is that many were conducted in invaded regions as opposed to those where it is native. Seeing the potential for threats to commercial species in these regions, there may have been additional interest in research spurred by concern, which would offset the relative obtainability of this information. Contrary to competition or predation, prey availability may be expected to most strongly influence distribution when their niches differ strongly from the predator (Holt 1987, Boyce & McDonald 1999). Many of these studies were also lab-derived, which likely masks the actual niche overlap and dynamics in the field.

It is worth noting that our study assumes the proportion of studies addressing a factor is an adequate indicator of their importance in shaping local distributions. While this method is contingent on these studies yielding supporting evidence (that is, they don't hold mixed opinions on whether a factor affects distribution), it is also vulnerable to unequal emphasis in the literature on different environmental factors, as noted above. While there may be an emphasis on managing our research to address needs fairly, imbalances may exist due to researcher or stakeholder interests (as noted in Nasser & Welch 2013). Variation in these interests by region (*e.g.* in invasive versus native regions; see Fig. 2.2) may further influence which research is emphasized. For this reason, in our study, the general amount of consensus and support for (or against) each factor may be a better indicator of important factors than how many studies address a factor. The latter still allows us to draw more confident conclusions, however, as well as highlighting the general nature of research concerning each factor (*e.g.* number of studies, age of studies) and potential areas warranting further research.

While the results of this review are assumed to be comprehensive, it may not always be possible to unearth all relevant documents using the methodology implemented. *C. maenas* has been extensively studied; the current body of publications is frequently updated, which increases the likelihood that some recent reports have been omitted from this study. Furthermore, while steps were taken to ensure a relatively objective collection of data, there is potential for subjectivity in interpretation of results. This is especially applicable to the descriptive studies involved, which may be less explicit in describing and referencing data supporting results. Consistency in analytical methods was prescribed to reduce this; the fact that separate analyses of both descriptive studies and statistically significant records supported similar factors is also reassuring. It is also assumed that the approach to collecting support for biotic interactions is sound; these studies were largely focused on the ability of green crab to predate or be displaced by species, and may not accurately reflect the entire field situation experienced. While direct competitive interactions were considered in lab studies, indirect competition (*i.e.* ability to more effectively handle or predate a food source) was omitted unless displacement in foraging was involved.

A final consideration is that at the local scale, the site under study needs to be taken into context. Different inshore regions vary in their topography, hydrodynamics, flora and fauna. While factors are likely to lie within some bounds in order to permit initial establishment, the full amplitude of an environmental gradient needs consideration, as this may vary between water body types. The sample size included in this study made direct comparison of significant factors by water body type difficult, which may be useful in comparing whether water body characteristics significantly influence which factors warrant consideration. While the objective of this study is to provide a general review of the most demonstrably effective local scale factors across regions, site differences may subsequently enhance or reduce their effect on *C. maenas*, if a factor is reduced or absent altogether. Therefore understanding of the local environment is beneficial when considering the model approach and may affect generalizability of any model output. Furthermore, regional variations (*i.e.*, latitudinal temperature changes) may also interact to affect distribution at finer scales; this interaction effect was not taken into account for the purpose of this review, although this issue has been highlighted in other studies attempting to generalize models (McAlpine *et al.* 2008). Ultimately the results of this study may act as a component of larger works addressing these scales. Future works may wish to account for more site-specific variations as well as different scales of influence.

One consideration for carrying these recommendations into future management is availability of data. Some inshore regions, which are more intensively studied (for instance, protected park areas), may already yield environmental data at an acceptable resolution, derived from previous studies. For example, Little Port Joli estuary already yields a wealth of information on bathymetry, sediment distribution, and vegetation monitoring among other factors, although some of this information is dated (especially eelgrass extent, which has been increasing in recent years) (*e.g.* Brylinsky, Kellock, Daborn *et al.* 1987, Pelletier 2009). In other locations, it may be less likely that environmental information will be have been collected in a similar fashion for factors relative to *C. maenas* distributions. In areas that are heavily invaded, initial removal efforts may benefit from monitoring relevant environmental factors alongside removals in order to provide additional information for modelling and for fishing/trapping efforts. In some areas where other inshore fisheries have already been undertaken, harvesters may already be familiar with important environmental factors and use them as an intuitive guide to trap setting.

2.5. Conclusions

This study highlights the key factors in the scientific literature affecting local scale habitat distribution of *C. maenas*. While crabs generally showed potential for distribution according to depth and presence of biotic interactions, the driving factors for different life stages differ somewhat, with juveniles and adults being uniquely influenced by vegetation characteristics, shelter, salinity and presence of food sources. Other internal and temporal factors were also found to interact with distributions along different environmental gradients, such as age, sex, moult stage, as well as seasonal, diel and tidal effects. These interactions affected the specific environmental conditions preferred, and how they changed at day or night, or over an annual cycle. There is potential as well for factors to vary in significance between clades. Such results illustrate the complexity of factors influencing local distributions of this species.

A mobile species such as *C. maenas* may be a challenge to model at such a fine scale due to data requirements. Considering the potential for regional and temporal fluctuations, recommendations for any “best” factors for modelling distributions may be difficult to prescribe. Nonetheless, this review provides key considerations concerning some of the most scientifically supported and accessible factors, which may inform practical considerations for fishing and management recommendations. Furthermore, inclusion of internal factors and temporal influences may help to better understand the full distribution and movements of *C. maenas* at the local scale, and help guide management direction, for example for future parks-based, or community or government-led removal initiatives.

Chapter 3: Local Knowledge of Distribution of European Green Crab (*Carcinus maenas*) in Southern Nova Scotian Coastal Waters

Jessica Cosham[1], Karen Beazley[1], Chris McCarthy[2]

3. School for Resource and Environmental Studies, Dalhousie University, 6100 University Ave, PO BOX 15000, Halifax, Nova Scotia, Canada, B3H 4R2
4. Kejimkujik National Park & NHS, Mainland Nova Scotia Field Unit, P.O. Box 236, Maitland Bridge, NS. B0T 1B0

Abstract

Local knowledge is making important contributions to environmental management, including the provision of information on species distributions and population characteristics. There is relatively little research addressing local knowledge that is in the early stages of development, even though it may be of interest and utility for management of novel species or other contemporary events. In this study we interviewed local harvesters with experience with a recently arrived invasive species, the European green crab *(Carcinus maenas),* to evaluate their knowledge of its local distribution along Nova Scotia's South Shore. Ten participants who had either fished green crab or were familiar with it as a by-catch participated in semi-structured interviews and map-facilitated elicitation. Environmental, temporal and internal-population factors that were frequently associated with green crab distributions were reported by participants. Environmental factors described by participants included primarily depth, vegetation, biotic interactions and bottom type. Furthermore, interactions with temporal factors, such as tidal and seasonal changes, as well as internal-population factors, such as sex and age, were observed by a number of participants. Internal factors were described more frequently and in-depth among participants with more experience and more direct associations with green crab than less invested and novice participants. With respect to the management of this species, local knowledge illustrates not only a nascent understanding of species distribution, but realization of internal population structure and changes along a temporal scale, which may help to refine management strategies. This study illustrates the potential for local knowledge to form and develop, even around relatively recent environmental events.

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Keywords: Local knowledge, green crab, *Carcinus maenas*, habitat, species distributions

3.1.Introduction

Local knowledge-holders are becoming increasingly acknowledged for their value in providing information for a number of management activities (Gass & Wilson 2005, Gerhardinger *et al.* 2009). While many definitions exist (Raymond *et al.* 2010), local knowledge typically contrasts with scientific knowledge in lacking systematic methods and means of communicating information. Instead, it is obtained through extensive exposure and interaction with one's surroundings. Local knowledge has proven an economical option for supplementing existing data or acting as a proxy for systematic field surveys (as seen in Patterson's work with elk populations (2014)), improving confidence in results and providing information that is up-to-date (Anuchiracheeva, Demaine, Shivakoti *et al.* 2003, Garcia-Quijano 2007, Niamir 2014). It can contribute to prioritizing areas for conservation, understanding population characteristics, monitoring and detection of environmental changes, and providing insight into species' distributions, among other things, especially at local scales where information may be scarce and costly to obtain (Mackinson 2001, Balram *et al.* 2004, Anadón, Giménez, Ballestar *et al.* 2009, Azzurro, Moschella & Maynou 2011, Zukowski, Curtis & Watts 2011, Bundy & Davis 2013).

Local knowledge has informed species distribution models in two primary ways: as an account of species occurrence within a given region, as well as providing an opinion on which environmental factors explain species' distributions (Gass & Wilson 2005, Anadón, Giménez, Ballestar *et al.* 2009, Niamir 2014). Surprisingly, there is little research using more recent and developing bodies of local knowledge, or research illustrating when we might expect this knowledge to transition from mere anecdote to a reliable source. Such information may have implications for management of unprecedented disturbances within regions, such as invasions by alien species. For natural resource harvesters and managers, local knowledge may prove valuable to management objectives such as maximization of catch, or directing for a specific demographic component of a population, and therefore understanding how local knowledge evolves in response to novel species is important.

The European Green Crab demonstrates such a case. Introduced to North America in the early 1800's, it now inhabits the majority of the Atlantic Coast from Newfoundland to Massachusetts and New York (Roman 2006, Blakeslee *et al.* 2010). It has been recognized for its negative economic and environmental impacts, including the reduction of keystone species such as eelgrass (*Zostera*), and predation of commercial species including soft shell clams (*Mya arenaria*), blue mussels (*Mytilus edulis*), oysters (*Crassostrea gigas*) and quahogs (*Mercenaria mercenaria*) (Davis, Short & Burdick 1998, Miron *et al.* 2002). Concern over its impacts has only intensified in recent years, as it is believed colder coastal conditions that were thought to keep populations in check have changed, coinciding with the arrival of a second population of allegedly more cold-tolerant crabs (Berrill 1982, Roman 2006). Recently there has been interest in managing population numbers to protect local ecosystems and commercial species. While this is still in the early stages of development, efforts undertaken by local fishers and government have included protected area-mandated projects, commercial fisheries, as well as other efforts to reduce population size (DFO 2011a, Cosham, Dalhousie University, *personal obs*.). By assessing the local level of understanding of *C. maenas* distributions, we can gain insight into the current local knowledge on this subject and better understand its potential to support management objectives.

In this study, we address the question of local knowledge development by interviewing fishermen with recent experience with *C. maenas* along the southern coast of Nova Scotia, Canada, between Port la Tour and St. Margarets Bay, within Nova Scotia's Lobster Fishing Areas (LFA) 33 and 34 (Fig. 3.1). By asking questions concerning their experiences with this invasive crustacean, we elucidate which environmental factors are most frequently used in identifying areas with higher densities of *C. maenas*. This information will provide better insight into the state of local knowledge concerning this species, and help understand its utility for management purposes.

3.2.Methods

We conducted in-person semi-structured interviews with 10 fishermen residing along the South Shore of Nova Scotia during the summer of 2014. Interviews were approximately 30 minutes to 1 hour in duration. These involved open-ended questions, mapping activities and harvest site visits. Resulting data were qualitatively and quantitatively analysed for key themes and sub-themes that were identified *a priori* (using published literature) and adjusted to suit coding themes as they emerged. Research protocols conform to Canada's Tri-Council Policy Statement for Ethical Conduct and were approved by Dalhousie University's Research Ethics Board.

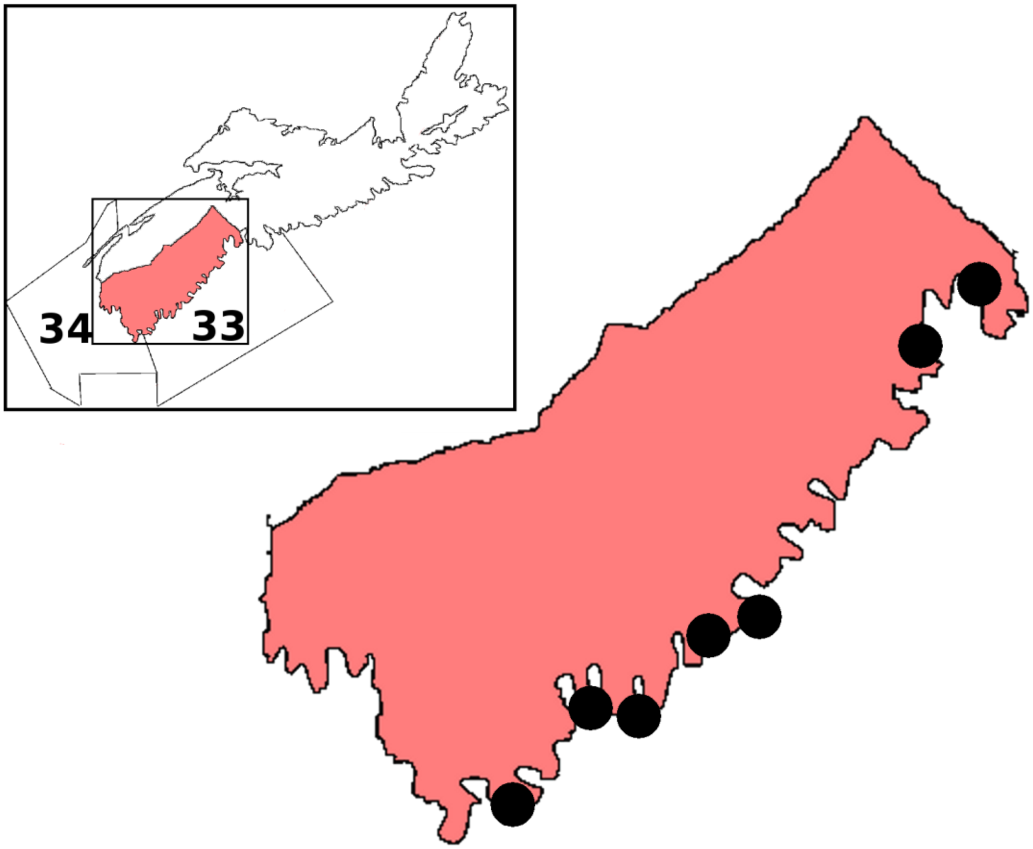

Figure 3.1: Map of Nova Scotia, indicating the recruitment area (the South Shore, as defined by Statistics Canada, in red) and rough fishing locations of participants (black circles). Lobster Fishing Areas (LFAS) 33 and 34 are outlined (map adapted from Province of Nova Scotia 2013).

3.2.1. Recruitment

Participants for this study were recruited from the South Shore of Nova Scotia (Fig. 3.1) and included locals who have experience with *C. maenas*, either through direct fishing, as bait, or as by-catch from lobster fishing. Participants had involvement with *C. maenas* populations at some location along the South Shore. Potential participants were identified through key contacts, snowball sampling, advertising at conferences, as well as circulation of recruitment materials to members of the *C. maenas* trial fishery through Fisheries and Oceans Canada. Preliminary contact and screening occurred through telephone calls, mail or email to establish eligibility, availability and willingness of participants to engage in semi-structured interviews. The total number of participants was 10 local knowledge holders. As the base of harvesters with substantial interaction with *C. maenas* along the southern coast is limited, efforts were made to ensure a comprehensive sample of willing participants rather than a randomized one. Recruitment took place from May until July of 2014, with interviews occurring in overlapping months and concluding in August 2014.

3.2.2 Interviews

The interview format was informal and took place primarily at participants' households, although some wharf and boat visits did occur. Interviews covered 1) participant experience (how long they had been fishing, and in which fisheries); 2) how long they had been observing or harvesting *C. maenas*; 3) within their fishing sites, areas of greatest catch abundance (*i.e.* seasonal changes, concentrations, or large numbers of green crab); 4) environmental factors they considered strongly associated with abundant populations of *C. maenas*; and 5) unique observations, or any additional comments about activities of *C. maenas* in their region (Table 3.1; Appendix F). Subsequent prompts elicited information about areas not fished or not initially mentioned by participants within the bounds of their fishing grounds (most harvesters worked within an estuary, harbor, or similarly delineated region). Interviews were restricted to single participants to avoid undue influence of other harvesters, and were recorded and later transcribed.

Table 3.1: Interview questions.

Q1. How long have you been fishing?
Q2. How long (would you say) have you been dealing with green crab?
Q3. When/where do you see them? When/where do you see them the most (concentrations/large numbers of them)? Does this change seasonally and if so, how?
Q4. Could you describe the location/show me a good fishing spot on a map/in person?
Q5. Have you ever noticed any interesting behaviour with green crab in your area? Such as?
Q6. Is there anything else you would like to ask about/discuss concerning green crab?

To facilitate recollection and explanation of fishing strategies and recollection of site characteristics, aerial maps of fishing locations were used in each interview. Images were obtained from ArcMap 10.1 base maps, Google Earth photos or provided by Parks Canada (Fig. 3.2). Fishing sites of participants were confirmed upon first contact or in follow-up calls in order to obtain accurate maps. Participants were given marking instruments to help indicate sites described. Maps were not a requisite in cases where site visits were made.

Figure 3.2: Example of an aerial photo depicting a participant's fishing area (Photo adapted from Google Maps 2014).

3.2.3 Coding and Analysis

The data collection phase was followed up with processing and analysis of the interview transcripts and map-based representations. An inductive-deductive coding style was used: environmental features inferred from scientific literature were used as a template for categorization, however to best suit participant descriptions new categories were developed as they emerged. Some categories were also redefined as interviews progressed to best suit participant descriptions (Table 3.2). A full list of coded results and their definitions can be seen in Appendices G and H.

Table 3.2: List of categories and sub-categories for environmental factors noted from literature (adjusted according to coding results). Dividing lines group factors into five broader categories (see section 2.3.1).

Category (Factor)	**Sub-Category**
Depth	Shallow or <10ft (3m)/ Moderate or 10-20ft (3-6m)/ Deep or >20ft (>6m) Other
Geography	Boulders or rocks / Ledges or ridges / Other / Exposure
Vegetation	Algae / Eelgrass / Kelp / Rockweed / Wrack/rot / Seaweed / Other
Biotic interactions (positive/negative)	Clams / Mussels / Eels / Lobsters / Rock crab / Birds / Other
Temperature	N/A
Salinity	Saline / Fresh / Brackish
Water movement	Flow / Calm
Bottom Type	Mud/soft / Cobble / Sand / Other
Temporal changes	Seasonal / Diel / Tidal

Interviews were transcribed using Express Scribe Pro Transcription Software and coded by selecting ‘bits’ of information (words, sentence fragments, etc.) relating to environmental factors. These could be taken from direct responses to questions posed (*e.g.* “Why do you think this is a good fishing spot? Why do you think you find more crabs here?”), as well as any descriptions or comments that addressed an environmental factor’s relationship to *C. maenas* distributions. Only original observations were considered (second hand anecdotes of others’ experiences were ignored). To be considered, a statement needed to be in response to a question relating to *C. maenas* distributions or associated somehow with comments on *C. maenas* occurrence, or trapping strategies employed. While participants often offered explanations for observations, empirical observations took priority in developing and categorizing bits. Factors were categorized as positively associated with *C. maenas* habitat use, negatively associated or not associated (the latter was rare and not used in weighing responses). Demographic associations to factors (*e.g.*, saying that females spawn in a specific region because of its vegetation) as well as temporal patterns (*i.e.*, diel, tidal and seasonal) and behaviours (*i.e.* spawning) were noted.

Statements describing background fishing experience of participants (total years fishing, fishery types, years and seasons exclusively targeting *C. maenas*) were collected and evaluated. These were used to characterize participants' fishing experience (in general and specifically with *C. maenas*).

Codes were classed and adjusted as new patterns emerged with subsequent reviews and cross-checks. Following initial highlighting of relevant statements, a second pass was made to 1) reconfirm the agreement of relevant comments and make any adjustments, and 2) begin initial sorting of bits into various categories (using categories derived from the literature). At this time the categories were reviewed for relevance and where necessary any emergent categories from the data were developed or revised. All interviews were reviewed according to any categorical revisions, as well as any revisions made to coding, and restructured so that categorized quotes could be compared alongside each other for logical consistency. Following this a final pass was made wherein all coded bits were checked for correct sorting and categorization.

3.2.4 Transcription and Coding Considerations

Steps were made to ensure that factors were only discussed following mention by the interviewee, to prevent prompting which might introduce a bias. However, prompting was used to elicit details about specific factors (for instance, to ask whether crabs were found at a specific depth, if depth was discussed by the participant). These entire events (*i.e.*, from when a participant mentioned a factor as well as their response to a prompt about details) were considered as a single response for a factor to negate any bias created by prompting.

Transcribed responses were typically considered isolated fractions of information 1) despite being broken up by a prompting question or comment by the interviewee, 2) despite being broken up by a descriptor pertaining to another category, 3) so long as a single location was discussed, or 4) so long as a single event was discussed.

In cases where a statement described multiple sub-categories from different categories (such as "open sand"), the statement was counted towards each factor mentioned (*e.g.*, "open" and "sand" would each count once towards the factors "geography" and "bottom type"). In cases where a statement described multiple sub-categories of the same factor ("algae and seaweed") the statement was placed under each sub-category (*e.g.*, 'algae" and "seaweed"), and only counted once towards the category in which they both occurred (vegetation). If contrasting situations were discussed (*i.e.* they like salt water, they don't like fresh water…) these were typically considered separate bits, however counted once towards the category.

In some cases harvesters noted that the factors they fished by were not always consistent with results (*i.e.* they may fish in a region which to their knowledge should yield catch, yet had no luck). For instance:

> And it’s a deep hole here. Now this is – this is like this other spot there… It’s a deep hole, and we don’t get much out of it…It’s another one I can’t explain. And it should be [a good fishing spot], right? (W. Richards)

In this case there is positive support for depth as a significant environmental factor, as this was still noted as an important indicator of *C. maenas* distributions. Such cases may indicate that other critical factors were not noted, or they may also be indicative of areas where *C. maenas* dispersal was limited.

3.2.5 Data Analysis

Factors were analyzed using a ‘weight of evidence’ approach (*i.e.* assuming that the influence of an attribute or factor has a direct relationship to its frequency of mention) (Mackinson 2000). Unlike in Mackinson’s work, our study observed the frequency of mention of each environmental factor in an interview relative to the frequency of mention of other factors, and used this to designate a rank order. Participants were re-contacted to review their results (the factors discussed taken from their interview, as well as their relative rankings) and to confirm their relative accuracy, as well to clarify any ambiguous concepts not adequately explained during the interview; 70% of participants were successfully re-contacted with this step. Of these, no corrections or revisions were requested or provided.

Following confirmation from participants, the frequency of mention of each factor (from each interview) was averaged to determine the mean frequency of mention across all interviews. In addition, the most frequently mentioned factors by participant were compared according to: 1) participant's association with *C. maenas* (as by-catch or directed catch); 2) seasons fished (summer versus winter fisheries); 3) previous fisheries-related experience; and, 4) estimated number of months' experience with *C. maenas* (counting only the assumed active months of harvesting), to determine whether these had an effect on the factors participants discussed most frequently.

3.3 Results

3.3.1 Participants

A total of 10 harvesters expressed interest in participating in this study; this sample represents a substantial subset of the entire population of *C. maenas* local knowledge holders (harvesters often experiencing *C. maenas* as bycatch, or catching *C. maenas* intentionally) in the region. Of these, two were associated with indirect harvesting of *C. maenas* as a bycatch while fishing lobster inshore, four were actively involved in the *C. maenas* trial fishery and harvesting *C. maenas* for commercial sale, and four were involved with *C. maenas* removals prior to the fishery implementation but still directing for the species. Years of fishing experience ranged from greater than 50 years to participants only beginning fishing through involvement with *C. maenas*; prior fisheries varied and included both offshore and inshore activities and involved a broad range of fisheries, from longline to Irish moss. Harvesters had been fishing *C. maenas* from one to eight years. Harvesters fished in various seasons, although the majority were involved in fishing in the late fall season through spring (November-May).

3.3.2 Interview Responses

Analysis revealed key external (environmental) and internal (population-related) factors. Each is described in terms of frequency and supported by sample quotes. The appearance of temporal and internal factors is also noted, as they interact with environmental factors; these are discussed in relation to participant experience.

3.3.2.1 Environmental Factors

Nine primary categories of environmental factors were identified, originating from the literature but supported and/or modified according to participant responses. These fall into five broader categories (adapted from Snickars *et al.* 2014): 1) bottom topography, including i) water depth and ii) geography (such as boulders and ridges), 2) biotic features, including i) vegetation, ii) positive biotic interactions and iii) negative biotic interactions, 3) hydrography, including i) water temperature and ii) water salinity, 4) substrate, including i) bottom type, and 5) exposure, including i) water movement (*i.e.* channel currents, open exposure). While many of these factors have been discussed in the literature, an emergent one, geography, was developed largely in response to a common mention of boulders, ledges and other sheltered areas by participants. While shelter is discussed in the literature, it is frequently in the form of shells or cobble (use of boulders and other structures for cover are less frequently the focus of studies, although they are present). The mechanisms driving biotic interactions are also more clearly stated in the literature (*i.e.* food sources as opposed to predation or competitive displacement), and so for the purpose of this study biotic interactions were generally classed as ‘positive’ (promoting *C. maenas* occurrence) or ‘negative’ (discouraging *C. maenas* occurrence). When all of the environmental factors identified through the analysis of transcripts were subsequently reviewed with participants, most agreed that all factors may have some degree of influence on distributions. Participants made no indication that any factors that they had not mentioned in their interviews were of equal or more relevance than those that they had specifically addressed in their interviews.

Depth was the most frequently discussed of all factors, both when averaged across all participants (24%; Fig. 3.3) as well as counting the most frequently top-ranked factor by participants (in 40% of interviews). With regards to ideal depths, there was some variation in responses, ranging from shallow waters (as shallow as <1 meter in the summer) to depths as great as 7.5 meters, especially in winter months (Fig. 3.4A). A number of participants identified prime depths at around 3-4.5 meters, while recognizing the potential for *C. maenas* to also be found in shallower or deeper waters. In general higher juvenile densities were noted at very shallow depths.

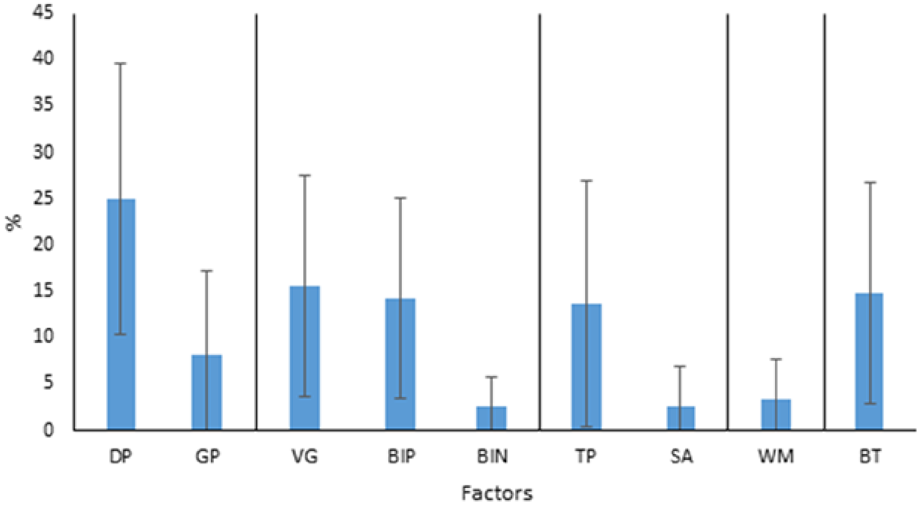

Figure 3.3: Mean percentage (%) of each interview spent discussing each environmental factor related to *C. maenas* distributions (this is defined as the number of coded bits addressing a specific factor / total number of coded bits). Final factors included (from left to right): Depth (DP), Geography (GP), Vegetation (VG), Biotic Interactions (positive and negative) (BIP, BIN), Temperature (TP), Salinity (SA) Water Movement (WM) and Bottom Type (BT). Dividing lines group factors into five broader categories (see section 2.3.1). Standard error is indicated.

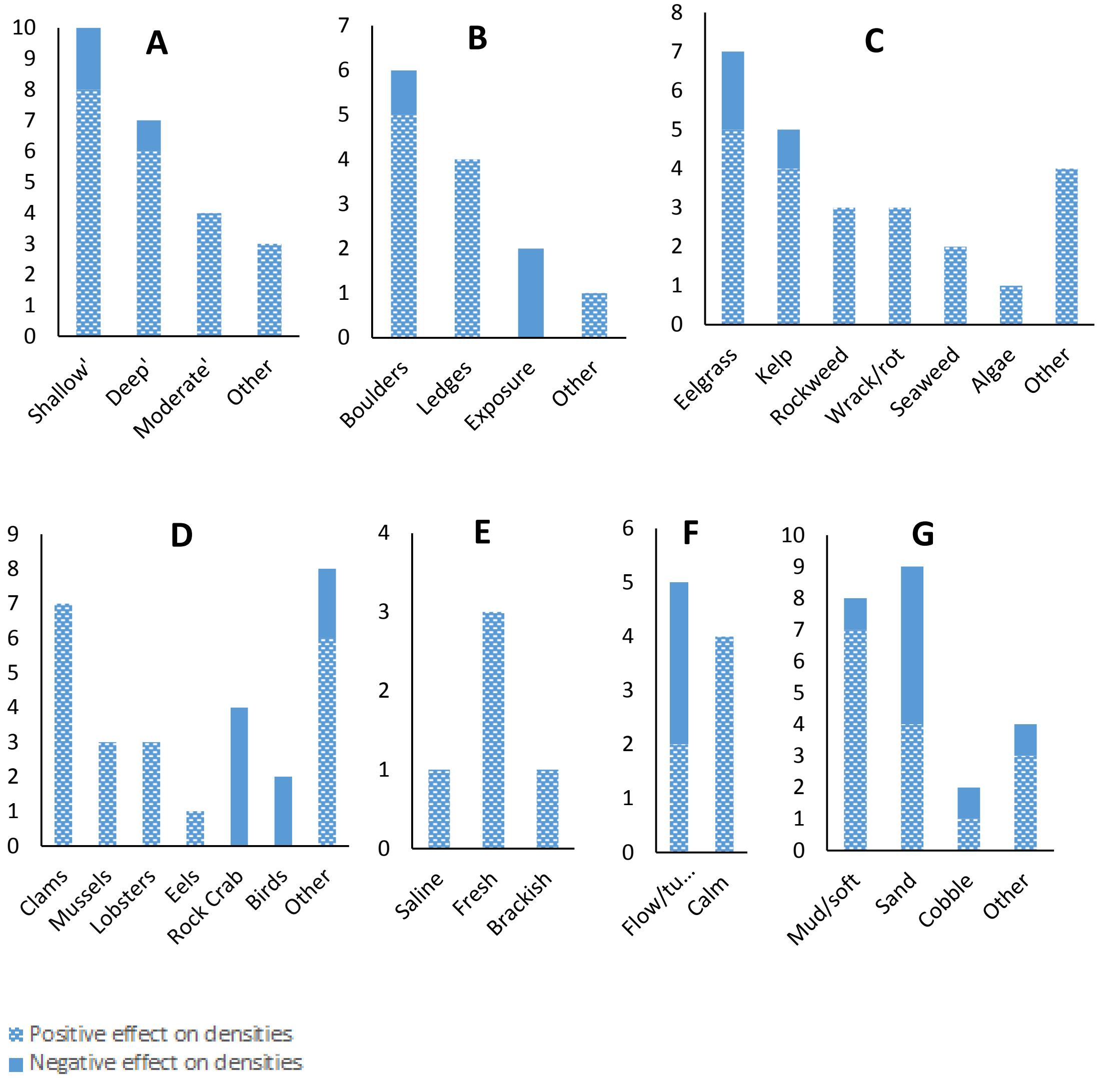

Figure 3.4: Bar graphs illustrating the number of participants supporting / refuting environmental conditions affecting *C. maenas* distributions. The number of participants addressing each condition is indicated (vertical axis). Factors are: (A) Depth, (B) Geography, (C) Vegetation, (D) Biotic Interactions (both positive and negative), (E) Water Salinity, (F) Water Movement and (G) Bottom Type.

In general there was a strong positive association with vegetative cover (Fig. 3.4C). Two participants refuted this, arguing that *C. maenas* were unlikely to be found in areas heavy with live vegetation (namely *Zostera*). These participants observed that ‘wrack’, or dead and rotting vegetation, was often a good crab fishing spot.

> Kelp, wrack - we'll call it - and that dead, ground up stuff - not the green, so much, you will get some in the green, you'll get some around the green, but if you haul up traps, traps you'll haul up through the green... not much in it, because it's the green... (W. Lloyd)

Both of these two participants harvested in the winter. This same vegetation type was noted among another participant as a source of shelter in colder temperatures, for instance in thermoregulation.

> And down in those channels, there's like old rotten eelgrass and kelp and stuff, and that produces methane which is warm....[W]hen you go in this old, decaying sea life, the temperature is a lot higher. So they bury in that - if the water gets cold enough. So that's how they protect themselves in the winter time, if it gets cold enough. If the winter's not cold enough they don't bother to do it... (R. Nickerson)

Bottom type and positive biotic interactions were the next most frequently noted factors. Clams, mussels, eels, and even lobsters were often mentioned as species likely found with *C. maenas*, whereas rock crabs and bird species were noted as potential predators, or at least species discouraging their presence (Fig. 3.4D). In general there was strong support for muddy or soft bottoms; participants frequently mentioned cobble and sand, although the latter was more frequently noted as a factor discouraging *C. maenas* use as well (Fig. 3.4G). Where sand was supported as a positive bottom type, it was often associated as a positive area for food. For example, participants reported that, “The hole that they dig in the flats... the crab digs in the sand to get that clam" (E. Himmelman); "Crabs will more generally be on the sand, because they can get more to eat on the sand" (W. Smith); "The softshell clams are more on the mud and sand" (R. Nickerson). Geographic factors, salinity, water movement and negative biotic interactions were the least frequently discussed factors (Fig. 3.4B, E, F & G).

The majority of participants associated seasonal changes in *C. maenas* distributions with changes in water temperature; this was confirmed when results were reviewed with participants. Diel and tidal changes in habitat use were also noted, although the exact associations to environmental factors were more diverse than season, relating instead to other factors. Associations were made with vegetation use (*e.g.* "When the tide goes…they're in the grass, right?" (E. Himmelman)), foraging (*e.g.* "Definitely [tide] plays a role in the shoals, like for instance the clam flats - right? Like you can definitely... between tides - see damage made into a clam flat…" (D. Bent)), shelter preference (*e.g.* "During the days they're gonna hide..." (B. Ford)) and other movements (*e.g.* "He buries [in the sand flats] when the tide comes…" (R. Nickerson)).

No strong association was found between participants' years fishing (*C. maenas* only or in total) and the factors discussed. Similarly, no connection was found between which season participants actively fished or how they observed *C. maenas* (as indirect by-catch, trial fishery or targeted early fishery) and which factors were noted.

3.3.2.2 Internal Factors

While most comments appeared to address *C. maenas* populations as a whole, some participants made observations relating to specific age classes, or specific sexes of *C. maenas* only.

> Those are all small crabs in there, all the time…. It's real shallow in there; probably, high tide, it would be 3feet [1m] maximum. It's an ultra-muddy bottom, so it's an easy spot; it's not a sand-based bottom, it's a mucky bottom. So, if you're small and you want to hide, it's nothin' to go like that and you're out of sight...
>
> (B. Ford)

Mention of internal factors showed some increase in frequency with the amount of time spent fishing *C. maenas* (Fig. 3.5A) although these did not correlate to the number of years of general fishing experience (Fig. 3.5B). The total amount of time discussing environmental factors was also positively related to fishing experience with *C. maenas* (Fig. 3.5C). Because the amount of comments specifying certain age or sex-classes was taken as a percentage of the total number of references to specific environmental factors, it is unlikely that the results in Fig. 3.5A are directly influenced by the length of conversation.

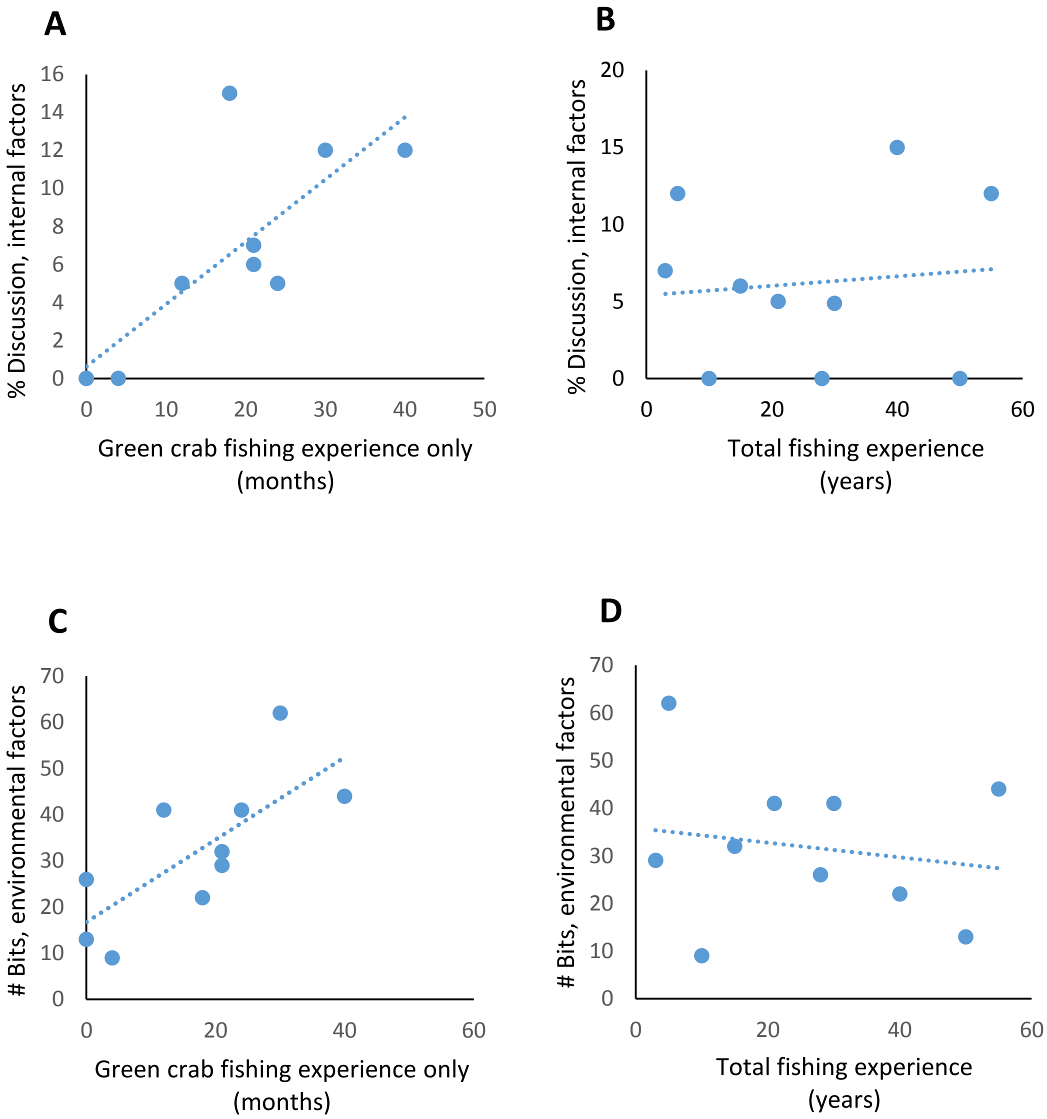

Figure 3.5: Scatterplots illustrating relationships between the total amount of discussion related to environmental factors (# bits; C, D) or the amount of time spent discussing internal factors (% discussion; A, B) and the amount of experience fishing *C. maenas* (in months; A, C) or the amount of total fishing experience (in years; B, D). Overlapping data in plot A reduces the number of visible markers.

3.4 Discussion

While some opinions showed variation, most participants agreed on similar factors (depth, biotic interactions, vegetation, and so forth) as strong determinants of *C. maenas* distributions. While depth was often described as general estimates in feet or fathoms (these were usually provided when prompted), it was also referred to relative to the fishing area as a whole (*e.g.* the best fishing being in the deepest areas of an estuary, such as 'holes', where areas suddenly dropped off, or into the 'shallows' along the shore, or even up along the shoreline). Vegetation references ranged widely. They included generalized mentions of vegetative life ("Any type of grass… or even like that, like that brown algae there, that kind of stuff? They will hide under" (W. Richards)), and specific references to given types of vegetation, such as algae, *Zostera*, or rockweed. Reference to biotic interactions varied also, although they were often species specific; regardless, they usually recognized the general importance of food sources in determining *C. maenas* distributions. There was little disagreement over which main species were positively (*i.e.* mussel, eel, clam, lobster) or negatively (*i.e.* rock crabs and birds) associated with green crab. These findings resonate with those found in previous research (Chapter 2).

While less frequent, temporal movements (*i.e.* with diel and circadian influences, as well as season/temperature) were also noted. Several participants agreed that crabs moved to deeper regions with colder weather, and many noted crabs ceasing activity and becoming unfishable during the coldest months. While only mentioned by a few participants, some also discussed increased activity (*i.e.* foraging) at night. Mention of tide was more diverse, with reference to shelter use (burying or hiding), foraging, or differential migrations in and out of the estuary with tide changes. The latter two areas were more surprising to hear mention of, as most harvesters fish a minimum of 24-hour soak periods (although some noted hauling traps more frequently), whereas tides operate on a 12 hour cycle. Cyclic changes, such as with tides, within 24-hour soak periods would likely be more difficult to observe from trapping alone. Such observations may have been from other activities or educated guesses.

Internal factors of *C. maenas* (*i.e.* sex, age) were noted as well as external (environmental) factors, and often distinguished some demographic structure within *C. maenas* populations. Such comments often referred to segregation of juveniles to “nursery” areas with unique characteristics, or of male/female segregation according to mating activities or general habitat preference. The frequency with which these internal factors were noted was partly associated with the amount of time a participant had spent harvesting *C. maenas*, suggesting a connection to participant experience. These observations should be taken with care, as it is difficult to quantify harvesters’ experience as well as their relative amount of time spent discussing internal factors. While some harvesters spent more years in the fishery, for example, there is no guarantee that their activities were as intense as other participants (in terms of fishing effort). Similarly, while internal factors may only be discussed on one or two singular occasions, they may be discussed in more or less detail, relating to a single or multiple environmental or temporal factor(s). Future studies may benefit from looking into or developing a framework for quantifying these parameters, as there was a challenge finding any effective methodologies for the purpose of this study.

There is little research explicitly stating when knowledge can be classified as ‘expert’ as opposed to ‘novice’; rather than a distinct threshold, it is often noted as a gradient from one to the other. While some authors have noted that the ‘master’ level of knowledge acknowledged in the literature may take on average 10 years to accumulate (*e.g.* Simon & Chase 1973), local knowledge experts have been qualified in other studies at as early as five years (Shafto & Coley 2003). Some argue that the shift from novice to expert can be defined by how individuals rationalize their explanations, with those with more experience drawing from more diverse and experience-based knowledge sources to rationalize decisions. In a study by Shafto & Coley (2003), novice and expert participants were asked to group fish species based on similar qualities. Experts completed this task drawing on taxonomic, ecological, commercial and behavioural knowledge whereas novices relied more so on visual and taxonomic cues. Some evidence of this may be visible from our results; while there was no notable trend between which factors were discussed and participants' experience, harvesters with greater and more direct involvement with *C. maenas* were more likely to notice differences in distribution of certain demographic groups of the species. These differences were often attributed to age or sex-specific ecological interactions or behaviours such as spawning, preferences for specific environmental conditions or protection. Similar explanations were attributed to *C. maenas* distribution in general, however, which makes this challenging to attribute. While it is evident that some novices were involved in this study (as the lower bracket of experience was as recent as one fishing season) it is difficult to delineate where and how many participants may be classed specifically as local 'experts'.

The fact that such external and internal factors are being noted may benefit management plans. While removal strategies are popular for mitigation purposes, population level responses such as compensation (if removals from a population allows more recruitment to occur) may hinder success, even though they may alter the immediate adverse impacts of invasive species (*e.g.* Weber, Hennen & Brown 2011, Frazer, Jacoby, Edwards *et al.* 2012, Ruiz-Navarro, Verdiell-Cubedo, Torralva *et al.*

2013). Therefore, the proportions of a population being targeted with removals may require consideration if management objectives are to be achieved. Supporting this perspective, Kanary, Musgrave, Tyson *et al*. (2014) developed a model predicting the potential effects of commercial harvests on *C. maenas* population. While not the primary aim of their research, it was noted that, excepting a high level of natural larval dispersal from targeted regions, fishing efforts focused on solely adult crabs were unlikely to reduce population levels. Understanding the connections between internal factors and this species' local distribution may contribute towards targeting more vulnerable age classes, such as juvenile nursery sites.

No participants currently appear to manage to this objective, which is unsurprising as current existing markets (primarily purchase for use as lobster bait) prefer larger individuals (Cosham, Dalhousie University, *personal obs*.). Some harvesters noted (albeit only a fraction of those interviewed) that their fishing activities had reduced populations, which may suggest that (based on the analyses of Kanary *et al.* 2014) their fishing grounds were more open to larval dispersal, and therefore, more susceptible to conventional fishing efforts. However, some harvesters were capable of distinguishing variations in internal population structure, such as differences in adult, juvenile and mating or spawning habitat. With incentive to harvest more vulnerable age classes, there may be an opportunity to more effectively combat green crab populations.

In general, the local knowledge as conveyed by the participants suggests that *C. maenas* are found (1) in shallower regions (while varying, no deeper than around 7.5 meters and possibly moving to shallower regions in warmer months), (2) with predominantly muddy bottom types - although this does not appear to be a strongly limiting factor and they may also be found on sand, cobble or mixed bottoms, (3) especially where food sources may be present on other bottom types. And, (4) vegetative cover (including and possibly emphasizing dead vegetation, especially in winter months) and other forms of shelter are generally preferred; many harvesters still noted them as a source of food or safety (for instance using mud for burrowing, or *Zostera* for food selection or shelter). Finally, (5) regions near fresh water outputs are preferred although these may vary depending on the age and sex of a crab. Conversely, exposed regions tend to be avoided, as well as areas occupied by rock crab and other potential predators. There is also somewhat of an aversion to more sandy-bottom regions, although support for this is weaker. These preferences may vary slightly by sex or age, for example with juveniles tending towards suitable nursery areas.

While our findings here show similarities to previous research (see Chapter 2), a more detailed comparison of local and more mainstream scientific conclusions around *C. maenas* distributions is warranted. Not only will this provide insight into the parallels and incongruences of these knowledge sources, it may also highlight their relative strengths and limitations. Such information may also help evaluate to what degree local knowledge of *C. maenas* distributions may be generalizable to other regional contexts.

There are some limitations to this study. One consideration is how participants may qualify ‘good’ versus ‘bad’ spots for finding *C. maenas* in the field. While participants may quantify abundance in pounds, as this is the means by which landings are often recorded for commercial fisheries, this says little about the population size. Most harvesters commercially interested are apt to aim for larger-sized (adult) crabs; indeed market interests and commercial mesh restrictions reinforce this. The fact that a number of harvesters also discriminated between adult and juvenile habitats, and further highlighted areas with both large catches and large individuals, further supports that, unless otherwise specified, 'good' fishing spots often refer to areas with reasonable densities of adults. Nonetheless, future works may benefit from clarifying how attentive participants are to numbers and sizes of captured individuals.

While the intention of this study was to be as comprehensive as possible in recruiting participants, it is likely that people were missed. The number of trial fishery participants, for instance, exceeds those involved in this study (DFO, *personal communication*, 2015). Some of these participants did not participate in the study, and while no more than five license holders have been active all years from the opening of the fishery in 2011, more were active in following years. As recruitment materials were circulated by a secondary party, the onus was on participants to contact the researcher. The ability to directly seek out and solicit participants for this reason was limited. It is also likely that harvesters from other commercial inshore fisheries have interacted with *C. maenas* (*i.e.* as by-catch) and were not recruited for this study. However, steps were taken to include all locals with the most extensive experience with *C. maenas*, and so it is anticipated that the majority of most experienced harvesters were involved.

As the majority of participants fish in winter/spring months, the applicability of our results to other seasons may warrant some caution. We have noted already that the nature of some responses are contingent on seasonal changes in the environment; internal factors such as phenology and age may have similar temporal elements. It may be anticipated, therefore, that preference for depths, vegetation, bottom type and other factors as well as their relative importance may be contingent on season.

Finally, it needs to be considered that interpretation of participant interviews is somewhat subjective. The process of coding attempts to reduce large volumes of information into more simplified, comparable themes. In this study steps were taken to generate categories reflective of participant responses; however, some descriptions were challenging to sort, and thus the participant's true meaning may not have always been reflected in these decisions. Furthermore the same descriptions may have had different meanings to different participants (*e.g.* while areas with channels may be seen as important for their depth to one participant, they may be important for water flow to another). While steps were taken to mitigate this by reviewing results summaries with participants, these potential miscommunications still reflect the challenge of knowledge translation.

3.5.*Conclusions*

The results of this study provide a snapshot of the local knowledge on *C. maenas* distributions on Nova Scotia's South Shore. While there is strong agreement on some factors, the recognition of others (such as salinity or geography) was vaguer. Furthermore, emphasis of sex and age-specific differences appears to increase with fishing experience, suggesting that local knowledge is still developing, which may yield future benefits to understanding different population characteristics, or different stages of influence that the invasive is having on different habitats or locations.

From a management point of view, it is important to understand the ecology of species in order to anticipate the impacts of various management strategies. An advantage of using local knowledge is that it is current, and may better reflect recent changes than data that is dated. For example, the impacts that the more recently introduced green crab clade may be having on ecological resources was detected by many of these fishers in this area before the scientific literature was able to capture this (McCarthy, *personal communication,* 2015). This study reflects how this knowledge may develop within a relatively short period of time. The new *C. maenas* fishery in southern Nova Scotia operates at a local scale, and it may be expected that reasonably fine variations in environmental conditions may impact fishing success. It may be difficult to sample adequately enough to inform local models and recommendations for all invaded areas. As fishing proceeds, the use of local knowledge to tailor long-term management practices may be an effective way to substitute more resource-intensive methods.

Chapter 4: Comparisons of Local and Scientific Knowledge Perspectives on Fine-Scale Distribution of European Green Crab (*Carcinus Maenas*)

Jessica Cosham[1], Karen Beazley[1], Chris McCarthy[2]

2. School for Resource and Environmental Studies, Dalhousie University, 6100 University Ave, PO BOX 15000, Halifax, Nova Scotia, Canada, B3H 4R2

3. Kejimkujik National Park & NHS, Mainland Nova Scotia Field Unit, P.O. Box 236, Maitland Bridge, NS. B0T 1B0

Abstract

While often employed separately, the co-implementation of local and scientific knowledge is increasingly used to improve understanding of environmental phenomena, as well as to increase acceptance of local natural resource management plans. We collected and compared local and scientific knowledge perspectives on the local-scale distribution of an invasive species, the European green crab (*C. maenas*), in order to identify areas of agreement and disagreement, as well as to highlight their relative strengths and limitations in understanding local-scale species distributions. Local knowledge collected from interviews with harvesters along the South Shore of Nova Scotia were compared with results of a comprehensive review of the literature on this topic, obtained from a broader regional scale. Local researcher input was used to help evaluate whether differences in harvester versus literature knowledge sources may be due to site-based differences or perspective-based differences. From these knowledge sources we elicited which environmental conditions promoted higher densities of *C. maenas*, as well as the relative importance of different environmental factors. While there was variation between all sources on the latter, local, scientific and local researcher knowledge sources held similar conclusions on which environmental conditions promote higher *C. maenas* densities. Possible explanations for observed disparities are discussed and include regional environmental variation, *C. maenas* origins and possible influences on behaviour, personal perceptions of participants, as well as the context of studies employed in our literature review. Disparities in relevant factors may be indicative of behavioural differences in *C. maenas* and may provide direction for future research. The agreement on environmental conditions promoting higher *C. maenas* densities suggests that local harvesters have a good knowledge of local (i.e. site-specific) distributions, although this knowledge may face some limitations if generalized to other geographic regions. Our results illustrate that the capacity of local knowledge holders to contribute to the understanding of spatial distribution of this species is comparable with that of science-based literature sources, particularly in local contexts.

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Keywords: *Carcinus maenas,* green crab, local knowledge, scientific knowledge, species distributions, invasive species

4.1.Introduction

Natural resource managers rely on a variety of sources to make informed decisions, drawing on information and knowledge from published literature, expert consultation, field sampling, and community engagement (Manchester & Bullock 2000, Gass & Wilson 2005, Pelletier 2009, Lin 2012, Patterson 2014). Knowledge can generally be broken down into two primary categories – formal scientific knowledge, and informal experiential knowledge (discussed in Raymond *et al.* 2010). Although these are not always mutually exclusive concepts, each of these knowledge sources are often met with their own advantages and limitations.

The merits of scientific knowledge are well summarized by Briggs (2005, p. 102) in an article discussing the integration of local and scientific knowledge: "Western science is seen to be open, systematic and objective, dependent very much on being a detached centre of rationality and intelligence…". It is also valued for its detail and precision, and is often more easily quantifiable for communication. Benefits aside, scientific knowledge also bears its limitations: research methods often require time and funding**,** and may not offer the comprehensiveness (spatially or temporally) or resolution required for certain management projects, leaving room for uncertainty (Gilchrist *et al.* 2005). Furthermore, the meaningful transfer of scientific knowledge across to users or managers can be a challenge, both in terms of understanding and acceptance (Roux, Rogers, Biggs *et al.* 2006). While secondary sources may be widely available, they may not address a specific region, may be out of date and not reflect the current situation, or both (see Chapter 2).

Conversely, local knowledge is largely experiential and accumulated through extensive exposure over a period of time. It is widely available in some regions, especially where local activities involve greater interaction and familiarity with the species of interest (Gilchrist *et al*. 2005). It is valued for its detail and sometimes highly useful for the temporal span it covers, which may note historic changes that could not be studied otherwise (*e.g.* Neis *et al.* 1999, Gass & Wilson 2005). This sort of knowledge has often been questioned in research for its non-methodical nature and subsequently its credibility, as well as its alleged poor generalizability compared to more traditional scientific methods (Leach & Mearns 1996, examples in Briggs 2005). Its implementation without scientific validation or support has also been cautioned, as its quality and quantity may vary widely depending on local association with a species, and may be limited in detail (Gilchrist *et al.* 2005). Nonetheless, arguments for its integration into scientific research and management are on the rise, with many recommendations as to how best to achieve this (Mackinson & Nottestad 1998, Neis *et al.* 1999, Mackinson 2001, Ballard, Fernandez-Gimenez, & Sturtevant 2008).

Local and scientific knowledge sources may be used together to better understand environmental systems, complementing, strengthening or checking each other – indeed the values of knowledge integration have been recognized, wherein sources are combined to produce a new or more confident understanding (*e.g.* as discussed in Raymond *et al.* 2010, Poizat & Baran 1997, Millar & Curtis 1999, Mackinson 2001, Huntington *et al.* 2004, Gilchrist *et al.* 2005). Concepts such as co-creation of knowledge (between resource managers and scientists) have been argued for, to improve the transferability and acceptance of knowledge between user groups while highlighting research needs (Roux *et al.* 2006). The relative benefits and limitations of these knowledge sources are still uncertain for a number of contexts.

In this paper we compare local and scientific perceptions of the environmental factors controlling distribution of an invasive species, the European green crab (*C. maenas*). To our knowledge no other research has assessed the knowledge of participants directly targeting *C. maenas*, which may in part be due to relatively recent approvals to fish this species in Nova Scotia (Cosham, Dalhousie University, *personal obs*.). Involvement of local knowledge in previous research on *C. maenas* has been primarily focused on temporal changes in abundance, although there has been some exploration of habitat use (Tremblay, Thompson & Paul 2006).

Our local and scientific knowledge sources differ in their geographic context (the local knowledge is from the South Shore of Nova Scotia, and the scientific knowledge is based on a number of local-scale case studies from other regions). For this reason, we used local researcher knowledge as a medium to help compare our results. The scientific researchers consulted possess both academic and experiential knowledge local to the Maritimes and abroad. They may consequently help identify incongruences between our knowledge sources that manifest from regional variation in habitats and those occurring from different perspectives (Fig. 4.1).

This project will serve as a comparative basis for the benefits and limitations of using scientific and local knowledge, in particular for *C. maenas* control efforts. While this paper provides insight into the local and scientific knowledge concerning this invasive species, it also provides insight into the capacity of local resource users to be involved in the management of this invasive species. We also explore the potential for generalization of the factors described in this research to understand local-scale distributions of *C. maenas* elsewhere.

	Site Specific ← **Geographic Spread of Knowledge** → Generalized
Informal ← **Knowledge Structure** → Formal	**Scientific Knowledge** Based on formal design & methods. Derived from broader geography outside of South Shore region. Applicability to South Shore uncertain. **Local Scientific Knowledge** More localized experience (Maritimes). Knowledge of relevant literature. Limited experiential knowledge around Maritimes. **Local Knowledge** Largely developed through informal experience. Restricted to region of activities. Often finer scale. Debatable generalizability.

Figure 4.1: Matrix illustrating the knowledge sources recruited for the purpose of this study: a review of the scientific literature (scientific knowledge), interviews with local harvesters (local knowledge) and consultation with local researchers (local scientific knowledge). These are situated along two separate gradients: the extent of geographic spread over which the knowledge is based, and the structure of the learning behind the knowledge source (adapted from Raymond *et al.* 2010).

4.2.Methods

The data for our comparative analysis were derived from our earlier research, in which we conducted interviews and an extensive literature review to obtain both local and scientific knowledge perspectives on factors shaping local distributions of green crab (see Chapters 2 and 3). Our primary interest was in those factors most highly ranked as influencing *C. maenas* densities, and what characteristics or conditions promoted high or low density areas for *C. maenas* (*e.g.* if depth is important, the depths at which *C. maenas* were usually at the highest densities). In the current study, the results were compared in order to highlight commonalities and incongruences in the factors noted, as well as interactions with temporal and internal differences. These were further compared to results obtained from consultation with local researchers possessing a mix of scientific and experiential knowledge.

4.2.1. Literature Review

We conducted an exhaustive review of articles, government documents, and other reputable publications addressing factors that may affect local scale distributions of green crab. These were compiled and analyzed to highlight the most prevalent factors, including those with the greatest number of related publications, the greatest number of records addressing the factor and the greatest degree of statistically significant support. The ideal conditions of each factor (those at which higher *C. maenas* densities occurred) were recorded; these were also considered according to age and origin of the population. Temporal and internal interactions were further noted. For full details on the methodology and results of this study see Chapter 2.

4.2.2. Participant Interviews

To obtain local knowledge concerning local-scale distributions of *C. maenas*, we conducted interviews with 10 participants with knowledge of *C. maenas* occurrence (either through targeted removals or by-catch) along the South Shore of Nova Scotia. Semi-structured interviews were conducted with mapping activities to elicit the factors most frequently noted when searching for high or low-quality *C. maenas* sites. These were coded and the most commonly mentioned factors were listed. In addition, discussion of temporal factors and internal factors (seasonal changes, individual age, sex, etc.) were noted; we assessed the latter for relationships to fishing experience (in general or exclusively pertaining to green crab), as well as the season fished. Further details relating to methodology and results can be found in Chapter 3.

4.2.3. Local Researcher Consultation

We also held consultations with three local researchers with a combination of knowledge (two with largely experiential, one with largely academic knowledge) of green crab distributions. The intent was to produce a body of knowledge to check reasons behind any differences in our knowledge sources. Most published sources in our literature review covered regions external to the southern shore of Nova Scotia, where our local knowledge sources are situated. As local knowledge is formed by different means (for instance, personal experience derived from local context as opposed to larger generalizations, and personal priorities) compared to formal research, incongruences in responses may be due to regional variations in *C. maenas* or may stem from deeper epistemological differences (Homann & Rischkowsky 2001, Briggs 2005). The expectation is that, with both field-based knowledge and some understanding of Maritime conditions, the researchers consulted will act as a midpoint in terms of knowledge formation and regional familiarity of the species, and will offer a means of checking against these variables.

One characteristic of researchers' responses is that there was less of a rank order supported: while researchers were more confident in saying 'yes, this is important', they were less apt to feel more strongly about one factor over another. This contrasts with other studies, in which greater difficulty was encountered by local knowledge holders than by experts in ranking factors (Mackinson 2001). Therefore, the factors derived from researchers are generally not ranked by them, but are instead evaluated according to: 1) how many researchers acknowledged them as being significant in affecting distributions at the local scale, and 2) if a rank order was provided, how highly a factor tended to be ranked.

4.2.4. Analysis

Categories from our literature review were used in the preliminary coding of the participant interviews; these categories were allowed some adjustment to better accommodate participant responses. The relative ranking of these factors/categories from each knowledge source were compiled into a matrix for comparison (Table 4.1). The environmental conditions which supposedly yield higher *C. maenas* densities were also compared. Interactions with additional factors (temporal and internal) were noted. As the relevance of internal factors was an emergent property in this study, their relevance was not fielded with our experts and did not emerge strongly in our consultations with them.

4.3.Results

Below is a general overview of the results obtained from our evaluation. We present a side-by-side comparison of each set of results from our knowledge sources. The internal and temporal factors are noted in the description of our results, as well as any broad limitations or benefits of each respective knowledge source.

4.3.1. Environmental Factors

Local and scientific knowledge produced similar categories of factors, relating to 1) depth, 2) shelter (in some element), 3) vegetation, 4) biotic interactions (positive and negative), 5) water salinity, 6) water temperature, 7) water movement and 8) bottom type.

Water chemistry factors (pH and dissolved oxygen) were not mentioned in interviews with local harvesters or researchers. While knowledge sources were in broad agreement of the environmental factors in terms of importance, there were some apparent differences (Table 4.1).

Table 4.1: Side-by-side comparison of the factors elicited by each respective knowledge source. The top three (dark gray) most strongly supported factors are indicated, followed by the moderately supported (medium gray) and the least supported (light gray). Dissolved oxygen (DO) and pH were only indicated in the literature. Dividing lines group factors into five broader categories (see section 2.3.1).

Scientific Knowledge	Local Knowledge	Local Scientific Knowledge
Depth	Depth	Depth
Shelter	Geography	Shelter
Vegetation	Vegetation	Vegetation
Food source	Positive Biotic Interactions	Food
Agonistic Interactions	Negative Biotic Interactions	Competition
Salinity	Salinity	Salinity
Temperature	Temperature	Temperature
DO	-	-
pH	-	-
Water Movement	Water Movement	Water Movement
Bottom Type	Bottom Type	Bottom Type

Overall, local, scientific and local researcher knowledge sources provided similar views of the conditions promoting *C. maenas* abundance (Table 4.2), although there were differences in some of the details as well as how results were communicated. For instance, while harvesters focused on geographic aspects that might provide shelter such as ledges, boulders and ridges, most literature focused on the use of shells and small stones. Some harvesters did occasionally mention increased amounts of shells as a good indicator of *C. maenas* presence, however this was less common. The exact species involved in biotic interactions was far more diverse in the literature, and while lobsters were only ever mentioned as a prey by harvesters, our literature review and consultation with local researchers largely identified lobster as a predator or at least outcompeting *C. maenas* for food, although this was size-dependant. Lobster (*Homarus americanus*) mortalities due to *C. maenas* were only recognized in a single study, which used specimens taken from the Canadian Maritimes (although the study sites were outside the region of our local knowledge sources). The importance of 'wrack', or detached vegetation which has settled on the seabed, also arose in a few separate harvester interviews. While this type of vegetation was not explicitly named by other knowledge sources, some harvesters stressed its importance as it frequently contained high densities of *C. maenas* (Chapter 3).

Table 4.2: Summaries of the environmental conditions associated with higher *C. maenas* densities, with respect to each environmental factor addressed. Summarized from results taken from Chapters 2 and 3 as well as consultations with local researchers. Local researchers did not comment on every factor, and therefore some details are summarized from only 1-2 consultations. Dividing lines group factors into five broader categories (see section 2.3.1).

Factor	Scientific Knowledge	Local Knowledge	Local Scientific Knowledge
Depth	Shallow tidal zone to around 5.5 meters. Affected by notable change in depth with diel phase, season and age, moult, and possibly sex. Often note seasonal migrations to deeper waters with cold.	Range from <1 meter to approx. 7.5 meters. Many interviewees estimate around 4-5 meters. Participants note change in depth with diel phase, season and age. Some note seasonal migrations to deeper waters with colder weather.	Largely present in the intertidal. Observed at 1 meter (low tide) to around 2 meters feet (high tide) during trapping. Seasonal migration to deeper water towards winter. Less certainty around limits to depth, as well as mechanisms creating depth limits (*e.g.* competition, predation).

Factor	**Scientific Knowledge**	**Local Knowledge**	**Local Scientific Knowledge**
Geography (Shelter)	General support for use of shells, mussel beds and rocks by *C. maenas*. Highly used by juveniles. More preferred by adults in presence of predators and at night.	General support of *C. maenas* preference for ledges, boulders or other geographic constructs. Avoidance of exposed areas.	Moreso sheltered areas preferred. Positively associated with rocky areas in some consultations.
Vegetation	General preference for vegetative cover. Possibly a greater requirement among juveniles. No known mention of wrack in the literature.	General preference for vegetation. Some participants especially noted importance of settled 'wrack' and argued against live species such as *Zostera*.	Apparent preference for vegetation. *Zostera* & weeds, types of algae all mentioned (correlated to preferred sediments)
Positive Biotic Interactions	Wide range of species predated on from fish (flounder) and (in one case) lobster to small molluscs. Namely shellfish. Outcome of forage success determined by *C. maenas* and prey size.	Narrower (but still wide) range of prey species mentioned, primarily shellfish. Small fry, lobster, small fish also noted. Effects of size not noted.	Narrower range of species mentioned, mainly shellfish (one researcher noted hierarchical preference for clams, mussels then scallops). Polychaetes also mentioned.
Negative Biotic Interactions	Wide range of competitive and predatory species noted. Outcomes of interactions sometimes size-dependent.	Narrow range of competitors noted, mainly rock crabs and birds. One harvester mentioned sculpin. Size-dependence not mentioned.	Believed to be outcompeted by native species, including rock crab, lobster and birds (gulls). Noted that predation doesn't seem to be an issue in northern latitudes (*e.g.* Newfoundland). Size dependence not mentioned.
Temperature	No major evidence of temperature impacts, other than moving deeper with colder seasonal water temperatures. Potential aversion to direct sunlight. Other depth-related migrations (*e.g.* tidal) may lessen with colder water.	No general impacts noted outside of seasonal movement to deeper areas by some participants. Lessening of feeding activities noted beyond certain temperature decreases.	Survive in wide range of temperatures. Some noted less activity / catchability in winter with a visible drop in catch in Jan-March, some noting seasonal movement to deeper areas (winter). Others noted finding green crab active at even 2C (based on observations further north).

Factor	**Scientific Knowledge**	**Local Knowledge**	**Local Scientific Knowledge**
Salinity	Preference around salinity ranging from 22‰ (brackish) to 35‰ (average ocean salinity). Varies dependent on moult phase (freshly moulted crabs more common in fresher water).	Generally supported higher densities in areas with fresher water (*e.g.* conspicuous freshwater outputs), although presence in a variety of salinities noted. Mortality in direct freshwater (*e.g.* from sudden heavy rainfalls) noted anecdotally. Anecdotal accounts of crabs moving upstream.	Survival in wide range of salinities, but prefer 'lower' salinities (*e.g.* near freshwater outputs). Noted that green crab dislike salinity fluctuations. Salinity preference may vary with age and sex.
Dissolved Oxygen	Only largely influences crabs by moult phase ('red' crabs prefer higher dissolved oxygen)	-	-
pH	-	-	-
Water Movement	Mixed results. Higher flow has seen higher densities, however lower flow may be useful for foraging. General preference for areas with less wave exposure.	General support for calm waters. Mixed opinions on areas with flow or wave exposure.	Calm waters (low flow, no disturbance) are preferred according to most participants. Some noted they may be adaptable to exposed areas.
Bottom Type	Variable; from mud to silt to sand to cobble.	High support for muddy bottoms; sand contested, more frequently not supported by participants. Some support for cobble/stony bottoms.	Some disagreement here. Disagreement on mud as preferred (*e.g.* for burying) or disliked (*e.g.* due to respiratory issues when perturbed). Some said crabs found on most bottoms (mud, sand, cobble).

4.3.2. Internal / Temporal Factors

Local, local researcher and science-based knowledge sources recognized some internal and temporal factors in shaping local distributions, although how frequently and with which factors differed somewhat between sources. In general the academic literature unearthed a greater variety of internal influences (including size, sex and moult phase) that acted on distributions, whereas the internal factors noted in local interviews were more limited, focusing on age class (juvenile and adult) or sex (male or female distributions, or those related to breeding activities). Some of these internal factors are evident in Table 4.2. All knowledge sources recognized influences relating to temporal changes, such as moving to tidal flats at night or with tidal changes, or changing depth preferences with seasonal temperature.

4.4.Discussion

4.4.1. *Environmental Factors*

Our results highlight two key observations. The environmental conditions promoting higher *C. maenas* densities were generally agreed upon between local and scientific knowledge sources, with some differences. The relative weight or ranking of environmental factors differed. While some factors, such as depth, showed strong support from most sources, others varied largely.

Previous studies have reached mixed outcomes when weighing or ranking environmental variables according to local knowledge. Patterson (2014) found that the rankings provided by participants largely differed from those found in ground-truthing factors affecting elk distributions. Conversely, Irvine *et al*. (2009) found that weights provided by participants through indirect elicitation methods (this involved weighting of factors according to the relative number of mentions during the interview) improved predictions of species distributions of another ungulate (red deer). Patterson attributed the discordance in their results to a number of variables, including background diversity in the participants involved and the relative values they held in relation to their environment. While participants knew locations where species were observed, Patterson concluded that they did not always necessarily note the broader factors shaping these locations. Our indirect method of elicitation, which was similar to the methods mentioned in Irvine *et al.*'s 2009 study, was assumed to reduce biases; however the differences observed between the conclusions of our local and scientific knowledge suggest that bias or other contextual factors may still be influencing participant responses.

There are several possible explanations for the differences we observed. For instance, Irvine *et al*. (2009) noted that regional variation in landscape characteristics may affect the relative importance of environmental factors. In our study, different fishing areas may have had different variations in factors (*e.g.* shallower slopes in harbours as opposed to deeply channeled estuaries) or be lacking other characteristics entirely (*e.g.* vegetated or not); consequently, the effect of some factors may have been more prevalent. Our local knowledge may frame but a subset of the environmental conditions in which *C. maenas* occurs, and variation in such context may warrant consideration. This would not be surprising with *C. maenas;* one local researcher noted that factors such as competition may differ in impact between Canada's East and West coasts, whereas others alluded to regional differences that may have implications for *C. maenas* populations (although these may have been in reference to either distribution or establishment). Similarly a local harvester (who fished several inshore areas) noted that differences may even exist between fishing sites.

Other sources of bias, such as the promotion of specific factors in media, may also have influenced the local perception of harvesters. Specific impacts of *C. maenas* are largely emphasized in the public media and in the literature around invaded regions, in particular damage to species such as commercially valuable shellfish (Chapter 2). There were occasional references to external sources in interviews ("some of the reports, some of the papers, you'll read that they'll withstand really low salinity…" (B. Ford)). Such information may create a bias that over-emphasizes certain factors and underemphasizes others, such as competitive interactions and predatory species.

There are elements of our scientific sources that may also influence our results. For instance, lab studies observing biotic interactions may falsely assume niche overlap, exaggerating the likelihood of competitive and predatory interactions (Chapter 2). Furthermore, similar to the argument posed by Irvine *et al*. (2009) concerning environmental context, behavioural differences may exist between *C. maenas* clades that may affect biotic interactions. Non-native *C. maenas* populations have been observed in higher densities where even strong predation (for instance, predation by seagulls) is present, which suggests that *C. maenas* may unwittingly occupy ecological 'traps' in non-native regions (Dwernychuk & Boag 1972, Ward-Fear, Brown, Greenlees *et al.* 2009). Different invasive cohorts have also exhibited varied levels of aggression and different competitive outcomes (Rossong *et al.* 2011). For such reasons, the regional context of studies may be expected to account in part for the relative influence of factors, as both internal and external environments of *C. maenas* change.

Use of local knowledge to rank environmental factors shaping species distributions may be possible, however should be undertaken with caution. Verification of this knowledge may be warranted, such as through local ground-truthing (*i.e.* testing a model against comprehensive trapping or observational data) as is common in such studies (*e.g.*

Irvine *et al.* 2009, Patterson 2014). Furthermore, as is frequently cautioned with local and indigenous knowledge sources, and as highlighted in some of our researcher and participant responses, contextual elements (such as the local environmental conditions which knowledge is based upon, as opposed to surrounding or more distant landscapes) may not be applicable across different scales and regions (Wohling 2009).

4.4.2. Environmental Conditions

Both scientific and local knowledge sources identified similar depth ranges, salinity conditions, presence of vegetation and geographic features promoting shelter as positive indicators of higher *C. maenas* densities. When there was disagreement over the 'ideal' environmental conditions in one knowledge source (*e.g.* ideal bottom type for *C. maenas*), similar discordance was also highlighted by the other knowledge source. Only a few environmental conditions were disagreed upon, such as the outcome of certain biotic interactions (for instance, where local knowledge identified lobster as a prey, our literature review primarily concluded that this was a predator and/or competitor. However our study omitted literature addressing indirect competition and some of these studies suggest that there is a size-dependant element to the biotic outcomes between *C. maenas* and lobster (*e.g.* Williams, MacSween & Rossong 2009). Where sizes weren't indicated by participants, this is difficult to compare).

The fact that both local-harvester and local-scientist observations of important environmental conditions resonate with those in the literature is reassuring. While the most popular means of incorporating local knowledge into understanding species distributions is through mapping activities (*e.g.* Gass & Wilson 2005, Irvine *et al.* 2009), there is also research supporting the use of local participants as consultants or experts, identifying ideal environmental conditions for species, as well as conditions for different distribution-related activities (*e.g.*, Silvano, MacCord, Lima *et al.* 2006, Beazley, Baldwin & Reining 2010). In Silvano *et al*. (2006), local harvesters were able to accurately identify important features characterizing migratory pathways for various fish species. Similarly, Irvine *et al*. (2009) found that participants were able to accurately identify environmental features positively or negatively associated with species distributions. While this information may not be as applicable to weighing factors (*i.e.* for species distribution models), they may help define the relationship between different environmental factors and higher densities of *C. maenas*. This may help inform model construction as well as direct fishing efforts.

Some factors may still be somewhat subject to regional variation, such as species-specific interactions and the relative presence of identified environmental characteristics. For example, our literature review highlighted species (such as Asian crab, *Hemigrapsus sanguineus*) currently limited to ranges outside of our local knowledge region (Stephenson, Steneck & Seeley 2009). While these may be expected to exert a strong influence on *C. maenas* distributions elsewhere, their relative absence along the South Shore (our study region) infers that such limitations will not be observed. Similar considerations may apply to plant species, food sources, temperatures and their interactions with depth, and so forth.

There are contrasting observations of competitive interactions between *C. maenas* and agonistic species (such as lobster) that are both present on the South Shore and elsewhere. These differences may illustrate a bias among participants, as aforementioned, or variation in local species behaviours. Related studies of *C. maenas* genetics and invasion history, and studies observing *C. maenas* competitive behaviours, also support different behaviours among the clades present in the Maritimes (Rossong *et al.* 2011). The further observation of this by locals may highlight a need for research in this area, as such behaviours may warrant consideration in management plans (*e.g.* Kanary *et al.* 2014).

4.4.3. Local and Scientific Knowledge and Broader Implications

Our research highlights a number of advantages and limitations with our respective knowledge sources. One particular challenge involved the interpretation of information that was necessary in order to make our knowledge sources comparable. Local knowledge had a greater predilection towards environmental features or landmarks in comparison to the scientific literature (*e.g.* pointing out holes or channels, rock outcroppings, shoals, etc). Previous work has argued that local monitoring of resource condition is often reliant on environmental factors that are readily observable, which may in part explain this tendency (*e.g.* while flow may not always be observable, a channel may be indicative of faster-moving water) (Berkes 2012, p. 201). Some of these environmental features were difficult to translate into environmental factors (*e.g.* channels could be perceived as geography, depth, or flow). While follow-up telephone calls with local participants were used to clarify some of these ambiguities, this in part highlights some of the disparities between the perception and motivations of our knowledge sources. While some adjustments were made to categories to account for local knowledge, there was a challenge in finding a common language through which both knowledge sources could be equitably expressed. This was further complicated by the use of qualitative terminology. While direct measures were given at times (*e.g.* trapping 500-

600 crabs per day in some regions; the best trapping at a given number of fathoms; *C. maenas* activity ceasing at a given temperature), often local terminology was qualitative and relative (*e.g.* “deep spots”, “fresh water”, “sandy bottom”, “colder temperatures”). Some of these were clarified; for instance most local participants were asked to specify depths to some degree, and some temperatures were provided, however these lacked comprehensiveness (usually estimates were given for a single snapshot, *e.g.* at which temperature *C. maenas* stopped being trappable or the absolute shallowest or deepest depths at which they were found). Some estimates (such as salinity) were not possible to obtain without appropriate instruments. This also existed in the scientific literature, although more often explicit measures were provided. While often communicating observations through a number of trends, details such as size, moult phase, crab densities, and so forth were often more clearly delineated. For this reason it is often easier to readily qualify the results observed from scientific knowledge sources. In contrast, qualitative measures from local knowledge may be applicable within a fishing region but not to other areas, where descriptors such as ‘deeper’ might infer an entirely different value. Therefore, the contextual nature of our local knowledge may lend them effective in the immediate region while limiting transferability.

The richness of information obtained from local participants provided additional insight into behaviour of *C. maenas*, some of which may indicate local abnormalities or rare events (for example, the cessation of feeding activities at given temperature, changes in population dynamics in response to system changes, and use of wrack or rot as a means of shelter). Some participants with longer fishing experience were able to provide estimates of the temporal trends in *C. maenas* abundance over the past decades. The academic studies involved were also often delimited to a specific research hypothesis and temporal as well as spatial range, which may limit the observation of such phenomena.

While our scientific resources often surpassed local knowledge in terms of specificity and ease of quantification, the current relevance and applicability to the South Shore may be challenged. A number of the articles dated to the 1950's or 1960's (for examples see Chapter 2) and may not accurately illustrate the present-day situation with *C. maenas*. Many of these sources are still frequently referenced in the literature, despite the fact that spread and adaptation to regions may have caused significant changes in the factors driving distributions since these times, especially in non-native regions. As the issues with *C. maenas* along the South Shore are fairly recent, the knowledge collected for this study is young by comparison to most studies (*e.g.* Shafto & Coley 2003, Silvano *et al.* 2006). Furthermore, as aforementioned, the results from our scientific review are averaged over a large regional area and their relevance to any one region may be questionable. While these may be useful in inferring those factors most warranting consideration, they are not impervious to local variation.

Assuming that the fishery gains popularity in the future, the quality and sample size of local observations will be expected to increase. On the Atlantic Coast, where such research is lacking and where control efforts are most urgent, this may increase the value of local knowledge as it accumulates, as well as any observation of changes or unique behaviours, as they may be integral to successful management. Such phenomena have been reported in the management practices of local knowledge bodies. It is for this reason that the Cree of northern Canada, for example, take note of a number of patterns in distribution or behaviour, as well as distribution and life cycles of fish that they harvest

(Berkes 2012, p. 148**)**. It is critical for a resource user to understand the habits of a resource in order to be successful.

If considering the potential applications of local knowledge to models, ranking elements may not be the best approach, however observations of local conditions shaping distributions may be of value. The fact that our knowledge sources agreed on the effects and characteristics of most environmental factors is reassuring, even if the specifics of these factors vary with local conditions.

4.4.4. Study Limitations

While steps were taken to ensure accuracy, interviews may not reflect the full nature of local participant perspectives. All three local researchers requested corrections to their original interview results, whereas none of the harvesters disputed the results of their interviews. This may in part be due to the elicitation methods used. Wherein researcher consultations were entirely conducted by phone, these interviews may not have been as effective as the face-to-face engagement with harvesters. These interviews also used visual cues to help harvesters think through and communicate their answers. There is also the possibility that other influences (*e.g.* lack of safety credibility, or the degree to which a person may be perceived as trustworthy or intimidating (Rogers 1995, p. 352)) dissuaded harvesters from bringing up any misunderstandings or concerns. Familiarity and trust play a role in working with participant groups, especially in research and management (*e.g.* Weeks & Packard 1997). Assuming that the safety credibility and/or trust between researchers in this case was greater than it was between researcher and harvester, the latter may have felt less comfortable in readdressing the results reviewed. As highlighted by Weeks & Packard, considering the context of relationships between parties in community-level research is important.

Our study also did not involve direct engagement of our knowledge groups to guide our interpretation and conclusions. As we collected and interpreted knowledge sources, another level of bias was introduced as data was subject to our own perspectives. This is in part reflected in the categorization and methods used for ranking environmental factors. Scientific knowledge led the basis for the categories upon which local interviews were based, whereas amendments to such categories from interviews were limited. This effectively capped the extent to which local knowledge holders were able to shape the research methods and outcome. However, under the given circumstances, opportunity for broader engagement of participants was limited by issues such as the time available to participants and their wide distribution across the Maritime Provinces.

As mentioned, there was sometimes a challenge in verifying secondary or anecdotal information versus explicit observation. The knowledge of some local participants may be expected to illustrate a blend of personal and shared knowledge (*i.e.* from reading news articles, journal reports and anecdote of peers). There is some possibility that the type of knowledge expressed by participants is not explicitly ‘local’ (*e.g.* Raymond *et al.* 2010). While we are not classifying local participants as “scientists” on this basis, it illustrates the permeation of knowledge and its potential impacts on ways of thinking. Indeed, the same phenomenon arguably exists within scientific knowledge spheres. This still does not detract from the potential contribution of these individuals. It may be expected that those with a greater investment in the resource will be more apt to conduct their own research to supplement experiential knowledge. This blended learning may still dilute or bias knowledge accrued from direct local observations. As participants were recruited according to their knowledge derived from experience (according to recruitment materials), and as they often took pride in challenging secondary data (*e.g.* "some of the reports, some of the papers, you'll read that they'll withstand really low salinity.… I'd be iffy on that one" (B. Ford)). It may be assumed that the primary source of knowledge communicated is experiential.

As consultation with local researchers provided rankings that conflicted with both other knowledge sources, it is difficult to determine whether differences are due specifically to regional variation, biases imposed by each knowledge source, or both. While researchers were asked to express their thoughts as they may pertain to the South Shore populations of *C. maenas*, their experience is not exclusive to the South Shore (including knowledge from other coasts and provinces also) and thus may not be the most effective measure of local context. Some of these researchers were also hesitant to rank factors. Access to a more comprehensive sample size of local researchers and local *C. maenas* harvesters in future studies may be beneficial.

4.5.Conclusions

While there are challenges associated with both local and scientific knowledge sources, our study highlights the potential for each of these to address each other's relative limitations: providing local, temporally relevant context and potentially unique events on one end, while framing broader context, definitions and categorization for environmental characteristics on the other. Local knowledge may be valuable, yet it may also be limited in transferability with respect to which factors take priority in shaping distributions - these may be expected to change among regions as species compositions, food types and other contextual elements change. Furthermore local knowledge may be limited by the individuals' association with *C. maenas* (*e.g.* people targeting this species directly as opposed to by-catch, as well as whether their objective is to reduce populations or maximize catch). Local knowledge of relevant environmental conditions positively or negatively affecting distributions may be generalizable to other regions, although the local context still warrants consideration in terms of local presence/absence of species, geographic features, as well as environmental gradients. Therefore, the local context should always be taken into consideration when generalizing knowledge.

The importance of assessing the validity and limitations of knowledge is widely recognized, and is an important element in increasing acceptance of less readily accepted knowledge sources in management (Gilchrist *et al.* 2005, Irvine *et al.* 2009, Service *et al.* 2014). This paper highlights the capacity for local knowledge holders to use environmental indicators in identifying 'good' fishing habitat, which were largely supported by findings in the current literature. Our work also illustrates the potential for local resource users to regulate fishing success and formulate important questions for future research, especially where unique phenomena are observed. Therefore, future research initiatives may be greatly facilitated by incorporating local knowledge into management plans while also receiving greater acceptance of recommendations by resource users.

Chapter 5: Conclusion

This chapter integrates the findings and conclusions of our preceding chapters and highlights directions for future research. We discuss the implications of our findings both as they pertain to our case study area along the South Shore of Nova Scotia, as well as in the broader sense of local knowledge applications in invasive species management. This will lead into discussion about the state of local knowledge on the South Shore and its potential contribution to management, as well as implications for modelling and understanding local-scale distributions of *C. maenas,* with some key conclusions.

5.1. Applicability of Local Knowledge to Environmental Management: What Have We Learned?

We have illustrated, through comparing the results of scientific and local studies, the differences and commonalities in knowledge about the determinants of *C. maenas* distribution at local scales. We have identified some of the benefits and limitations of our contrasting knowledge systems and sources for environmental management. We have also demonstrated the importance of considering the local context underpinning knowledge, as well as how incongruences in information (*i.e.* between local and scientific knowledge) may offer directions for future research and management related to green crab. While both knowledge sources addressed environmental factors bearing influence at local scales (despite one drawing from a broader variety of regions), the resulting conclusions differed in some cases, which may highlight questions warranting further exploration.

As discussed, different knowledge perspectives can confirm or challenge information or conclusions stemming from a single knowledge source. The exclusion of either local or scientific knowledge in our study would have affected the resulting conclusions about factors for which there is consensus (or lack thereof) between the two knowledge groups. Differences between knowledge sources, which may reflect local variation in *C. maenas* distributions, biases in the data or methodological inconsistencies may have been overlooked if only one source was examined. In contrast, agreement in the results (such as the specific conditions where higher densities of *C. maenas* are found) across these two knowledge sources reinforces confidence in some of these findings. Where consensus occurred between our local knowledge and scientific knowledge stemming from several geographical regions, it is likely that the general environmental conditions with which *C. maenas* is associated along the South Shore are similar to those in other areas. If environmental characteristics (*e.g.* range of depth inshore, salinity, local species, vegetation) vary between regions hosting this species, however, they may be expected to have an effect on local scale distribution also. In general, consensus exists between scientific and local knowledge that *C. maenas* is associated with vegetated areas, as well as prey species (such as clams, mussels and oysters, small fish and polychaetes), shelter (the exact types varied between knowledge sources, and included rocks, ledges, and shells) and lower salinities (brackish, not fresh water). *C. maenas* faces agonistic interactions and predation from a variety of species, which may be responsible for displacement from local areas, although the existence of these interactions may vary by geographic region (for example, *C. maenas* may only experience range overlap with *Hemigrapsus sanguineus* in certain areas where it is native or invasive). Our knowledge sources agreed on similar but broad depth preferences, which ranged from the shoreline to around 5.5-7.5 meters in depth and changed according to a number of temporal patterns, such as seasonal, tidal or diel variation. Acknowledgement of temperature-based behaviour in association with season was also noted among some local participants and scientific articles, namely migration to deeper areas in the winter.

Conversely, it appears that bottom type is not necessarily as influential as some other factors it was infrequently addressed in the scientific literature, although this may in part be due to a bias in academic interests. While participants sometimes attributed it as important, both knowledge sources also faced some conflict in making determinations of bottom types promoting higher *C. maenas* densities. It may be possible that bottom type is associated with other important factors within regions, such as the presence of *Zostera*, which may grow better on specific bottom types according to nutrient composition and anchorage, among other characteristics (Short 1987, Terrados *et al.* 1999, Hizon-Fradejas, Nakano, Nakai *et al.* 2009). Thus, the presence of factors such as vegetation may be more adequate indicators of *C. maenas* presence if they are directly associated with their distributions. The possibility of such associations was commented on by some participants.

While amounts of exposure (*i.e.* to wave action or current) may bear some influence, either directly or indirectly on *C. maenas* distributions, neither local nor scientific knowledge paid much attention to this, and both held inconsistent views. While most of our knowledge sources agreed that calmer regions were apt to be preferred by *C. maenas*, there was also recognition that they could potentially adapt to more exposed regions, and one literature source even noted that *C. maenas* densities were higher in areas with high flows (despite being less able to locate and handle prey) (Robinson, Smee & Trussell 2011). Some participants noted that even if *C. maenas* were present in areas exposed to flow, it was too challenging to trap when there was a strong current and that they were frequently hauling flipped traps. Thus, regardless of the impact on distributions, it may be difficult to conclusively attribute this factor as a reliable indicator.

Both knowledge sources indicated that lower salinities may be attractive when available to green crab, and that visible freshwater outputs (*e.g.* river mouths) should be noted by managers when identifying areas likely to yield higher *C. maenas* catches. Fresh water may be lethal, as both studies and participants noted that crabs in fresh water, or very low salinity water, were often found dead (one participant held beliefs contrary to this, however they were based on anecdotal accounts from a colleague). This may relate to a similar observation in some of our reviewed literature, which noted that some green crabs were averse to areas with high fluctuations in salinity, or large fluxes of freshwater – namely those nearing moult (*i.e.* "red crabs").

Such results suggest that even in the current, early stages of local knowledge development, local participants hold considerable knowledge relating to local *C. maenas* distribution. This is not surprising. As Bundy & Davis (2013 p. 8) clearly pointed out:

> "By the very nature of the fishing, where harvesters fish for the same commercially valuable species, most of the ecological content of [local knowledge] will be framed by the harvesters' knowledge requirements for achieving livelihood success…. [M]arine harvesters' observations and the knowledge system

> about local fishing grounds built upon these will emphasise associations judged to most directly impact on their access and livelihood success."

In light of this point, it may be expected that factors such as habitat selection, migration and seasonal distribution, and diet of target species – factors directly relating to fishing success - would be of great interest to harvesters (Neis *et al*. 1999). The amount of time spent by *C. maenas* harvesters in the field may be quite high, in some cases a daily activity lasting several months (Cosham, Dalhousie University*, personal obs*.), and therefore, observations of such phenomena may accrue quickly. Furthermore, participants with more years of harvesting *C. maenas* or more directly involved with the fishery (*i.e.* harvesters observing *C. maenas* as a primary source of income as opposed to by-catch) usually held more detailed knowledge of internal population structure, suggesting that these details are further developed with time and experience.

5.2. What Questions Have Arisen?

The results of our research produce a number of questions that may lead to future studies. For example, what are the links between the origins of *C. maenas* populations and the impact on their behaviour (*e.g.* competitive dynamics) and local scale distributions in new environments? In populations where geographic separation has occurred to some degree, and different environmental conditions are experienced by these separated populations, variations in behaviours and environmental tolerances may occur with time. Such geographic variation has been observed in other species, from other crabs, to marine invertebrates and amphibians, affecting prey preference (Sotka & Hay 2002), thermal tolerance (Winne & Keck 2005, Sorte, Jones & Miller 2011, Gaitán-

Espitia *et al*. 2014) and response to water chemistry (Räsänen, Laurila & Merilä 2003). *C. maenas* poses a similar potential, having experienced geographic segregation in its native region of Europe. On the Atlantic Coast of North America at least one secondary invasion has resulted in the presence of multiple genetically distinct populations (Roman 2006). Previous research has suggested that these populations may exhibit unique physiological and behavioural differences in terms of their cold tolerances and their biotic interactions with *Homarus americanus*, however differences beyond this are largely unexplored. Such variations, along with regional differences in the local environment, may have implications for local scale distributions of *C. maenas* in their new range, as well as the long-term impacts of different *C. maenas* genotypes appearing along the coast.

Some research has already been conducted on the behavioural differences between different populations of *C. maenas* along the Atlantic Coast (Rossong *et al*. 2011, Haarr & Rochette 2012). In our research, the relative weights of factors affecting local *C. maenas* distributions along the South Shore varied considerably from those in the literature (namely from other geographic regions), although the effects of regional environmental variations and clade-based effects were difficult to isolate. As populations intermingle and spread, it may be anticipated that if differences in behaviour and physiological tolerances exist between clades of *C. maenas*, they will play into the long-term impacts of this species. This may affect both persistence in coastal areas and interactions with other species. While our local knowledge incorporates information from a number of regions along the South Shore, these all fall within regions where admixing of *C. maenas* populations has occurred, and do not involve a sample size adequate to compare behavioural differences associated with genetic variation.

Some anecdotal accounts do highlight areas for potential exploration, such as the current and potential interactions between *C. maenas* and lobster (*Homarus americanus)*. Lobster comprises a significant portion of fisheries value in the Maritimes (garnering over $900 million in exports alone in 2012), with Lobster Fishing Areas 33 and 34 (containing the southern shore of Nova Scotia) contributing substantially to this (Thériault, Hanlon & Creed 2013). Therefore, further understanding of the potential impacts of *C. maenas* on lobster along the South Shore region may be of strong interest, not only to researchers but a number of local stakeholders relying on this resource. We highlighted participant claims that *C. maenas* predates lobster. *C. maenas* also has demonstrated effectiveness as a lobster bait (Ryan, Livingstone, Barry *et al.* 2014), and therefore is also a potential food source for lobster in coastal areas. It has already been acknowledged in the literature that biotic interactions between these species change with size of agonistic pairs and native origin of *C. maenas*, with more northerly lineages proving to be more successful competitors (for examples and discussion see Rossong *et al*. 2006, Williams *et al.* 2006, Lynch & Rochette 2009, Williams *et al.* 2009, Rossong *et al*. 2011, Haarr & Rochette 2012). These studies have been mostly conducted outside of the South Shore region. As harvesters only held generalized beliefs or observations of lobsters being predated, it is difficult to detail the full nature of these interactions (*i.e.* the sizes of competing individuals, as this would be a key aspect in outcomes of their biotic interactions). Previous work has noted that depth-based separation of habitat means that larger *C. maenas* are more likely to interact with smaller lobster, as larger lobster are found in deeper water (Rossong *et al*. 2006). How these interactions play out along the South Shore may warrant future investigation, especially with respect to the population differences in *C. maenas,* degree of habitat overlap and how interactions may vary with respect to size disparities (*e.g.* whether the origins of a *C. maenas* population affects the likelihood and nature of interactions with larger lobsters).

5.3. Further Insights - How Scientific and Local Knowledge May Complement Each Other

A recognized characteristic of our local knowledge is that it is inherently contextual, and therefore may be difficult to generalize to different regions. This being said, it is possible that local knowledge may work well to complement local management. Silvano & Begossi (2009) illustrated how co-management could be tailored to better suit local conditions by involving harvesters' experiential knowledge. These researchers presented a case study with small-scale tropical fisheries of bluefish. They argued that scientific data for this species was scarce for some regions and demonstrated how all sources of data, including local knowledge, can be useful in generating local baseline information to direct management. While information on *C. maenas* is broadly available from other regions, there is comparatively little data on its local-scale distributions along the South Shore of Canada, and it is possible that local environmental conditions (as well as the specific population of *C. maenas*) will need to be taken into consideration. Furthermore, with the relatively recent establishment of a *C. maenas* fishery in Nova Scotia, scientific knowledge of many population-related aspects is still scarce. There is uncertainty with respect to local population-level responses to fishing, as well as the impacts of future environmental conditions on *C. maenas* population viability. The potential implications of this have been illustrated along the Western Atlantic coast, where recent cold winters have preceded drastic declines in green crab populations (Cosham, Dalhousie University, *personal obs*.).

In light of such facts, local knowledge of *C. maenas* in this region, despite its *developing* state in comparison to most examples of local knowledge in the literature (see Shafto & Coley 2003, Silvano *et al*. 2006, Garcia-Quijano 2007, Silvano & Begossi 2009), may be an asset to management. If harvesters remain largely invested in the resource (*e.g.* if a viable market arises or if other resources they are reliant on, such as lobster, are negatively affected by it), their local knowledge may be enhanced and used alongside pre-existing information to improve the underlying expertise guiding management decisions. Invested harvesters are in a uniquely qualified position to gain and potentially share temporally and spatially relevant information on *C. maenas*. In protected areas where government control of invasive species may be needed to protect sensitive ecosystems, a more informed understanding of local population distribution may help refine trapping efforts and increase efficiencies, freeing up resources for other monitoring projects (Hansen & Jones 2008). With this in mind, consultation and decision-making between local stakeholder groups with local knowledge may serve to enhance management through a more integrated approach.

Possibly one of the greater challenges with this research was the disparity in how knowledge was presented by local and scientific knowledge holders, and how this may have affected their representation in our results. This is an acknowledged issue with synthesizing knowledge from different knowledge holders for management purposes. Differences often exist in the underlying contexts and “ways of thinking” on which people's knowledge is structured and articulated. That is to say, a person's background, experiences and culture will play a role in the way they interpret their observations, as well as how they communicate their knowledge. Such differences can create challenges when it comes to knowledge integration, especially as the norm is to conform other knowledge forms to be compatible with the framework in power, in our case that of Western science, which may reduce and distill knowledge (see Nadasdy 1999). This highlights the concern with knowledge integration that, when simply translated or reduced to fit pre-established scientific frameworks, the full potential of other knowledge sources may be undermined. Some researchers suggest that the consultation of local knowledge holders throughout the research process, as opposed to just fitting their knowledge into a pre-defined scientific framework, may help to create a product that more equitably represents and values the knowledge of different stakeholder groups (Bundy & Davis 2013). Further collaboration may also improve the likelihood that conclusions are accepted by local stakeholders, increase credibility of knowledge sources, improve knowledge flow and understanding between stakeholders, build trust and provide a greater level of empowerment among local stakeholders, as they are given a voice in the research and management of resources (Weeks & Packard 1997, Roux *et al*. 2006, Fernandez-Gimenez, Ballard & Sturtevant 2008, Raymond *et al*. 2010, Bundy & Davis 2013).

Our project did not assess the interest or willingness of local harvesters to engage in research or management of this species, nor did it explore the full potential of legislation and local (*i.e.* community) context affecting the appropriateness of such integrated approaches. A number of participants showed strong interest in the future success of the fishery, and may be willing to enhance their involvement, especially if it means improved management of the green crab fishery or improved restoration of local degraded habitats. Involvement on the part of local stakeholders also requires time and commitment and even if the context is otherwise ideal for such an approach, the local capacity for (and interest in) more local-scale management may need to be better understood before taking further steps.

5.4.Potential Applications to Modelling and Management

The results of our research may help inform local-scale models and predictions by elucidating the factors most feasibly monitored and most apt to be driving *C. maenas* distributions within inshore regions. We have highlighted a number of the environmental factors and conditions above that our knowledge sources agreed play a role (or not) in the local distribution of *C. maenas*. We have provided a summary of these factors, as well as our relative confidence in their utility in local-scale modelling (Table 5.1). These measures of confidence are based on the overall amount of support for each factor's influence by our knowledge sources, as well as how well they agree on the state of each factor providing higher densities of *C. maenas*. These factors come with some caveats which are not explicitly measured, such as availability of pre-existing data or feasibility of collecting new environmental data, how a factor may be most successfully modelled (e.g. broken down by different demographic portions of the population, accounting for seasonal variation), as well as the local environment's biophysical structure, which may also influence the relative applicability and influence of these factors.

Table 5.1: Brief summary of the environmental factors reviewed that may influence local-scale distribution of *C. maenas*. Factors are ordered according to researcher confidence that they play a role in forming local-scale distribution.

Factor	Confidence	Ideal Conditions	Internal Variations	Temporal Variations	Additional Considerations
Depth	Strong	Variable; from tidal to ~20-25 feet.	Yes	Yes	Contingent on many interacting variables.
Food / positive interactions	Strong	Abundance of shellfish, (potentially) lobster; lesser preference for other species.	Yes	Yes/No	Size-dependent. Feeding ceases in winter & with some phenological activities.
Agonistic / negative interactions	Strong	Aversion to rock crab, birds, other local competitors / predators.	Yes	No	Size and species dependant.
Vegetation	Strong	Preference for vegetated areas (e.g. eelgrass, kelp, rockweed, irish moss, seaweed, wrack).	Yes	Yes/No	Use of wrack may be important in winter. Some parts of population (e.g. juveniles, females) may favour vegetation more heavily.
Salinity	Moderate	Preference for fresh water outputs; aversion to pure fresh water or fluctuating salinity.	Yes	No	Some moult phases, sex, age classes more partial to lower salinities.
Shelter	Moderate	Preference for ledges, boulders, stones, shell cover, aversion to open areas.	Yes	Yes	Use of shelter may vary from day/night. Shelter type may vary with age.
Temperature	Moderate	Variable tolerance.	Yes/No	Yes	Movement to greater depths with cooling.
Bottom Type	Weak	Variable; mud, lesser for cobble, sand.	Yes/No	No	Bottom preference may vary with age.
Water Movement	Weak	Variable.	No	No	
Dissolved Oxygen	Weak	Variable.	Yes	No	Moult phase affects DO tolerance.
pH	Weak	N/A	No	No	

Targeting these areas may not always yield superior harvests. In some cases, harvesters and researchers commented on observing such high densities of *C. maenas* that inshore areas appeared saturated, or that there was little visible variation in density among areas. In such cases, targeting habitats where critical age classes are more common (assuming that this is an economically feasible option) along with other classes may contribute to more effective reduction of even high densities of invasive populations (*e.g.* Buhle, Margolis & Ruesink 2005, Weber *et al.* 2011, Kanary *et al*. 2014). It may be difficult to reduce populations by fishing for fecund females unless more effective removal methods are used; egg-bearing females in early summer do not usually forage, limiting the period in which they are susceptible to trapping, and are less apt to enter traps already holding male crabs (Munch-Petersen, Sparre & Hoffmann 1982, Audet, Miron & Moriyasu 2008, de Rivera *et al.* 2007). Targeting of juvenile nursery sites may be feasible, especially as participants often identified these as being separate from other areas with high densities of *C. maenas*. Assuming the technology is available (i.e. traps suitable to nursery sites and with adequate mesh size), trapping juvenile populations in tandem with more commonly harvested age classes may be an effective means of population reduction in over-crowded areas. In areas where populations are less dense, it may be anticipated that they are more concentrated in higher quality habitats and focusing fishing efforts to these regions may be ideal. Movement to deeper, sheltered areas (*i.e.* those with wrack) in the winter may potentially yield populations according to some participants, even in colder months.

All in all, our research provides insights into the factors that may warrant modelling when trying to understand local-scale distributions. It also provides insight into some phenological, age and sex-based differences, which may drive population structure and require separate models or trapping strategies. Because understanding of local environmental conditions is necessary and not often available at the required resolution, it may be challenging to accurately predict species distributions at such a fine scale; however, persons residing in fishing regions (especially those with prior experience and familiarity with inshore habitats, *i.e.* through other harvesting activities) may possess such environmental information on the local ecosystem. Collaboration between such persons and experienced *C. maenas* harvesters to identify prospective hotspots may be possible, and thus it may be possible to refine fishing strategies when first addressing an invaded area. For example, Kejimkujik National Park Seaside encapsulates two ecologically significant estuaries, both of which have been impacted by the *C. maenas* invasion in recent years (Ure *et al.* 2010). Intensive trapping efforts have reduced populations to target numbers in one of these estuaries, Little Port Joli. During this process a number of hotspots, hosting very high densities of *C. maenas,* as well as a number of nursery areas hosting almost exclusively juveniles, were identified. Through our interviews, we found that participants in this region have also noted changes in distribution of the species with temporal changes in the environment, such as shifts in hydrodynamics brought on by construction (*i.e.* bridge removal) (Dowd, Wong & McCarthy 2014). This understanding of the local environment and behaviour of *C. maenas* in relation to environmental factors may be transferable to similar invaded ecosystems, defining similar hotspots for fishing. Furthermore, understanding of the internal population structure in such regions may be used to target specific age classes, which may also be applicable to other regions to improve efficacy of harvest or control efforts. Such an approach would require considerable communication and cooperation between stakeholders.

5.5. Conclusions

Local and scientific knowledge are powerful complements, however their specific strengths and weaknesses need to be understood. Many harvesters who are invested in Nova Scotia's *C. maenas* fishery are dependent on effective fishing strategies, and understanding where and when crabs occur in higher densities plays a role in this. While eliciting and ranking the exact factors driving distributions may warrant more in-depth exploration, our knowledge sources generally agreed on how *C. maenas* distribution relates to environmental conditions. In part, this may illustrate a developing expertise of *C. maenas* among local harvesters. The temporal duration of this knowledge may be useful in the future also. As we have mentioned previously, a key advantage of local knowledge is that it covers longer timespans than most scientific studies (which often focus on a detailed snapshot of a situation instead). Population ecology may also vary depending on the structure of local ecosystems. Considering the developing state of *C. maenas*-related local knowledge, knowledge holders may have less insight into how *C. maenas* population dynamics may shift with time, and thus the conclusions drawn from their observations may be contingent on the state of the invasion (*i.e.* recently arrived, established, spreading towards equilibrium or, in some cases, moving towards population crash). As experience increases however, understanding of the invasion state of local populations (as well as how their distributions may shift with the state and local ecosystem) may increase and contribute to planning more effective removal strategies. How these interactions will differ may be better understood through the inclusion of local knowledge in research and management. We have highlighted several possible ways in which this may be accomplished, including the comparison of same-scale results to increase understanding and confidence, as well as contrasting results and noting disparities to highlight future directions for research. With this in mind, the involvement of harvesters in management may be beneficial, particularly for eliciting local nuances that may significantly influence the success of management decisions.

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Appendix A – Literature review guides.

Table A1. Keywords used in article search for literature review.

Key Search Terms
Green Crab OR Shore Crab OR *Carcinus maenas*
Habitat AND Selection OR Use
Environmental AND Factors OR Variables
Distribution
Abundance
Occurrence

Table A2. The decision-making framework for literature review when including studies with multiple outcomes.

Multiple Studies	In the case of conference proceedings divulging separate studies, the results from each study was recognized as a separate record (the conference title was included along with the study title following an insert such as 'from'). Care was taken to ensure that double-reporting did not occur (for instance, if conference results were later published as a journal article).
Multiple Populations	In the case of studies addressing multiple geographic populations of green crab with clearly separated results (*not* addressing separate sample stations within a single water body, for instance) each population was included as a separate record (same study number, however indicated with a numerical subsection, *i.e.* 2a or 2b).
Multiple Experiments	In a number of studies multiple trials were conducted (for instance, lab and field components would both be tested). These were considered as the same studies, so long as the same population was used, however site conditions and results were recorded as two separate records, with the first record always indicating the field trial conditions and results.
Multiple Results	In cases where several statistics summarize results, all suggesting the same trend, the weakest p value was stated (*i.e.* if several trials suggest that *C. maenas* prefers a certain depth, with all trials providing p-values < 0.05, this value was noted).

Appendix B: Definition of codes used for literature summary documents.

Document Type		Age Group		Support
JP	Published Journal Article	**J**	Juvenile	**1** Strong statistical ($P < 0.005$)
GR	Government Report	**A**	Adult	**2** Statistical ($0.005 < p < 0.05$)
B	Book Section	**B**	Both	**3** Observational
Th	Thesis			**4** Discussed or speculated
				5 Refuted or non-significant ($P > 0.05$)

Clades	
NN	Northern Europe, Native
NI	Northern Europe, Non-native
SN	Southern Europe, Native
SI	Southern Europe, Non-native
MR	Mixed Origins (UK, Australia, Southwest NS

Appendix C: Article information for documents included in literature review (See Appendix B for codes). Full citations can be found in the references.

#	Publication Year	Author	Title	Clade	Location	Name	Country	Doc. Type	Research Year(s)
1	1995	Aagaard, A., Warman, C., Depledge, M.	Tidal and seasonal changes in the temporal and spatial distribution of foraging *Carcinus maenas* in the weakly tidal littoral zone of Kerteminde Fjord, Denmark	NN	Funen	Kerteminde	Denmark	JP	1992-1993
2	2008	Almeida, M.J., Flores, A. A. V & Quieroga, H.	Effect of crab size and habitat type on locomotory activity of juvenile shore crabs, *Carcinus maenas*	SN	Southwest coast	Mira	SW Portugal	JP	2003
3	2011	Almeida, M.J., Gonzalez-Gordillo, J.I., Flores, A.A.V. *et al.*	Cannibalism, post-settlement growth rate and size refuge in a recruitment-limited population of the shore crab *Carcinus maenas*	SN	Ria de Aveiro	Canal de Mira	Portugal	JP	2002
4a	2009	Amaral, V., Cabral, H. N., Jenkins, S. *et al.*	Comparing quality of estuarine and nearshore intertidal habitats for *Carcinus maenas*	SN	Southwest coast	Mira	Portugal	JP	2005
4b	2009	Amaral, V., Cabral, H. N., Jenkins, S. *et al.*	Comparing quality of estuarine and nearshore intertidal habitats for *Carcinus maenas*	MR	Southwest coast	Yealm & Salcombe-Kingsbridge; Downderry and Wembury	England	JP	2005
5	1987	Ameyaw-Akumfi, C. & Naylor, E.	Spontaneous and induced components of salinity preference behaviour in *Carcinus maenas*	MR	Caernarfon	River Gwyrfai	North Wales, UK	JP	1985
6	1999	Ansell, A.D., Comely, C.A. & Robb, L.	Distribution, movements and diet of macrocrustaceans on a Scottish sandy beach with particular reference to predation on juvenile fishes.	MR	Firth of Lorn, West Coast	Ardmucknish Bay	Scotland	JP	1990
7	1973	Atkinson, R.J.A. & Parsons, A.J.	Seasonal patterns of migration and locomotor rhythmicity in populations of *Carcinus*	MR	Pt. St. Mary's and Mumbles	Pt. St. Mary's and Mumbles	Isle of Man and South Wales, UK	JP	1970-1971
8	2005	Baeta, A., Cabral, H. N., Neto, J. M. *et al.*	Biology, population dynamics and secondary production of the green crab *Carcinus maenas (*L.) in a temperate estuary	SN	Mondego Estuary	Mondego	Portugal	JP	2003, 2004

#	Publication Year	Author	Title	Clade	Location	Name	Country	Doc. Type	Research Year(s)
9	2009	Belair, M.C. & Miron, G.	Predation behaviour of *Cancer irroratus* and *Carcinus maenas* during conspecific and heterospecific challenges	NI	Brudnell Point & Cardinal River; New	Brudnell Point & Cardinal River; New	PEI, Canada	JP	2007
10	1982	Berrill, M.	The life cycle of the green crab *Carcinus maenas* at the Northern end of its range	SI	Central coast	Boothbay Harbor	Maine, USA	JP	1979-1980
11	2010	Bessa, F., Baeta, A., Martinho, F. *et al.*	Seasonal and temporal variations in population dynamics of the *Carcinus maenas* (L.): the effect of an extreme drought event in a southern European estuary	SN	West Coast	Mondego Estuary	Portugal	JP	2003-2007
12	2009	Breen, E. & Metaxas, A.	Overlap in the distributions between indigenous and non-indigenous decapods in a brackish micro-tidal system	NI	NS	Bras D'Or	Canada	JP	2005-2006
13	1966	Crothers, J.H.	The Biology of the Shore Crab *Carcinus maenas* (L.) 2. The life of the adult crab	MR	South-West Wales	Dale Fort Field Centre	UK	B	1963-1966
14	1979	Crothersn J.H.	The distribution of crabs in Dale Roads (Milford Haven, Pembrokeshire) during Summer	MR	Milford Haven	Dale Roads	UK	JP	1964, 1966
15	1970	Crothers, J.H.	The distribution of crabs on rocky shores around the Dale Peninsula	MR	Milford Haven	Dale Peninsua	UK	JP	1964, 1966
17	1981	Dare, P.J. & Edwards, D. B.	Underwater television observations on the intertidal movements of shore crabs, *Carcinus maenas*, across a mudflat	MR	Menai Strait	Menai Strait	North Wales, UK	JP	N/A
16	1983	Dare, P.J, Davies, G.& Edwards, D.B.	Predation on juvenile Pacific oysters (*Crassostrea gigas* Thunberg) and mussels (*Mytilus edulis* L.) by shore crabs (*Carcinus maenas* L.)	MR	Menai Strait	Tal-y-foel & Bangor	UK	GR	1974-1977

#	Publication Year	Author	Title	Clade	Location	Name	Country	Doc. Type	Research Year(s)
19	2004	DeGraaf, J.D. & Tyrrell, M.C.	Comparison of the feeding rates of two introduced crab species, *Carcinus maenas* and *Hemigrapsus sanguineus*, on the blue mussel, *Mytilua edulis*	SI	Lab	N/A	USA	JP	2004
18	2005	DeRiviera, C.E., Ruiz, G.M., Hines, A.H. *et al*.	Biotic Resistance to Invasion: Native Predator Limits Abundance and Distribution of an Introduced Crab	SI	Waquoit Bay, Chesapeake Bay, Point	Various	Cape Cod, Massachusetts, USA	JP	2001-2002
20	2008	Edgell, T.C. & Rochette, R.	Differential Snail predation by an exotic crab and the geography of shell-claw covariance in the Northwest Atlantic	MR	Fundy	St. Andrews	Canada	JP	2005-2006
21	1958	Edwards, R.L.	Movements of individual members in a population of the shore crab, *Carcinus maenas* L., in the littoral zone	MR	Southampton Water	Chilling	UK	JP	1950's
22	2005	Ellis, J. C., Chen, W., O'Keefe, B. *et al.*	Predation by gulls on crabs in rocky intertidal and shallow subtidal zones of the Gulf of Maine	SI	Maine	Various	USA	JP	2000-2003
23	2000	Fairchild, E. A.,& Howell, W.	Predator–prey size relationship between *Pseudopleuronectes americanus* and *Carcinus maenas*	SI	New Hampshire	N/A	USA	JP	1998
24	2004	Floyd, T. & Williams, J.	Impact of green crab (*Carcinus maenas* L.) predation on a population of soft-shell clams (*Mya arenaria* L.) In the Southern Gulf of St. Lawrence	NI	NS	Pomquet Harbour	Canada	JP	2001
25	2013	Fulton, B.A., Fairchild, E.A. & Warner, R.	The green crab *Carcinus maenas i*n two New Hampshire estuaries. Part 1: spatial and temporal distribution, sex ratio, average size, and mass	SI	New Hampshire	Great Bay, Hampton-Seabrook	USA	JP	2009-2010
26	2014	Garside, C.J. & Bishop, M.J.	The distribution of the European shore crab, *Carcinus maenas*, with respect to mangrove forests in southeastern Australia	MR	New South Wales	Merimbula Lake, Bermagui River	Australia	JP	2011
27	2011	Gregory, G.J. & Quijon, P.A.	The impact of a coastal invasive predator on infaunal communities: Assessing the roles of density and a native counterpart	NI	PEI	Souris River	Canada	JP	2007
28	2006	Griffen, B.D., & Byers, J.E.	Intraguild predation reduces redundancy of predator species in multiple predator assemblage	SI	New Hampshire	Odiorne Pt.	USA	JP	2004

#	Publication Year	Author	Title	Clade	Location	Name	Country	Doc. Type	Research Year(s)
29	2012	Haarr, M.L.& Rochette, R.	The effect of geographic origin on interactions between adult invasive green crabs *Carcinus maenas* and juvenile American lobsters *Homarus americanus* in Atlantic Canada	NI & SI & MR	Various	Various	Canada	JP	2009
30	1998	Hedvall, O., Moksnes, P., & Pihl. L.	Active habitat selection by megalopae and juvenile shore crabs *Carcinus maenas*: a laboratory study in an annular flume	NN	West Coast	Gullmarsfjord	Sweden	JP	1996
31	2003	Hunt, C.E. & Behrens Yamada. S.	Biotic resistance experienced by an invasive crustacean in a temperate estuary	SI	Yaquina Bay	Yaquina	Oregon, USA	JP	1999
32	1993	Hunter, E. & Naylor, E.	Intertidal migration by the shore crab *Carcinus maenas*	MR	North Wales	Menai Strait	UK	JP	1992
33	2002	Jensen, G., McDonald, P. & Armstrong, D.	East Meets West: Competitive interactions between green crab *Carcinus maenas*, and native and introduced shore crab *Hemigrapsus spp.*	MR	Bodega Bay Harbor	Bodega Bay; Placentia Bay	California	JP	1998-2000
34	2007	Jensen, G., McDonald, P. & Armstrong,	Biotic resistance to green crab, *Carcinus maenas,* in California bays	SI	Bodega Bay Harbor (BBH), Tomales Bay	Bodega Bay Harbor (BBH), Tomales Bay,	California, USA	JP	2001
35	1976	Klein Breteler, W.C.M.	Migration of the shore crab, *Carcinus maenas*, in the Dutch Wadden sea	NN	Western Dutch Wadden Sea	Balgzand	Denmark	JP	1972-1973
36	2002	Lazzari, M.A.	Epibenthic fishes and decapod crustaceans in northern estuaries: a comparison of vegetated and unvegetated habitats in Maine	SI	Maine	Casco Bay; Weskeag River	USA	JP	1999
37	2009	League-Pike, P.E.& Shulman, M.J.	Intraguild Predators: Behavioral Changes and Mortality of the Green Crab (*Carcinus maenas*) During Interactions with the American Lobster (*Homarus americanus*) and Jonah Crab (*Cancer borealis*)	SI	West Coast of Appledore Island, Gulf of Maine		USA	JP	2006
38	1999	Leonard, G.H., Ewanchuk, P.J. & Bertness,	How recruitment, intraspecific interactions, and predation control species borders in a tidal estuary	SI	Maine	N/A	USA	JP	1997

#	Publication Year	Author	Title	Clade	Location	Name	Country	Doc. Type	Research Year(s)
39	1998	Leonard, G.H., Levine, J.M., Schmidt, P.R. *et al.*	Flow-driven variation in intertidal community structure in a Maine estuary	SI	Maine	Damariscotta River	USA	JP	1994, 1995
40	2002	Lohrer, A.M.,& Whitlatch, R.B.	Interactions among aliens: apparent replacement of one exotic species by another	SI	Conneticut; Rhode Island	New Haven, Millstone Point;	Southern New	JP	1996-1999
41	2007	MacDonald, J., Roudez, R., Glover, T...*et al.*	The invasive green crab and Japanese shore crab: behavioral interactions with a native crab species, the blue crab	SI	Lab	N/A	USA	JP	2004-2005
42	2006	McDonald, S. P., Holsman, K.K., Beauchamp, D. A. *et al.*	Bioenergetics Modeling to Investigate Habitat Use by the Nonindigenous Crab , *Carcinus maenas* , in Willapa Bay, Washington	SI	South Stackpole; Nahcotta	Willapa	Washington, USA	JP	1999-2001
43	2001	McDonald, P S., Jensen, G C. & Armstrong, D. A.	The competitive and predatory impacts of the nonindigenous crab *Carcinus maenas* (L.) on early benthic phase Dungeness crab *Cancer magister* Dana.	SI	Lab	Bodega	California, USA	JP	1998-1999
44	1992	McGraw, I.J. & Naylor, E.	Salinity preference of the shore crab *Carcinus maenas* in relation to coloration during intermoult and to prior acclimation	MR	Menai Straits		North Wales, UK	JP	NA
45	1992	McGaw, I.J., & Naylor, E.	Distribution and rhythmic locomotor patterns of estuarine and open-shore populations of *Carcinus maenas*	MR	Southwest Wales	Foryd Bay	UK	JP	1989
46	2000	McKnight, A., Mathews, L.M. & Avery, R., Lee, K.T.	Distribution is correlated with color phase in Green Crabs, *Carcinus maenas* (Linnaeus, 1758) in Southern New England	SI	Vaarious	Various	USA	JP	1995
47	2005	Miron, G., Audet, D., Landry, T. *et al.*	Predation potential of the invasive green crab (*Carcinus maenas)* and other common predators on commercial bivalve species found on Prince Edward Island	NI	PEI	St. Mary's Bay	Canada	JP	2000
48	1998	Moksnes, P-O.	The relative importance of habitat-specific settlement, predation and juvenile dispersal for distribution and abundance of young juvenile shore crabs *Carcinus maenas*	NN	West Coast	Bokevik & Torserod (Gullmarsfjord)	Sweden	JP	N/A

#	Publication Year	Author	Title	Clade	Location	Name	Country	Doc. Type	Research Year(s)
49	2004	Moksnes, P.O.	Interference competition for space in nursery habitats: density-dependent efforts on growth and dispersal in juvenile shore crabs *Carcinus maenas*	NN	West Coast	Bokevik & Torserod (Gullmarsfjord)	Sweden	JP	1997, 1998
51	1962	Naylor, E.	Seasonal changes in a population of *Carcinus maenas* (L.) in the littoral zone	MR	Mumbles Point	Swansea Bay	Wales, UK	JP	1958-1961
50	2011	DFO	Ecological assessment of the invasive European green crab (*Carcinus maenas)* in Newfoundland: 2007-2009.	NI	*	Placentia Bay, St. George's Bay	Newfoundland, Canada	GR	2007-2009
52	2011	Pennell, C.	Acoustic Telemetry to Track Green Crab *From*: Regional Advisory Process on European Green Crab (*Carcinus maenas)*, populations and mitigations in the Newfoundland and Labrador Region	NI	Placentia Bay	Placentia	Newfoundland, Canada	GR	2008; 2009
53	2011	Pickering, T. & Quijon, P.A.	Potential effects of a non-indigenous predator in its expanded range: assessing green crab, *Carcinus maenas*, prey preference in a productive coastal area of Atlantic Canada	NI	PEI	North River	Canada	JP	2009-2010
54	1989	Reid, D.G. & Aldrich, J.C.	Variations in response to environmental hypoxia of different colour forms of the shore crab, *Carcinus maenas*	MR	North Wales	Menai Strait	UK	JP	1987
55	2004	Rewitz, K., Styrishave, B., Depledge, M.H. *et al.*	Spatial and Temporal Distribution of Shore Crabs *Carcinus maenas* in a Small Tidal Estuary	MR	Looe Estuary	Looe	Cornwall, UK	JP	N/A
56	2004	Ross, D.J., Johnson, C.R., Hewitt, C.L. *et al.*	Interaction and impacts of two introduced species on a soft-sediment marine assemblage in SE Tasmania	MR	Bay/Estuary	King George Sound	Tasmania	JP	N/A

#	Publication Year	Author	Title	Clade	Location	Name	Country	Doc. Type	Research Year(s)
57	2003	Sharp, G., Semple, R., Connolly, K. *et al.*	Ecological Assessment of the Basin Head Lagoon : a Proposed Marine Protected Area	NI	Basin Head	Basin Head	Prince Edward Island, Canada	GR	2000;2001
58	2013	Sigurdsson, G.M. & Rochette, R.	Predation by green crab and sand shrimp on settling and recently settled American lobster postlarvae	NI	NB	St. Andrews	Canada	JP	N/A
59	2013	Silva, A.C.F., Boaventura, D.M., Thompson, R.C. *et al.*	Spatial and temporal patterns of subtidal and intertidal crabs excursions	MR	Southwest UK	Mouth Batten & Jennycliff	UK	JP	2006-2007
60	2010	Silva, A.C.F., Hawkins, S.J., Boaventura, D.M. *et al.*	Use of the intertidal zone by mobile predators: influence of wave exposure, tidal phase, and elevation on abundance and diet.	MR	Southwest region	Thurlestone & Portwrinkle; Mount Batten & Jennycliff	UK	JP	2005
61	2009	Smallegance, I.M., van Noordwijk, G.E., van der Meer, J. *et al.*	Spatial distribution of shore crabs *Carcinus maenas* in an intertidal environment in relation to their morphology, prey availability and competition	SN	Dutch Wadden Sea	Balgzand, Ballastplaat, Waardgronden	Netherlands	JP	2004
62	2011	Therriault, T.	European Green Crab in British Columbia - Population and Impact *From*: Regional Advisory Process on European Green Crab (*Carcinus maenas*), populations and mitigations in the Newfoundland and Labrador Region	SI	West Coast	Various	British Columbia, Canada	GR	2006-2009
63	1994	Thiel, M. & Dernedde, T.	Recruitment of shore crabs *Carcinus maenas* on tidal flats: mussel clumps as an important refuge for juveniles	NN	Wadden Sea	Nord-Sylter Wattenmeer	Scandinavia	JP	1991, 1992
64	2007	Thompson, W.J.	Population-level effects of the European green crab (*Carcinus maenas* , L .) in an eelgrass community of the southern Gulf of St . Lawrence	NI	Nova Scotia	Caribou Harbor	Canada	Th	2003
65	2012	Todd, P. A., Oh, J., Loke, L.H.L. *et al.*	Multi-scale phenotype-substrate matching: Evidence from shore crabs (*Carcinus maenas* L.)	MR	Various	Various	Scotland	JP	2003-2005

#	Publication Year	Author	Title	Clade	Location	Name	Country	Doc. Type	Research Year(s)
66	2005	Tremblay, M., Paul, K. & Lawton, P.	Lobsters and other invertebrates in relation to bottom habitat in the Bras d ’ Or Lakes : Application of video and SCUBA transects	NI	Cape Breton	Bras D'or	Nova Scotia, Canada	GR	2002-2003
67	2012	Van den Brink, A., Winjhoven, S. & McLay, C.	Competition and niche segregation following the arrival of *Hemigrapsus takanoi* in the formerly *Carcinus maenas* dominated Dutch delta	NN	Various	Various	Denmark	JP	1990-2011
68	1992	Van der Meeren, G.I., Van der Meeren, C.I.	Location of spawning shore crabs *Carcinus maenas* (L. 1758) (Decapoda Brachyura)	NN	Herdla	N/A	Norway	JP	1986 - 1987
69	2002	Walton, W.C., MacKinnon, C., Rodriguez, L.F. *et al.*	Effect of an invasive crab upon a marine fishery: green crab, *Carcinus maenas*, predation upon a venerid clam, *Katelysia scalarina,* in Tasmania (Australia)	MR	Coastal regions	George's Bay	Tasmania	JP	1996-98
70	1993	Warman, C.G., Reid, D.G. & Naylor, E.	Variation in the tidal migratory behaviour and rhythmic light-responsiveness in the shore crab, *Carcinus maenas*	MR	Menai Strait	Ynys Faelog	UK	JP	1990
71	2009	Williams, P.J., MacSween, C. & Rossong, M.	Competition between green crab (*Carcinus maenas*) and american lobster (*Homarus americanus*)	NI	Nova Scotia	Pomquet Harbour	Canada	JP	2005

Appendix D: Records of factors taken from studies in literature review, including age class, the type of support included, as well as any interacting factors and (in the case of biotic interactions) species involved. (See Appendix B for codes). A brief description of each record is included.

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Bottom type	**8**	B	3	Females and larger males were correlated with medium sediment… Juveniles were correlated with mud.		cw x sex x color
	66	A	3	Green crab were most often found on mixes sand/mud mixes with gravel or cobble.		*
	35	B	3	In regions with muddy or sandy bottoms, most juvenile crabs (<20mm) were found on the flats at low tide. Most crabs >20mm were found on flats in the sandy area at low tide; half of the 20-30mm crabs in the muddy area were on flats at low tide (no larger crabs there then, all in gullies - tidal migrations to flats.		depth x time (tidal) x cw
	11	B	3	Young male and female juveniles were correlated with mud and silt. Older juveniles and adults (with slightly older male age classes included) correlated with coarse sand.		cw x sex
	12	B	1	r value between 0.23-0.45 in all cases in terms of correlation between green crab abundance and amount of cobble substrate at sites.		*
	68	A	3	During the February dive, during spawning season, females were found buried in sand.		Sex x temperature

Factor	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Agonistic Interactions (Competition or Predation)	**67**	B	3	Following arrival of *H. takanoi*, encounter rate of *C. maenas* in any location has decreased to roughly half (on soft, from ~2.5 to 1.3%, on hard from ~5.5 to 3.4%). Further elements of study suggest displacement of *C.maenas* by *H. takanoi*.	*H. takanoi*	*
	33a	B	1	*H. sanguineus* absent/present: ~100%/~20% *C. maenas* using under rock space.	*H. sanguineus*	*
	33a	B	1	*C. maenas* densities under shells went from 10.8/m to virtually nil after 5 months (constructed at start).	*H. orogonensis*	*
	33a	B	3	*H. orogonensis* absent/present: ~97%/20% *C. maenas* using under rock space.	*H. orogonensis*	*
	33b	J	2	*H. orogonensis* present/absent: ~7%/46% *C.maenas* under shell.	*H. orogonensis*	*
	33b	J	2	*H. sanguineus* present/absent: ~6.6%/42% *C. maenas* under shell.	*H. sanguineus*	*
	33b	B	3	*H. sanguineus* displaced *C. maenas*~ 50 times; was displaced ~5 times.	*H. sanguineus*	*
	33b	B	3	*C. maenas* and *H.orogonensis* had similar numbers of displacements.	*H. orogonensis*	*
	42	A	4	Attributes limited distribution of green crab to agonistic interactions with *C. magister*.	*C. magister*	*
	43	A	5	In shell refuges with/without green crab: 29-54% vs. 73-88% Dungeness crab stayed.	*C. magister*	*

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Agonistic Interactions (Competition or Predation)	**43**	B	5	*C. maenas* caused *C. magister* to retreat 2.47 times more often than they themselves retreated.	*C. magister*	*
	43	J	5	Use of shells alone/together: *C. maenas* 69/75% *C. magister* 81/12.5% Food: *C. maenas* displaced *C. magister* 2.5 more often than retreated.	*C. magister*	*
	18	A	2	Mean catch of *C. maenas* / *C. sapidus* per trap strongly inversely correlated a) across sites (r=0.24) and within site (Waquoit Bay; catch when *C. sapidus* absent 0-48; when most abundant at 5 crabs *C. maenas* virtually absent). *C. maenas* mortality rates directly correlated to *C. sapidus* abundance.	*C. sapidus*	*
	31	A	1	Mortality rates of *C. maenas* when paired: 32-76% (depending on size disparities).	*C. productus*	cw
	31	A	2	Significant negative correlation in numbers in trapping exercises (roughly -0.75 for Pearson correlation coefficient).	*C. productus*	*
	31	A	5	N/A.	*C. magister*	*
	31	A	5	N/A.	*H. orogonensis*	*
	9	A	3	Rock crabs and green crabs were rarely on the same mussel sock. In August a survey found 3 mussel socks with both species (green crabs on top of sock).	*C. irroratus*	*
	40a	B	1	When ~10mm cw differential, 50-80% chance of predation by *H. sanguineus*.	*H. sanguineus*	cw

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Agonistic Interactions (Competition or Predation)	**40b**	B	3	From 1996-99, avg. crab densities found to be strongly inversely correlated - as *H.sanguineus* moved in, *C.maenas* densities declined.	*H. sanguineus*	*
	34	A	1	Capture rates of *C. maenas* and *Cancer spp*. were markedly inverted (green crab in high intertidal and away from subtidal channels) - additional experiments in the study suggest predation on green crab by Cancer *spp*.	*C. antennarius , C. productus*	*
	48	J	5	N/A.	*various spps.*	*
	37	A	1	6 medium crabs + 1 (72-79mm CL) lobster = 9/10 crab deaths.	*lobster*	cw
	37	A	1	With lobster: ~20% exposed, ~27% hidden. Without lobster ~40% exposed (large diel variation), ~12% hidden.	*lobster*	*
	37	A	4	6 medium green crab + 2 *C. borealis*, 2 green crab deaths.	*C. borealis*	*
	12	B	5	Species did not demonstrate a negative association, overlap, or other avoidance in regions. Most individuals were juveniles/young adults.	*C. irroratus*	*
	12	B	5	Species did not demonstrate an association, overlap, or other avoidance in regions. Most individuals were juveniles/young adults.… *D. sayi* in many cases had a positive (r2=.06-.35) correlation with *C. maenas*, although not in all cases.	*D. sayi*	cw

Factor (Main)	**Paper #**	**Age Class**	**Support**	**Effect**	**Species (Biotic interactions)**	**Factor (Interactions)**
Agonistic Interactions (Competition or Predation)	**49**	J	2	Low density in area: 53-86% of juveniles in beds. High density: 13-37% found in beds.	*C. maenas*	cw x density
	3	J	2	Variable; all predation in high *Zostera* low (<1 ind./case) vs. low *Zostera* (.25-2.6 ind./case). Small (5mm cw) prey typically consumed less than large (~0-2 less per case) depending on predator size (15-25mm cw).	*C.maenas*	habitat x cw
	59	A	5	N/A.	*C. pagurus*	*
	59	A	5	N/A.	*N. puber*	*
	14	A	5	Occurrence with *C.maenas* present/absent: 36/59.	*P. bernhardus*	*
	14	A	5	Occurrence with *C.maenas* present/absent: 0/95.	*I. dorynchus*	*
	14	A	5	Occurrence with *C.maenas* present/absent: 4/91.	*M. rostrata*	*
	14	A	5	Occurrence with *C.maenas* present/absent: 9/86.	*M. puber*	*
	14	A	5	Occurrence with *C.maenas* present/absent: 0/95.	*A. hyndmanni*	*
	14	A	5	Occurrence with *C.maenas* present/absent: 8/87.	*C. pagurus*	*
	14	A	5	Occurrence with *C.maenas* present/absent: 3/92.	*M. depurator*	*

Factor (Main)	**Paper #**	**Age Class**	**Support**	**Effect**	**Species (Biotic interactions)**	**Factor (Interactions)**
Agonistic Interactions (Competition or Predation)	**27**	A	1	At high densities of interspecific competitors, prey densities were more or less unchanged. With low competitor densities, there was a significant decrease in prey (in all but small polychaetes).	*rock crab*	*
	29	A	5	Lobster mortality: Differed significantly depending on crab origin (89% vs 65-67%); some suggestion that lobster origin also had an effect; on average smaller lobsters (28mm CL) were sig. more likely to be killed than larger lobster (31.6mm CL; p=0.03).	*lobster*	*
	56	A	2	Number of *F. tenuicostata* hinges (per m^2) decreased by approx. 15 (~53 to 38) when seastars (*A. amurensis*) added to cage treatment with *C. maenas*.	*A. amurensis*	*
	71	A	3	Against gc 55-75mm cw, 72-80 mm cl lobster had 10 interactions; displaced *C. maenas* 50% of time.	*lobsters*	*
	41	A	3	Each *C. maenas* and *H. sanguineus* won nearly half of their conflicts; no significant difference between the number of victories between *C. maenas* and *H. sanguineus*, though *H. sanguineus* was more apt to instigate conflict with any species than *C.maenas*.	*H. sanguineus*	*
	41	A	5	*C. sapidus* only won ~2% of its competitions against *C.maenas* or *H.sanguineus* (significantly fewer victories).	*C. sapidus*	*

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Agonistic Interactions	**28**	J	2	Large *C.maenas* + large *H.sanguineus* = 45% consumption vs. expected 60% Small *C. maenas* + Large *H. sanguineus* = 20% consumption vs. expected 42%.	*H. sanguineus*	cw
	26	B	5	Crabs heavily predated on; however tendency to be found in highest densities in habitats where predation is greatest (may be due to study effects).	*Larus (gulls)*	*
Depth	**8**	A	3	Females and males were correlated to depth (includes more small female classes). Red crabs correlated with depth (prefer deeper water); green crab associated with upstream.		cw x sex x color
	10	B	3	<30mm cw (juvenile) crabs were most common under intertidal rocks and rockweed. Crabs >30mm cw (adult) were more common in (shallow) subtidal water; many foraged intertidally at high tide. Used intertidal cover while molting.		cw
	17	A	3	Peak flood movements inshore occurred in around 0.5-2.5m depth of water; out, occurred in 1.5-0.5m (few crabs found in <0.5m water); usually began to appear migrating at around .3-.4m depth; tidal range between 2.7-4.9m depending on season; 4.3-5.4h for 90% of crabs to move >25m upshore from littoral.		*
	50	B	3	Populations concentrated to shallow inshore waters (<5m).		*
	50	J	3	Juveniles largely concentrated in intertidal among kelp and rocks.		cw

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Depth	**66**	A	3	~58% of green crab at 3-6.1m; ~28% at 6.1-9.1m; ~14% at >9.1m.		*
	55	B	2	Mean top CPUE values found at stations with mean depths of 1.6/1.8/1.9 (Mean CPUEs between spring/neap tides: 17.5/19.5/18, respectively) versus 1.5-0.6 depth (excluding site at ocean mouth, 2.2m) with mean CPUEs of 3.5-9.		*
	55	J	2	Difficult to find exact supporting values; study strongly supports that juvenile crabs were significantly larger at 1.8 than 1.4m… notes also that these catches changed with period in tidal cycle, with increases in juvenile catches at low tide.		cw x tide
	55	A	2	Most adult shore crabs caught at high tide / More adult crabs were caught at night. During high tide: mean CPUE during night. 18.2 / day 11.8 ~ 5.5 for low tide, both day and night.		cw x circadian
	42	A	3	CPUE increased very slightly with increasing depth (0 at .3m MLLW m to .013 crabs/trap/day at 1.5m MLLW), highest in mid-littoral with *Spartina.*		*
	52	A	3	Female green crab were common shallow and moved deeper in the fall (still near coves). Movements to deeper water were correlated with temperature decreases.		*
	62	A	3	Green crabs remained shallower than 5m. Larger crabs migrated deeper occasionally.		cw

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Depth	**57**	B	3	CPUE increased in the channel in the fall - study suggests migration to deeper water with temperature drops.		season
	7	B	3	Crabs/month in summer (May-October) - 200-300 between tidemarks, ~10 sublittoral. In winter (November-April), 0-100 intertidal, ~5-40 sublittoral.		season
	7	B	3	Tidal migration disappeared in winter; excludes ovigerous females and juveniles; overall activity increased at night regardless of season. Female crabs dominated the summer creel and showed rhythmic behaviour (non-ovigerous); arrhythmic in winter, hiding under rocks in intertidal zone (ovigerous); both temperature and season were discussed, however ~8°C appeared to be the temperature at which rhythmicity stopped.		season x Sex x CW x Tide
	51	B	3	Small crabs (<35mm cw) present at low tide on shoreline - less movement than larger adults. Adults migrated with tide in warmer months, ceasing in winter (January/february). Fewer crabs found in deepest areas (6m) in June/July. More males found at MTL on average than females (198 vs 82); more females at LWS than males (170/119); few of either sex at 3fm (~32 each sex).		cw x Sex x season
	35	J	3	The number of juvenile crabs caught per m^2 with the digging net in the main gully of the muddy area was 16x lower than the number caught by quantitative sampling on the nearby flats. Potential effect of gathering efficiencies.		cw

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Depth	**1**	B	3	February-May 0-2 crabs caught at 0.1-0.5m, 1-28 caught at 1-4m. August-October, 10-133 crabs caught/station, 9-82 crabs caught/station.		*
	1	B	2	Fewer "non-green" crabs at inner stations than at outer stations as opposed to expected numbers.		Color x season
	1	J	1	More juveniles tended to be captured at deeper stations at both high and low tide (1-4m vs. < 1m; 28.5-39.9 vs. 35.8-45.1 juveniles of total proportion of catch).		cw
	1	B	3	Female numbers at 0.1m: 0 in February and May. 68 in October. Moderate (~10-37) at all depths in August.		Sex x season
	11	B	3	Red females and males were distributed mainly at the mouth and associated with larger depths… Females and larger males were found at the mouth (A), the station with bigger depths.		color x sex x cw
	12	B	1	*C. maenas* abundance highest at between 0.5-1.5m (between 0-14 ind./m) versus greater depths (~0-1 ind./m). Greatest at 0.5m.		*
	32	B	1	Average collection per 6 hour sample period of traps facing/against tidal flow: 19/2.6.		*
	32	B	2	Study suggests that there is evidence supporting interactions, however apparent that most of effect is due to differences in catches at stations and not circadian differences.		circadian

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Depth	**32**	B	3	Red crabs were absent from the upper shore at low tide - always most common (up to 49%) at the deepest stations.		color
	32	A	3	Crabs 30-50mm cw were most common upper to mid shore; crabs 50-60mm cw dominated lower shore (*i.e.* subtidal); was also found that cw sizes increased at stations as tide came in (typically a 20-30mm cw increase).		cw
	32	B	3	Fewer crabs were found in intertidal migrations in the winter months: mean catches of green crabs at low (shore; searching)/high (trapping) tide in July/September and October/December: means 2.53/21.13 versus .48/.867.		season
	32	B	3	Percent males captured in stations changes from 61-96% moving from deepest to shallowest stations (from upper shore to lower shore); strongly suggests that only males are migrating inshore.		sex
	61	B	3	In only one case was total abundance at any distance from a gully greater than crab densities within a gully.		*
	61	B	2	Abundances of green & red males decreased w/ distance from gully. Same for females, yet the abundance of green females first decreased and then increased with increasing distance from the gully.		Distance x depth x sex x color
	6	A	1	Density (# ind./100m^2) at 0.5/5m: 0.75/3.		*

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Depth	**6**	A	2	At msssr: 6ind/100m^2 at 3m 1-3 ind/100m^2 at all other depths at ss+1 & sr: ~4.5-6.5ind/100m^2 at 5m 0-5-ind/100m^2 at all other depths at ss-3/sr+3, 0-2 ind/100m^2 at all depths.		Circadian
	6	A	2	No. ind/100m at low/high tide, ~1.6/0.9		Time (tide)
	13	B	3	Ratios change moving offshore: (% Green/Red) Mid Shore: 86/14 Lower Shore: 65/35 Sublittoral: 46/54.		Color
	13	B	3	Most ~20-30mm cw onshore (138 out of 140) Most 40-50mm cw between shore & 3fm (95-99%) Most 60mm at 0-3fm (~80%) Most 70mm at 3fm (~65%).		cw
	13	B	3	Rate of parisitization changes with depth: Onshore (0.7%) 0-3fm (8%) 3-6fm (17%) >6fm (75%.)		Parasitization
	59	B	3	Noted in mark recapture: Of individuals marked at low/high tide: ~22 recaptured at high tide, 100 recaptured at low tide. / ~50 recaptured at high tide, 18 recaptured at low tide.		*
	68	A	3	No females were found below 6m depth. During February dive, during spawning season, females were found buried in sand at depths no greater than 3m.		sex

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Depth	**14**	A	3	CPUE of crabs found at different depths: Onshore - 64% 0-3fm - 31% 3-6fm - 2% >6fm - 0.08%.		*
	60	A	1	Significantly more crabs on upper than lower shore (18-24 versus 0-2 crabs).		*
	60	A	3	Active during nocturnal low tides - an average of 132 individuals recorded active per observer per hour.		circadian x time (tidal)
	60	A	3	Female *C. maenas* concentrated to upper shore - males concentrated to lower shore.		sex
	60	A	1	*C. maenas* larger (mean difference in size: ~12%) on the upper shore than on the lower shore at exposed locations… Also *C. maenas* was significantly larger at sheltered locations and lower on the shoreline in sheltered locations.		water movement x cw
	70	B	3	Small (<35mm cw; juvenile) crabs location from low water mark at low/high tide was relatively similar (most at approx 30m; mid-tidal level) compared to large (>35mm) crabs who moved with the tide (from -10m below low water mark at low tide to mid-tidal at high tide).		circadian x cw x tide
	70	B	3	Green crabs predominated all shore heights at high tide (roughly 55-40%). Red crabs were most abundant offshore at high tide (roughly 30/70) however at low tide green crabs migrated out, just surpassing them in densities (45/55).		color

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Depth	**70**	B	3	Observed (without evidence demonstrated in study) that sex-differences in migration existed, and majority of intertidal migrations were male.		sex
	21	A	3	Males collected from area B (further offshore / deeper) consistently larger than those taken from areas A & C (roughly same depth); differences highly sig. in all cases. No significant difference between males taken in areas A and C except in the case of those taken in August.		sex x cw
	21	A	3	Males, area B - small in April, peak in May, dropped in August. Areas A and C - peak in July, drop in August. Females - lower in May than in April - rose steadily, peaked in August.		sex x time (seasonal)
	21	A	3	Up and down movement - male crabs came in with the tide for short time before moving back to sublittoral.		sex x time (tidal)
Dissolved Oxygen	**8**	B	3	(Ordination diagram) red crabs correlated with DO.		color
	55	B	5	No effect of DO.		*
	18	A	5	*C. maenas* abundance did not change with temperature, salinity, or DO.		*
	54	A	1	O_2 tension of emersion: ~30 red shell, ~16 green shell.		color

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Dissolved O_2	**11**	B	3	Males and females (slightly smaller classes of females) positively correlated with dissolved oxygen...Red females and males were usually closer to the estuary mouth. Their distributions were associated with higher dissolved O_2.		color x sex x cw
Food source	**50**	B	3	Highest concentrations of crabs in *Zostera* and *Mytilus* beds.	*Mytilus*	*
	43	A	2	Mortality with *C. maenas*: ~13%. Without: 1%.	*C. magister*	*
	40b	B	1	When included in cages with *C. maenas*, only 5% of *M. edulis* survived.	*M. edulis*	*
	39	A	2	Predation rate (% mortality/predator) in high/low flow sites: *Nucella*: ~0/1.5 *Littorina*: ~0/1.1 *Mytilus*:~1/9.	*Nucella, Littorina, Mytilus*	water move ment
	61	B	3	(Ordination diagram) only red juvenile males didn't show any correlation with large shrimps.	*C. crangon*	sex x cw x color
	16	A	3	In field: observed .5-1g oysters for 4h - met by 40-50 crabs (30-45mm cw) = 6% mortality… In lab: study was able to identify cut off rates at which expected no consumption of oysters.	*oysters*	cw
	16	A	3	In lab: dependant on size of crab (25-75mm cw) and mussel (15-40mm), daily consumption rates ranged from 32-.67 mussels In field: observed in 8h a 24.3% mortality rate by green crabs, mainly >50mm cw.	*mussel*	cw

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Food Source	**16**	A	3	Crabs ate more oysters in warmer water (18-21 °C) than at lower (12-16 °C) - not significant in all cases.	*oysters*	tempe rature
	23	A	1	Across all crab sizes, small (<20mm) flounder had a sig. high mortality rate (30%) compared to all other mortality rates (<17%).	*Flounder*	cw
	24	A	2	Large (>17mm) softshell clams did not show sig. predation differences among treatments; small (<17mm) softshell clams showed sig. predation in enclosures with 1-5 crabs: in uncaged/exclosures, clam densities ~1200-1700/m, in enclosures ~300-350/m^2 (~3 months).	*clams*	cw
	27	A	1	When combined at high densities of interspecific competitors, prey densities remained similar to those in ambient treatments. With low competitor densities, prey levels dropped significantly (in all but small polychaetes).	*various*	comp etition
	27	A	2	On average, treatments with green crabs decreased prey (infaunal; both polychaetes and molluscs) densities by ~1/3 to 3/4 their ambient densities (excluding molluscs <5mm); predation intensity didn't increase with crab density, suggesting density-dependant mediation.	*various*	specie s x size x comp etition

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Food Source	**47**	A	1	Consumption: never consumes large (25-40mm) oysters. Single choice: preferred small (0-25mm) mussels & (0-15mm) clams (~45-50% mortality) to other sizes/species (0-24% mortality) Multiple choice: similar preferences; consumes more 0-25mm oysters (70-85%) than clams (0-15mm ~58% mortality); 0-25mm mussels 67-100% mortality; all others 0-25% mortality ***Similar trends in other experiments, except broader size class of clams consumed. Green crab weighed on average ~ 60g for experiments.	*oysters, mussels, clams*	cw
	47	A	1	Consumption: Never consumes large (25-40mm) oysters. Single choice: Preferred small (0-25mm) Mussels & (0-15mm) clams (~45-50% mortality) to other sizes/species (0-24% mortality) Multiple Choice: Similar preferences; consumes more 0-25mm oysters (70-85%) than clams (0-15mm ~58% mortality); 0-25mm mussels 67-100% mortality; all others 0-25% mortality ***Similar trends in other experiments, except broader size class of clams consumed. Green crab weighed on average ~ 60g for experiments.	*oysters, mussels, clams*	species

Factor (Main)	**Paper #**	**Age Class**	**Support**	**Effect**	**Species (Biotic interactions)**	**Factor (Interactions)**
Food Source	**53a/b**	A	1	Consumption rate decreased with increased prey size/decreased crab size in (lab)(field); 25-35mm versus small (35-45mm) crabs, mortality (0-3)(0-6) versus large (55-75) crabs, (0-9)(0-10)(by species) 15-25mm versus small crabs, mortality (0-10)(0-10) versus large crabs (5-10)(5-10)	*oysters, mussels, clams*	cw
	53a/b	A	3	Consumption: clams > mussels > oysters From small (35-45mm) - large (55-75) crabs, lab / field trials Clams (2-10) / (6-10) Mussels (0-8) / (0-10) Oysters (0-5) / (0-5) *Across range of crab and prey sizes; comparing lab/field trials; 15-35mm specimens.	*clams, mussels, oysters*	species
	20a/b	A	1	*L. obtusata* shells collected - more than double the total percent collected were scarred (predated) compared to *L. littorea*. In lab predation: 1/150 (L.l) vs. 96/150 (L.o) after ~200h.	*L. obtusata, L. littorea*	species
	20b	A	5	*L. obtusata* demonstrated size-related survivorship gradient (~ small = 2, medium = 3.5, large = 6).	*L. obtusata*	cw
	56	A	5	Study notes that while sig difference wasn't picked up on, the change in abundance was present and would have had to have been enormous to elicit a strong p-value.	*F. tenuicostata*	*
	56	A	5	Worth noting that all mussels in study were quite large (>25mm).	*mussels*	*

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Food Source	**56**	A	2	Number of *F. tenuicostata* hinges (per m^2) decreased by approx. 18 when seastars (*A. amurensis*) added to cage treatment with *C. maenas.*	*F. tenuicostata*	competition
	56	A	2	*C. maenas* predation significantly shifted size distribution of molluscs, suggesting size-specific predation.	*F. tenuicostata*	cw
	58	J	1	% survival with/without crab (14-26mm cw) treatment: Start: 100/100 6h: ~98/~40 12h:~90/~15 18h: ~85/~4.	*lobster postlarvae*	*
	64	A	2	In general, total biomass of taxa was 53% lower in high crab density cages than in cages without green crabs.	*various*	*
	69	A	2	Survival of clams in areas with/without green crab: 79%/98%.	*clams*	*
	69	A	1	Large (50-65mm cw) crabs heavily consumed small (5-12mm sl) clams compared to small (30-40mm) crabs; larger (14-33mm sl) clams were less perturbed by both crab classes; in most cases survival was close to 100%.	*clams*	cw
	69	A	1	(50-65mm) large males preyed more heavily on the clams than large females in one trial - not consistent among all tests.	*clams*	sex
	19	J	2	*C.maenas* (~22.5mm cw) mean consumption of mussels: small (~5mm=17) medium (~10mm = 13) and large (~14.5-21mm = 9).	*mussels*	cw

Factor (Main)	**Paper #**	**Age Class**	**Support**	**Effect**	**Species (Biotic interactions)**	**Factor (Interactions)**
Food Source	**38**	A	1	With juvenile crabs, barnacle survival neared ~100%; with adults survival ranges from ~37%-80% (with/without neighbors).	*S. balanoides*,	cw
	28	J	2	Large *C.maenas* (~26mm)+ large competitor (~21mm) = 45% consumption versus expected 60% small *C.maenas* (~13mm)+large competitor = 20% consumption vs. expected 42% ** Other combos NS.	*h.sanguineus*	competition x cw
pH	**55**	B	5	No effect of pH.		*
Salinity	**8**	A	3	Females and (larger) males correlated with salinity changes.		Sex x cw
	44	A	2	Red crabs - Left 11‰, stayed in 17‰, moved to 22‰ Green crabs - Left 5‰, stayed in 11-17‰, moved to 22‰ No sig. migration 22-40‰ -Preference for min. 22‰ salinity.		color
	5	A	2	In 5-22 ‰ salinity~ 75 in 22‰ salinity In 22-40‰ salinity~ 40% at 34‰ salinity Preference for 34% salinity.		*
	55	B	3	Rarely in water salinity < 15‰, ideally >20‰, highest CPUE at 35‰.		*
	52	A	4	Crabs released on one side of the bay moved to other side of bay; possibly due to mating/moulting or reproductive activities.		sex/Rep. Cond.

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Salinity	**62**	A	3	High catch rates correlated with decreased salinity; no green crab have been obtained from inside or mainland waters.		*
	18	A	5	Crab abundance not linked to salinity.		*
	25	B	3	Estuary #1: CPUE highest mid-estuary (attributed to larger salinity gradient - lower overall mean salinity, 27‰ - and *C. maenas* limitations on salinity tolerance). Most females in October-November, Estuary #2: CPUE consistently increased moving up estuary (salinity higher overall, ~32‰).		*
	46	A	1	% Red *C. maenas* in exposed/inland: 40,27,7 / 10,18,7,5. Red prefer exposed (fewer salinity fluctuations).		color x temp
	14	A	4	Attributes some aspects of distribution to amount of fluctuating salinity present in regions - some are expected to remain fully saline whereas others fluctuate.		*
	45a/b	A	3	Maximum survival: green 22‰, red 34‰. Numbers at sites, pooled over summer: high/dynamic salinity (25-34‰ / 0-2 6‰): (males) Green: 550-1000 / 550-1000, Red: 80-550 / 5-50 (Females) Green: 130-410 / 480-580 Red: 280-480 / ~200.		color x sex x salinity
	21	A	4	Population density is much higher in one region of sites sampled - attributed to a local freshwater input.		*

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Shelter	**10**	B	3	Crabs <30mm cw were most common under rocks and rockweed in intertidal. Crabs >30mm cw were more common in shallow subtidal; many moved intertidally to forage at high tide - under intertidal protective cover when they molted.		molting x cw
	63	J	2	Mussel beds~ 12-16ind./500cm Mud~ 0-2ind./500cm.		*
	63	J	3	In areas with mussel clumps present/absent (ind./500cm^2): Site 1 High intertidal - ~1.3/1 Mid intertidal - ~1.7/0.2 Low intertidal - ~1.2/0 In areas with mussel clumps present/absent (ind./500cm^2; pooled results): Site 2 High intertidal - ~1-1.9/0-0.4 Upper mid - ~0.3-1/0.1-0.2 Lower mid - ~0.5-1.1/0-0.3 Low - ~1.3-2.1/0.2-0.3 *winter number too low; omitted.		Depth
	67	B	2	Soft substrate, no shells/stones~ 2.5% encounter rate* soft substrate with shells/stones~ 5.5% encounter rate* *only in absence of *H. takanoi.*		*
	33a	B	1	*C. maenas* densities under shells went from 10.8/m^2 to virtually 0 after 5 months (constructed at start).		Competition
	33a	B	1	*H. sanguineus* absent/present: ~100%/~20% *C. maenas* using under rock space vs other areas.		Competition

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Shelter	**33a**	B	3	*H. orogonensis* absent/present: ~97%/20% *C. maenas* using under rock space.		Competition
	33b	J	2	*H. orogonensis* present/absent: ~7%/46% *C. maenas* under shell vs. other areas *H. sanguineus* present/absent: ~6.6%/42% *C. maenas* under shell vs. other areas.		Competition
	50	J	3	Juveniles largely concentrated in intertidal among kelp and rocks.		cw
	65	B	1	Patterned: ~50% mussels / ~30% rocks / 25% algae.		carapace pattern
	30	J	3	~ 60% of juveniles found in mussel beds; 10% in eelgrass; 30% in algae; ~1% on sand.		*
	48	J	2	2-3 instar: 50-190crab/m^2 4-9 instar: 15-160crab/m^2.		cw
	37	A	2	Day: 15% exposed, 58% sheltered, 23% hidden Night: 50% exposed, 32% sheltered, 10% hidden.		circadian
	37	A	1	With lobster: ~20% exposed, ~27% hidden. Without lobster ~40% exposed (large diel variation), ~12% hidden.		competition
	49	J	1	Exponential relationship of (J4-9) crabs in area / (J7) crabs in mussel beds: <20crabs/m / <5crabs/bed 25crabs/m / 18crabs/bed. At low densities 53-86% of crabs in beds (which covered 6% of total habitat).		density, cw

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Temperature	**8**	B	5	Temperature wasn't correlated with any crab demographic.		*
	55	B	5	No effect of temperature.		*
	52	A	3	Females stayed in shallow water, moving deeper later in fall. This was correlated with temperature decreases.		sex x time x depth
	57	B	3	Numbers captured in channels increase in fall - suggest a movement to deeper depth with decreased temperatures.		depth x time
	18	A	5	*C. maenas* abundance not associated with temperature.		*
	7	B	3	Tidal migration disappeared in winter; Not applicable to ovigerous females and juveniles; overall activity increased at night regardless of season. Female crabs dominated the summer creel and showed rhythmic behaviour (non-ovigerous); arhythmic in winter, hiding under rocks in intertidal zone (ovigerous); both temperature and season were discussed, however ~8 °C appeared to be the temperature at which rhythmicity stopped.		depth x sex x cw x tide x time
	7	B	3	Crabs/month In summer (May-October) - 200-300 between tidemarks, ~10 sublittoral. In winter (November-April), 0-100 intertidal, ~5-40 sublittoral.		depth x time
	1	B	2	Fewer "non-green" crabs at inner stations than at outer stations as opposed to expected numbers.		Color x Depth

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Temperature	**1**	B	3	Female #'s at 0.1m: 0 in February, May 68 in October. Moderate (~10-37) at all depths in August.		Depth x sex x time
	11	J	3	Juveniles were correlated to high temperature.		cw
	46	A	1	(Temperature fluctuations) % red in exposed/inland: 40, 27, 7 / 10, 18, 7, 5.		color
	26	B	2	When offered a choice of unshaded and shaded microhabitat, crabs spent over double the amount of time in the shade (83% shaded: 37% unshaded.		*
Vegetation	**2**	J	2	No *Zostera*~ 5-15ind./m^2 / *Zostera*~ 18-95ind./m^2.		*
	8	J	3	Juveniles were correlated with algae.		cw
	10	B	3	Crabs <30mm cw = under rocks/rockweed intertidal crabs >30mm cw = more often shallow subtidal, but many foraged intertidally at high tide - used intertidal cover for moulting.		Tidal column x color x cw
	63	J	3	Greatest concentrations in eelgrass and mussel beds.		*
	50	B	3	Densities in mussel beds don't differ sig. from surrounding seagrass ($p > 0.1$) however are sig. greater than surrounding sand flats ($p < 0.05$).		*
	42	A	3	CPUE was highest in the *Spartina* edge habitat (0.014 crabs/trap/day versus 0-0.008 crabs/trap/day).		*

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Vegetation	**65**	B	1	Patterned: ~50% mussels / ~30% rocks / 25% algae (inversed for plain specimens).		carapace pattern
	65	J	3	Juveniles were strongly related to algal cover.		cw
	30	J	1	~ 60% of juveniles found in mussel beds; 10% in eelgrass; 30% in algae; ~0% on sand.		*
	48	J	2	2-3 instar: 15-65crab/m eelgrass, 0-30crab/m algae 4-9 instar: 2-55crab/m eelgrass, 0-10 crab/m algae.		*
	11	J	4	Juveniles were correlated with algal cover.		cw
	3	J	2	Mixed/*Zostera* patches before/after recruitment: ~4.5ind/m^2 / 5.5ind/m^2 / 1.5ind/m^2 / 19ind/m^2.		season / time
	36	B	1	Eelgrass/sand: Bay: 1.5 / 0.2 River: 2.4 / 0.6.		*
	26	B	3	On average, *C.maenas* were higher densities in mangrove vs. unvegetated habitat. (overall 1.2 crabs/trap vegetated versus .39 crabs/trap).		*
	4a	B	2	No *Zostera*~ 64-65ind./m^2 / *Zostera*~ 135-165ind./m^2.		*
	4b	B	4	No *Zostera*~ 55-85ind./m^2 / *Zostera*~ 95-115ind./m^2.		*

Factor (Main)	Paper #	Age Class	Support	Effect	Species (Biotic interactions)	Factor (Interactions)
Water movement	**39**	A	2	Green crab density at high/low flow sites (110cm/s / 10cm/s): ~ 54/m^2 / 10/m^2). Note study combines green and rock crabs.		*
	39	A	2	Predation rate (%mortality/predator) in high/low flow sites: *Nucella*: ~0/1.5 *Littorina*: ~0/1.1 *Mytilus*:~1/9.		food source
	15	B	3	In exposure grades high>low, numbers of young/adult: 45,42,83,84,92,100 / 0,9,40,50,85,100.		*
	60	A	1	*C. maenas* were larger (mean difference in size: ~12%) on the upper shore than on the lower shore at exposed locations… also, *C. maenas* was significantly larger at sheltered locations and lower on the shoreline in sheltered locations.		cw
	60	A	5	Average 2-24 versus 0-17 crabs in sheltered vs. exposed areas; at high tide underwater. Only significant (p = 0.03) when considering interactions with tidal level.		depth (tidal zone)

Appendix E: Brief summary of conditions promoting the greatest densities of *C. maenas,* according to the literature. Specific differences concerning internal factors are noted.

		Bottom Type	**Agonistic**	**Depth**	**Dissolved Oxygen**
Overall		General variation in bottom type preference - may not be largely constraining	**Competing or Predating species:** *H. americanus* *A. amurensis* *C. antennarius* *C. borealis* *C. irroratus* *C. maenas* *C. magister* *H. orogonensis* *C. productus* *H. sanguineus* *C. sapidus* *H. takanoi* **Outcompeted or No-interaction species:** *H. americanus* *P. bernhardus* *M. depurator* *I. dorynchus* *C. irroratus* *Larus* *C. magister* *H. orogonensis* *C. pagarus* *N. puber* *M. rostrata* *C. sapidus* *D. sayi*	Depth preferences vary from intertidal to ~6m. Many studies towards centre of this. Common seasonal migration to deeper waters with cold. Depth distribution affected by tidal phase, season, moult phase, etc.	_
By color	**Red**	_		Deeper water	Higher DO
	Green	_		Shallower water, more variable	No DO pref.
By age	**Juvenile**	Mud or Silt/Sand		Greater tendancy to be in intertidal or onshore - less affected by seasonal tendency for migration	_
	Adult	Mud/Sand		Deeper with size, migrates with tide	_
By Sex	**Male**	_		Some evidence of deeper water	_
	Female	Bury in sand in winter		_	_
Notes		_	Largely size dependent	Variability in observations	_

		Food Source	pH	Salinity	Shelter
Overall		**Predated Species:** *H. americanus* (postlarvae) *P. americanus* *M. arenaria* *S. balanoides,* *C. crangon* *Crassostrea* *G. gemma* *L. littorea* *Littorina* *Mytilus* *Nucella* Polychaetes (various) *H sanguineus* *F. tenuicostata* **Non-Predated Species:** *F. tenuicostata*	_	around 22-35‰ salinity	Shelter overall preferred characteristic. Shells, mussel beds and rocks common source of shelter.
By color	**Red**		_	Consistent high salinity	_
	Green		_	Lower salinity; tolerant to fluctuations	_
By age	**Juvenile**		_	_	Preference for mussel beds for shelter. Potential priority over vegetation. Also use kelp/rockweed and rocks.
	Adult		_	_	Shelter more prioritized in presence of major predators, while moulting and in daytime. Preference for rocks or shell fragments. Also relies on vegetation.
By Sex	**Male**		_	_	_
	Female		_	_	_
Notes		Largely size dependent	_	_	_

		Temperature	**Vegetation**	**Water Movement**
Overall		No major evidence of temperature impacts, other than tendency to move to deeper water in the winter. Potential aversion to direct heat, potential lessening of other depth-related migrations with cooling.	General preference for vegetative cover (algae, eelgrass or kelp). Some evidence of greater constraint to areas in juveniles.	High flow has higher densities, however low flow shows better use for predation. General preference for areas with less wave exposure.
By color	**Red**	_	_	_
	Green	_	_	_
By age	**Juvenile**	May prefer warmer waters	May prefer mussel beds over vegetation. Largely prefers vegetation.	_
	Adult	_	Still prefers vegetation. May be less dependent on it compared to juveniles.	_
By Sex	**Male**	_	_	_
	Female	_	_	_
Notes		_	_	_

Appendix F – Script illustrating the process undertaken when interviewing participants.

School for Resource and Environmental Studies
Suite 5010, 6100 University Ave
Faculty of Management,
Dalhousie University
Halifax, NS, B3H 4R2

This interview guide is constructed to give a general idea of the intended progression of interviews conducted with participants. As this is a semi-structured interview, questions included comprise a general checklist to ensure that similar information and inquiries are provided to everyone. Due to the nature of the interview population (researchers and fishermen), the questions addressed may vary depending on their relevance.

Initial Briefing

Good morning/afternoon, thank you again for taking your time to participate in my study. I appreciate any and all information you can provide. This will be a very informal interview – mostly to gain an overview of your experience relating to *C. maenas* and your thoughts / observations / insights from local interaction / research with *C. maenas* in the Maritimes. I will ask a few specific questions pertaining to this, mostly to ensure similar information is covered by all participants. The entire interview is expected to take roughly 30 minutes.

If it is all right with you, to ensure accuracy of documentation and so I don't need to be distracted with writing, I would like to record the interview. Do I have your permission to record this conversation? Also if you find it useful to help explain, I have additional maps of the SWNS coast that you may like to indicate regions on.

(The above script may deviate if the interview leads to a site visitation, as GPS marking will be used in lieu of or in addition to a map.)

Questions – please note that these are to outline the general progression of the interview, as opposed to acting as an explicit script to be followed.

1. How long have you been fishing?

2. How long (would you say) have you been dealing with *C. maenas*?

3. When/where do you see them? Where and when do you see them the most (concentrations; or large numbers of them)? Does this change seasonally, and if so, how?

4. Could you describe the location / show me a good fishing spot on a map / in person?

5. Have you ever noticed any interesting / behaviour with *C. maenas* in your area? Such as?

6. Is there anything else you would like to ask about / discuss concerning *C. maenas*?

Closing Remarks/Departure:

Thank you again for your time today, it was a great opportunity to hear about your experiences with *C. maenas* in the field. If you have any further questions or comments please don't hesitate to contact me. If it is all right, would you mind if I contact you in the future if I have a follow up question, or to confirm parts of your interview transcript?

If you are interested in updates I will email/mail these to you in the future. If so, how/where would you like to receive them?

Appendix G – Definitions of categories used in the coding process.

Category	Definition	Sub-Categories
Bottom Type	Includes any reference to fishing by observing or associating green crab with a certain sediment type. Excludes references to geological landforms or physical formations in the bottom, vegetation, presence of biota etc.	**Mud/soft:** Any reference to a bottom type as soft, mud, muddy or dark. **Cobble:** Reference to a bottom type composed of cobble, gravel, or small pebbles. **Sand/hard:** Any reference to a bottom that is sandy, a sand-flat, sand-based bottom, or hard bottom. **Other:** Any generic reference to setting by "what's on the bottom", "what the bottom looks like", etc. without insinuating a specific bottom type. Includes looking for "sediment".
Vegetation	Includes any bits mentioning fishing by vegetation or observing more crab associated/associating more crab with a type of vegetation.	**Seaweed:** Any case where seaweed is specifically mentioned. **Eelgrass/grass:** Any case where eelgrass is specifically mentioned. **Wrack/rot:** Any marine vegetation referred to as detached, dead or rotting. **Misc.:** Any descriptions not specifically referring/belonging to any of the abovementioned categories, or using their names so as to not explicitly refer to them as a preferred/avoided quality.
Depth	Includes any reference to the depth of water as being important when fishing (excluding reasons such as impact on trap access) or green crab movement / occurrence. Includes depth measurements or descriptive terms. References to distance from the shoreline or within the tidal column are similarly considered.	**Shallow:** Reference to fishing at/seeing more green crab at shallow/er, shoal, on dry ground or at depths of <10ft. Also includes mention of areas "close to shore", or in /above the intertidal zone. **Moderate:** Only quotes stating depths of 10-20ft. deep water. **Deep:** Reference to deep/er water, or depths of >20ft. Also includes bits discussing holes or channels where context does not indicate a reference to flow.

Category	Definition	Sub-Categories
Temperature	Any bit indicating temperature or season as being important to green crab activity (the latter being confirmed by most participants as a function of temperature).	N/A
Geography	Any reference to changes in the soil/bottom structure (excluding channels and holes) as relevant to green crab occurrence/abundance.	**Boulders:** Any mention of boulders or large rocks, rocky bottom, rock piles. **Ledges/ridges:** Any mention of cliffs or sharp drop-offs, banks, hard sandbars. **Open/Flat:** Any reference to an area specifically as open, exposed, or void of shelter.
Salinity	Any references to changes in salinity, fresh/sea/brackish water, or sources which may drive changes in local salinity.	**More saline**: References to fresh water, fresh water outflows, streams, or channels (when salinity is important as in context), or low salinity. **Less saline**: Referring to more saline regions. **Brackish:** Specific reference to brackish water**.** **Misc:** Pertaining to areas more difficult to classify, *i.e.* fluctuating salinity.
Water Movement	References to turbidity (*i.e.* mixing or wave action) or stream flows (when contextualized not as sources of freshwater).	**Calm:** References to areas with relatively calm, low flow, or low circulation hydrodynamics as relevant to green crab abundance/presence. **Flow:** References to areas having a current, circulation, swells or rougher waters as relevant to green crab abundance/presence.

Category	Definition	Sub-Categories
Biotic Interactions	Any reference to interactions with other fauna, either through direct competition (*i.e.* displacement, mortality or avoidance of individuals), or with individuals taking on predator/prey roles. Interspecific interactions (*i.e.* ontogenetic and sex-based segregation) are included in the "behaviours" category.	Sub-categories indicate species and assumed positive or negative interactions.

Appendix H – Coded results from 10 semi-structured interviews with harvesters concerning *C. maenas* on the South Shore, Nova Scotia. Codes identify individual bits taken from transcribed conversations. Features were categorized as positively or negatively influencing *C. maenas* distributions; those not exerting an effect (unimportant) were not used in weighting. Colored codes indicate quotes specifically indicating juvenile (green) or sex-specific (purple) habitat use by the given factors. Red codes were omitted as they were details specifically inquired after or quotes attributing non-significance of an environmental factor. Frequency of discussion (%) of each factor relative to all factors is indicated.

	Category	Sub-category	Positive Features	Unimportant/ Negative Features	# bits	%
1	Bottom Type	Mud/soft	**133A, 143B, 462A, 468A,**			
		Sand		**470B,** 564A,		
		Other	10A, 404A, 501A		9	15.00%
	Vegetation	Algae	16A, 224B, 559A,			
		Eelgrass	462B, 224A,			
		Kelp	27B,			
		Seaweed	592A,			
		Other	50A,		8	13.33%
	Depth	Shallow' or <10ft		**133B,**		
		Deep' or >20ft	5A, 7A, 72A, 198A, 223A, 502A, 544A, 604A, 616A, 302A,	422A,		
		Other		317A,	13	21.67%
	Geography	Boulders/Rocks	23A, 224A, 271A, 409A, 598A, 623A,			
		Ledges/Ridges	157A, 200A			
		Exposure		317B, 409A, **470A,** 617A	11	18.33%
	Water movement	Flow		118A, 257A, 572A, 189A, 196A		
		Calm	**142A,** 199A		7	11.67%
	Biotic interactions	Clams	11A, 103A, 208A,			
		Other	372A, 380A, 317C,	**143A,**		
		Rock Crab		240A, 330A,		
		Birds		544C, **134A,**	11	18.33%
	Temporal change	Seasonal		**152A, 229A**		
		Tidal	544A,		1	1.67%
	TOTAL				**59**	

#	**Category**	**Sub-category**	**Positive Features**	**Unimportant/ Negative Features**	**# bits**	**%**
3	Bottom Type	Mud/soft				
		Sand	52A,			
					1	4.76%
	Vegetation	Algae				
		Eelgrass Seaweed	82B, **98A, 103A,**			
		Misc.			3	14.29%
	Depth	Shallow' or <10ft	67B, **106A,**			
		Deep' or >20ft	**72A,** 125A, 144B,			
		Other	49A	**86A,**	7	33.33%
	Temperature		67A, 126A, 137A, 145A,		5	23.81%
	Biotic Interactions	Clams	58A,			
		Mussels	41A,			
		Misc.	67C, 154A,		4	19.05%
	Temporal change	Tidal	82A,		1	4.76%
	TOTAL				**18**	

#	Category	Sub-category	Positive Features	Unimportant/ Negative Features	# bits	%
4	Bottom Type	Sand	72A,		1	8.33%
	Vegetation	Eelgrass	41A, 55A, 70C,			
		Misc.			3	25.00%
	Depth	Shallow' or <10ft	41A, 70A,			
		Moderate' or 10-20ft	**46A,**			
		Deep' or >20ft		44A, 52A, 70A,	4	33.33%
	Geography	Boulders/Rocks	41C,	70B, 73B,	3	25.00%
	Biotic Interactions	Misc.	73A,		1	8.33%
	Temporal change	Seasonal	38A,			0.00%
	TOTAL				**12**	

#	Category	Sub-category	Positive Features	Unimportant/ Negative Features	# bits	%
5	Bottom Type	Mud/soft	226B,	126A,		
		Cobble		223A,		
		Sand	112A, 226B,		3	7.50%
	Vegetation	Eelgrass	**186A,**			
		Rockweed	**186A, 193A,**			
		Wrack/rot	57A, 59A, 118A, 213A		6	15.00%
	Depth	Shallow' or <10ft	62A, 102A, 113A,	114A,		
		Deep' or >20ft	117A, 52B, 206A, 97B, 230A	96B	10	25.00%
	Temperature		51B, 57B, 96A, 117B, 155A, 169A, 174A, 201C, 205A, 216A		10	25.00%
	Geography	Boulders/Rocks	**186A,**		1	2.5%
	Biotic Interactions	Clams	64B, 126B, 134A, 226A, 235A, 73A,			
		Lobsters	73A,			
		Misc.	97A, 151A, 216B,		10	25.00%
	Temporal change	Diel	112C,			
		Tidal	112B,		2	5.00%
	TOTAL				**40**	

#	Category	Sub-category	Positive Features	Unimportant/ Negative Features	# bits	%
7	Bottom Type	Mud/soft	79B, 87A, 108A, 121A, 148A, 174A,			
		Sand		116A	7	29.17%
	Depth	Shallow' or <10ft	79A, 99A,		2	8.33%
	Temperature		4A, 89A, 124A, 128A, 134A, 151A, 165A, 173A,		8	33.33%
	Water movement	Flow	177A, 184A,		2	8.33%
	Biotic Interactions	Clams	2A,			
		Mussels	3A,			
		Lobsters	116B,			
		Misc.	70A,	143A,	5	20.83%
	TOTAL				**24**	

#	Category	Sub-category	Positive Features	Unimportant/ Negative Features	# bits	%
8	Bottom Type	Sand		270A,	1	2.63%
	Vegetation	Eelgrass	115A,			
		Rockweed	92B, 115A, 234B, 311B, 316C,			
		Misc.	**59A,** 220A, 250A		8	21.05%
	Depth	Shallow' or <10ft	262A,			
		Deep' or >20ft	223A, 243A, 312A,			
		Other	**116A,**		5	13.16%
	Temperature		205A,		1	2.63%
	Geography	Boulders/Rocks	93A,			
		Ledges/Ridges	93A, 257A		2	5.26%
	Salinity	Less saline	91A, 234A, 283A, 311A, 316A,			
					5	13.16%
	Water movement	Flow	316B,			
		Calm	249A,		2	5.26%
	Biotic Interactions	Clams	132B, 312B,			
		Mussels	312B,			
		Eels	162A, 312B,			
		Rock Crab		331A,		
		Misc.	59A, 80A, 96A, 102A, 220B, 262B, 281A, 317A, 322A, 337A,		14	36.84%
	Temporal change	Tidal	132A, 76A,		2	5.26%
	TOTAL				**41**	

#	Category	Sub-category	Positive Features	Unimportant/ Negative Features	# bits	%
9	Bottom Type	Mud/soft	**220B,**			
		Sand		**220B,**	1	3.70%
	Vegetation	Kelp	186A,			
		Seaweed	186A, 228C		2	7.41%
	Depth	Shallow' or <10ft	**220A,**	153A, 159B, 228A,		
		Moderate' or 10-20ft	137A, 130A,			
		Deep' or >20ft	125A, 142A, 145A, 147A, 151A, 154A, 159A, 162A, 179A,			
		Other	213A,		15	55.56%
	Temperature		198A,		1	3.70%
	Geography	Boulders/Rocks	177A, 228B,			
		Misc.	214A,			
		Open/flat		188A, 228B,	4	14.81%
	Salinity	Misc.	111B,		1	3.70%
	Water movement	Flow		230B,	1	3.70%
	Biotic Interactions	Clams	230B,			
		Rock Crab		193A,	2	7.41%
	Temporal change	Diel	214A,			
		Tidal	111A,		2	7.41%
	TOTAL				**27**	

#	Category	Sub-category	Positive Features	Unimportant/ Negative Features	# bits	%
10	Bottom Type	Mud/soft	39A, 352A,			
		Other	183A,	13A,	4	13.33%
	Vegetation	Eelgrass		36A,180A,		
		Kelp	96A,			
		Wrack/rot	14A,			
		Misc.	**197A**		5	16.67%
	Depth	Shallow' or <10ft	361A,			
		Moderate' or 10-20ft	356A,			
		Deep' or >20ft	230A, 307A, 315A, 337A,	361A,		
		Other			6	20.00%
	Temperature		131A, 143A, **152A**, 230A, 336A, 341A,		5	16.67%
	Geography	Ledges/Ridges	204A,		1	3.33%
	Salinity	More saline	**53B,**			
		Less saline	**53B,** 355A,		2	6.67%
	Biotic Interactions	Clams	246A, 276A, 358A,			
		Lobsters	255A,			
		Rock Crab		1A,		
		Birds		16A,		
		Misc.	40A, 276A,		7	23.33%
	Temporal change	Tidal	9A,		1	3.33%
	TOTAL				**30**	

#	Category	Sub-category	Positive Features	Unimportant/ Negative Features	# bits	%
12	Bottom Type	Mud/soft	19A, 42A,			
		Cobble	15B, 142A,			
		Sand	**168A,**	204A, 199A, 324A,		
		Other	141A, 122A,		10	23.33%
	Vegetation	Kelp	129B,	153A,		
		Eelgrass	87A, **172A,**	122B, 132A, 140A, 354A, 324B,		
		Rockweed	39B,			
		Wrack/rot	102A, 132A, 142B, 248A, 264A, 281A, 129B, 153A, 324B,			
		Misc.	230A,		16	40.00%
	Depth	Shallow' or <10ft	15A, 109B, 39A,		3	7.50%
	Temperature		324A,		1	2.50%
	Geography	Boulders/Rocks	27A, 18A,	41A,		
		Ledges/Ridges	87B, 261A,		5	12.50%
	Salinity	Less Saline	142C,			
		Brackish	142C,		1	2.50%
	Water movement	Flow		280A,		
		Calm	28A,		2	5.00%
	Biotic Interactions	Misc.	129A, 324C,		2	5.00%
	Temporal change	Tidal	231A,		1	2.50%
	TOTAL				**40**	

#	Category	Sub-category	Positive Features	Unimportant/ Negative Features	# bits	%
13	Bottom Type	Mud/soft	35A, 45A,			
		Sand	40A,		3	37.50%
	Depth	Shallow' or <10ft	91A,			
		Moderate' or 10-20ft	81A,			
		Deep' or >20ft	89A,		3	37.50%
	Temperature		99A, 106A		2	25.00%
	TOTAL				**8**	