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Maritimes Region

Development of a Monitoring Framework for the Potential Establishment of a Commercial Whelk Fishery in the Maritimes Region (4VS, 4W)

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Canada

Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Whelk fishing has a long history throughout the range of the species. In the Fisheries and Oceans Canada (DFO) Maritimes Region, an offshore exploratory whelk fishery commenced within North Atlantic Fisheries Organization (NAFO) divisions 4W and 4Vs during 2012. To date, license holders have found several areas that have yielded high landings of whelk. In 4Vs, landings have been strong with continual growth as larger areas are explored and the Total Allowable Catch (TAC) increased. Landings have reached as high as 665 tonnes in 2018, with an average Catch Per Unit Effort (CPUE) from 2009 to 2019 of 14.9 kg/trap. In 4W, a single area yielding high landings of whelk has been identified recently with landings as high as 211 tonnes. The CPUE in this division is lower than that of 4Vs, with a mean CPUE from 2012 to 2019 of 3.5 kg/trap.

Fisheries Management has requested advice from DFO Science to assess current metrics gathered by the license holders, as well as establish priority areas for research and analysis that will enable development of a stock assessment framework for offshore whelk. Developing an assessment of stock status is currently hampered by limited information with regards to natural abundance of whelk within fished areas and the spatial extent and variation of whelk populations. Currently, there are no independent surveys that adequately sample whelk. Information on whelk is based solely on data collected by the exploratory license holders, who are currently collecting a host of useful biological data. Metrics such as age- and size-at-maturity could be refined through alteration of the methods used and through defining the timing of the reproductive cycles.

Most importantly, though, is the need to identify population structure. This species exhibits a low dispersal potential due to its direct development in benthic egg capsules and low adult movement. This results in local adaptation and potential genetic differences at small spatial scales. Whelk are vulnerable to local depletion due to these factors and their management should be applied to biologically relevant management units such as subpopulations. Management can be informed by many of the metrics currently collected by industry, and identifying population structure has been prioritized in the research plans of the license holders. Further work to identify the spatial extent of various subpopulations should be prioritized to establish these management units and to determine appropriate management strategies (such as Minimum Legal Size [MLS] informed by the life-history traits of the respective subpopulations).

INTRODUCTION

Buccinum undatum, the Waved Whelk, is a ubiquitous marine gastropod within the North Atlantic, distributed from the low water mark to depths of up to 600 m (Hansson 1998, Weetman et al. 2006, Włodarska-Kowalczuk 2007, Heude-Berthelin et al. 2011). Despite the wide range of this species, they exhibit limited dispersal potential as a result of internal fertilization, direct development of larvae within demersal egg capsules (i.e., lack of planktonic larvae), and limited adult movement (Pálsson et al. 2014, Lapointe and Sainte-Marie 1992, Hancock 1963, Himmelman and Hamel 1993). This lack of dispersal also contributes to the great deal of spatial variability observed in shell morphology, size at sexual maturity, and size frequency of whelk populations, as well as genetic differentiation over relatively small spatial scales (Weetman et al. 2006, Shelmerdine et al. 2007, Pálsson et al. 2014, McIntyre et al. 2015, Valentinsson et al. 1999). This makes whelk populations vulnerable to local depletion or even extirpation (Gendron 1991, de Jonge et al. 1993) and slow to recover from their removal.

Whelk fishing has been common throughout the range of the species and has recently increased in intensity, driven by the demand of Far Eastern markets. Offshore and inshore fisheries for whelk have been conducted for over a decade in the Fisheries and Oceans Canada (DFO) Newfoundland and Quebec Regions, respectively. In the Maritimes Region, attempts have been made to establish an inshore fishery; however, only a few areas were identified with economically viable quantities. In 2012, an offshore exploratory whelk fishery commenced within North Atlantic Fisheries Organization (NAFO) divisions 4W and 4Vs, finding several areas with high densities of whelk in the offshore 4Vs area and more recently in 4W. Developing an assessment of stock status, however, is hampered by limited information with regards to natural abundance of whelk within fished areas, spatial extent, and variation of whelk populations. Currently, there are no independent surveys that adequately sample whelk; thus, information on these stocks is based solely on data collected by the two exploratory license holders.

DFO Fisheries Management has requested advice from DFO Science to assess current metrics gathered by the license holders, as well as establish priority areas for research and analysis that will enable development of a stock assessment framework for offshore whelk. The information will be used by license holders to improve their research and fishing plans and, ultimately, to develop an assessment framework for the exploratory fishery that is consistent with DFO's Precautionary Approach. The results of this review are provided in this Research Document and include recommendations for industry research priorities and considerations for management of the resource.

WHELK BIOLOGY

The Waved Whelk (*Buccinum undatum)* is a boreal neogastropod mollusc, commonly found along the coasts of northern Europe, Iceland, and northeastern North America from New Jersey to Labrador, with occurrences as far north as Baffin Island and in Hudson Bay (OBIS 2019). Whelk inhabit a variety of marine environments but are predominantly found on soft-sediment habitats. They are distributed vertically between the low tide mark to depths of 600 m, but they are predominantly found in the greatest densities within the shallowest parts of their range (Hansson 1998, Weetman et al. 2006, Włodarska-Kowalczuk 2007, Heude-Berthelin et al. 2011). At these shallow depths, with greater influence of freshwater inputs, they are known to tolerate salinities down to 18‰ (Staaland 1972).

Waved Whelk is a relatively large gastropod, reaching sizes of up to 150 mm in Shell Length (SL) and ages of 11–13 years (Kideys 1996, Shelmerdine et al. 2007, Flight 1988). Individuals tend to be larger at greater depths, compared to populations in shallow water (Valentinsson et al. 1999). Their shells contain large whorls with light spiral sculpturing (running perpendicular to the axis of coiling) and larger waved axial sculpturing (running parallel with the axis of coiling) from which it gets its name (*undatum* means wavy). The shell exhibits high variability in colour, including light cream, dark brown, and red. The body of the whelk is typically white with mottled black dots.

The common prey of Waved Whelk, depending on size and habitat, are echinoderms, small crustaceans, polychaetes, and molluscs (Hancock 1967, Nielsen 1975, Taylor 1978, Jalbert and Himmelman 1989). In the case of bivalves, Waved Whelk gain access to their prey by either prying valves open using their muscular foot, inserting the lip of their own shell between the valves, or by breaking the lip of the valves with their own shell (Nielsen 1975). In addition to being an active predator, the Waved Whelk is also a known scavenger (Hancock 1967, Nielsen 1975), readily taking advantage of chance food encounters. This includes opportunistic scavenging on the prey of the Polar Sea Star (*Leptasterias polaris)* (Rochette et al. 2001). Whelk are known to accumulate phycotoxins, such as Paralytic Shellfish Poisoning (PSP), through ingestion of prey such as bivalves (Caddy and Chandler 1968). Their feeding behaviour exhibits a distinct annual cycle relating to the reproductive cycle. In the Gulf of St. Lawrence, Canada, for example, the percentage of individuals with food in their stomachs peaks in winter and falls to 5% in mid-May, with continued low levels until October, coinciding with the onset of reproduction during summer (Martel et al. 1986b).

Using their muscular foot, whelk are capable of moving a maximal of approximately 50 m a day with an average speed of 11.4 cm per minute (Himmelman 1988) and a maximum observed speed of 20 cm per minute (Gros and Santarelli 1986) when moving upstream towards baited traps. Diving surveys, however, have shown whelk to be predominantly sedentary with little adult movement (Pálsson et al. 2014, Lapointe and Sainte-Marie 1992). They spend a large portion of their time quiescent, often completely or partially buried (Hancock, 1963, Himmelman and Hamel 1993) with their proboscis extended out of the substrate and into the water column. They are known to become highly active in the presence of chemical cues from potential food sources (Crisp 1978, Crisp et al. 1978).

Sea stars are one of the more common predators of Waved Whelk, including both Common Starfish (*Asterias rubens)* and Polar Sea Stars in the Western Atlantic. Waved Whelk represent 5–15% of the diet of Polar Sea Stars inhabiting waters of 5–15 m depth and is the third most important prey (Himmelman and Dutil 1991, Gaymer et al. 2004). Other predators include crabs such as Toad Crab (*Hyas araneus)* and Atlantic Rock Crab (*Cancer irroratus),* as well as Spiny Dogfish (*Squalus acanthias*), Atlantic Cod (*Gadus morhua*), and American Lobster (*Homarus americanus*) (Thomas and Himmelman 1988). The Sea Urchin (*Strongylocentrotus droebachiensis)* is known to feed upon the egg cases laid by whelk, even during the laying process (Dumont et al. 2008). This predation is heaviest in exposed locations, leading to damage of > 50% of the surface of the egg capsules (Dumont et al. 2008).

Whelk are also known to be hosts for a number of parasites (Siddall et al. 1993, Tétreault et al. 2000), such as the castrating trematode, *Neophasis* sp., which, when in sufficient quantities within the gonads, can effectively castrate the host whelk, thereby reducing fecundity (Tétreault et al. 2000).

Breeding in Waved Whelk involves an internal fertilization where sperm can be held for up to eight weeks within the seminal receptacle (Martel et al. 1986a) allowing for protracted egg laying. Females will lay egg capsules, both individually and in groups, on vertical surfaces such as walls, boulders, and algal stipes (Dumont et al. 2008). They are known to lay 80–150 spherical, demersal egg capsules (Valentinsson 2002), each containing 475 to 2639 eggs (Smith and Thatje 2013). Of these, only approximately 1% are developing eggs (Smith and Thatje 2013) and the majority are nurse eggs for consumption by the larvae. The snails emerge from the egg capsules fully developed after breaking through the capsule walls using radular scraping (Smith and Thatje 2013). The total number of eggs and developing larvae are directly correlated with the size of egg capsules (Smith and Thatje 2013). Offspring quality does not differ for different-sized whelk; however, larger whelk produced greater numbers of eggs (Valentinsson 2002). The number of hatchlings per gram of body weight was constant with female size, indicating that relative fecundity did not change (Valentinsson 2002).

Fecundity may also be influenced by the occurrence of imposex (the growing of masculine sex organs superimposed onto the female's sex organs). The chemical Tributyltin (TBT), historically used as an antifouling agent in paints, is known to cause imposex and subsequent sterility in populations of Waved Whelk, with notable occurrences in the North Sea (Nicolson and Evans 1997).

The timing and duration of various reproductive cycles in these snails differs geographically. Throughout much of western European waters, populations of whelk will breed in late summer (July–September) with egg-laying occurring October to January, from northern France to the Shetland Islands (Kideys et al. 1993, Henderson and Simpson 2006, Heude-Berthelin et al. 2011, Haig et al. 2015). Embryogenesis in this area takes 3–5 months, with hatching occurring January through May, which corresponds with temperatures ranging from 4–12 °C in France and the Irish Sea (Kideys et al. 1993, Henderson and Simpson 2006, Heude-Berthelin et al. 2011). Whelk spawning in western Iceland follows a similar reproductive pattern to the rest of the western European populations (Magnúsdóttir 2010). Whelk in Swedish and Danish waters in eastern Europe, exhibit embryogenesis durations similar to populations in the west, but are known to spawn throughout the year (Valentinsson 2002).

In North America, breeding in the Gulf of St. Lawrence begins in mid-May with spawning occurring June–July after water temperatures rise to 7 °C (Martel et al. 1986a). Eggs hatch in late autumn and winter after 5–8 months of embryogenesis (Martel et al. 1986a,b), at which time temperatures may descend to zero or -1 °C (Drinkwater and Gilbert 2004, Galbraith 2006).

The mechanisms driving these differences in timing of reproductive cycles are not known; however, it has been suggested that the reproductive timing in this region may coincide with the brooding period of the Polar Sea Star. This species of sea star aggregates in autumn, spawns December–January, and its eggs develop over 200 days, during which time females will cease eating until June or July (Himmelman et al. 1982, Bauvin et al. 1986, Hamel and Mercier 1995, Gaymer and Himmelman 2013).

Whelk exhibit a great deal of spatial variability in their size at sexual maturity, often over very small spatial scales. As summarized in Borsetti et al. (2018), size-at-maturity throughout the UK (United Kingdom) and Ireland ranges from 41.8 to 85.1 mm for males and 52.8 to 83.2 mm for females. Differences among populations in the UK were found to vary by as much as 8.7 mm SL between two populations located only 13 km apart (Haig et al. 2015). In Swedish waters, size-at-sexual-maturity has been shown to range from 53.5 to 71.9 mm for males and 51.5 to 71.5 mm for females (Valentinsson et al. 1999). In Iceland, size at sexual maturity ranged from 47.5 to 75.5 mm for males (see Borsetti et al. 2018). In the United States (US), size at sexual maturity ranges from 56.8 to 57.8 mm for males and 59.4 to 72.8 mm for females (Borsetti et al. 2018). In the Gulf of St. Lawrence, Canada, size at sexual maturity ranges from 49 to 76.4 mm in males and 60.3 to 80.8 mm in females (Gendron 1992). Additionally, for English populations of whelk, the lowest absolute maturity values observed for any given site by McIntyre et al. (2015) were 37 mm and 36.6 mm, for males and females, respectively. The largest immature whelk observed in that study were 88.6 mm and 84.4 mm for males and females, respectively.

Size at sexual maturity was not correlated with any latitudinal trend (McIntyre et al. 2015) but was negatively correlated with temperature (Bell and Walker 1998, McIntyre et al. 2015) and positively correlated with depth (McIntyre et al. 2015, Haig et al. 2015). Differences have also been observed in the growth rates and age at sexual maturity, with whelk in Swedish waters reaching sexual maturity at age of 6 to 8 years at one site and 8 to 9 years for another (Valentinsson et al. 1999). It is likely that local conditions have a stronger influence on growth and maturity than broader-scale latitudinal conditions.

Differences between sexes with respect to size at sexual maturity are inconsistent throughout the organism’s range (see Borsetti et al. 2018). Across the UK (McIntyre et al. 2015) and Canada (Gendron 1992), sites were inconsistent in the differences in size at sexual maturity between males and females. For populations from the Brittany coast of France and the US Mid-Atlantic, males attained sexual maturity at a smaller size than females (Heude-Berthelin et al. 2011, Borsetti et al. 2018) whereas for populations in Sweden, females attained sexual maturity at a smaller size than males (Valentinsson et al. 1999).

Given the limited adult movement potential, the behavioural trait of remaining predominantly quiescent, and the lack of pelagic larval stages, it is not surprising that this species exhibits a high degree of spatial variability in traits such as size distribution, shell morphology, genetic structure, size at maturity, and growth over very small spatial scales (Weetman et al. 2006, Shelmerdine et al. 2007, Pálsson et al. 2014, McIntyre et al. 2015, Valentinsson et al. 1999). Experiments have shown there is very little mixing between adjacent areas, particularly when communities are enclosed or physically isolated (Hancock 1963, Weetman et al. 2006). The observed differences in morphological, physiological, and genetic traits over very small spatial scales suggest that this species may exist in multiple subpopulations over small spatial scales.

HISTORY OF COMMERCIAL WHELK FISHERIES

INTERNATIONAL FISHERIES

Whelk fishing is typically conducted using baited pots (Hancock 1963, Santarelli and Gros 1985, Himmelman 1988), often composed of either plastic tubs with a netted entrance and escape holes for undersized whelk, or with netted pots on metal frames. The whelk fishery has a long tradition in European waters. The UK whelk fishery started in the early 1900s (Dakin 1912) and has expanded considerably with increasing demand from the Far East. Landings increased throughout the 1900s (Fahy et al. 2000) attaining catches as high as 22,700 t in 2016 (MMO 2019). Most of the current catch is exported to markets in the Far East (Shelmerdine et al. 2007). Whelk are a non-quota species throughout the UK and much of the European Union and their management policies consist of a baseline Minimum Landing Size (MLS) set at 45 mm SL. Many local and national policies, however, also have different requirements on reporting and often set their own limits on catch, total pots, size and number of escape holes, number of licenses, and MLS (Skerritt and Durrance 2018). For example, although the national MLS is 45 mm SL for the UK, regional management measures have been put in place to increase the MLS to 55 mm for Wales, 70 mm for the Isle of Man, and 75 mm for the Shetland Islands. Since UK whelk populations show high variability for size at maturity throughout their range and at small spatial scales, there is little rationale for a uniform approach of a single common MLS. In fact, the size at maturity for many populations throughout the UK are known to be greater than the European Union MLS of 45 mm SL (Haig et al. 2015, Bell and Walker 1998). The percentage of mature whelk at the MLS of 45 mm was 5% for most sites around the English coast (McIntyre et al. 2015) and the percentage of whelk caught between the MLS of 45 mm and the measured size-of-maturity for many areas, ranged from 7 to 58% (Haig et al. 2015).

Understanding the effects of fishing efforts in European waters, and the setting of appropriate reference points, are hampered by a lack of information on whelk populations. Current policies are reliant mostly on industry-led data, predominantly Catch Per Unit Effort (CPUE). With these limited management policies for the whelk fisheries of the North Atlantic, there are concerns that whelk stocks are currently overfished (Nicholson and Evans 1997, McIntyre et al. 2015, Shrives et al. 2015) and indeed, several local populations of Waved Whelk have been depleted (Gendron 1991, de Jonge et al. 1993). Depletion experiments also indicated that after one year, there was no recovery of the depleted population. CPUE decreased during the experiment and remained at similarly low levels one year later (Valentinsson et al. 1999), suggesting that if populations do become depleted, they are likely to recover slowly. In other commercially-targeted gastropod fisheries, unmanaged effort and overfishing have decreased size-at-maturity (Torroglosa and Giménez 2010); however, there are currently no indications to support a decrease in size-of-maturity among targeted Waved Whelk populations for the UK as a result of fishing (McIntyre et al. 2015).

OTHER CANADIAN FISHERIES

Whelk fishing is also a growing industry in eastern Canada. In the Newfoundland Region, the establishment of an inshore fishery began in 1987, with great interest from fishermen and processors, but ultimately was hampered by marketability and limited availability of whelk (Flight 1988). This fishery waxed and waned depending on market value. In the early 2000s, an offshore fishery in NAFO subdivision 3Ps started with fishing from April to September. Data on size-at-maturity for males is known for this area and is below the set minimum size of 63 mm; however, female maturity is unknown (DFO 2013). As of 2013, there were still significant knowledge gaps in the reproductive potential of the populations and individual growth rates. Similar to the European fisheries, there are also no independent surveys for population abundance from which to set biomass-based reference points. Preliminary information on catches throughout Newfoundland (with a great deal of effort concentrated in the 3Ps subdivision) indicated strong catches through the late 2000s (with upwards of 6,000 t caught) but a gradual decrease after 2014 to a low of 234 t in 2019. Total Allowable Catch (TAC) was set at 5,000 t for 2015 onward but in 2019 no TAC limit was reported. CPUE data were not available in these preliminary summaries, so it is not possible to specifically attribute this reduction in landings to a depletion of the populations around 3Ps or to a decrease in effort; however, the removal of the TAC could indicate that a decreased population was a likely contributor.

The fishery in the Quebec Region has a much longer history than the Newfoundland Region, dating back to the 1940s. The inshore fishery for whelk is managed in 15 fishing areas, with regulations on the number of licenses, traps, and the minimum legal size (70 mm SL). Additionally, there are quotas set on landings for several of the fishing areas. Industry collects data on landings in tonnes of live weight, fishing effort in number of trap hauls, CPUE in kilograms per trap haul (standardized for soak time), average size (mm), and percentage of sub-legal-size whelk in landings (Brulotte 2012). Unlike many of the other fisheries, the Quebec Region conducts independent stock surveys within Fishing Areas 1 and 2, every two years, using a Digby scallop dredge (Brulotte 2012). From these data, differences in size-at-maturity and size-frequency for each fishing area have been calculated (DFO 2018). This includes both male and female size-at-maturity, using Bell and Walkers (1998) Gonadosomatic Index (GSI) to determine female maturity (Brulotte 2012). Determining female size-at-maturity is necessary, to ensure all whelk have the opportunity to reproduce at least once prior to being caught. They have also established growth curves for these areas using pooled data across the three areas (Brulotte 2015); however, these areas may have different growth rates.

Catches in the Quebec Region have increased significantly since the mid-1980s with total landings across all fishing areas ranging between 937 and 1,623 t (DFO 2018). The CPUE when compared to a baseline level in 2001 has fluctuated in all fishing areas, with relative stability in most areas and both increases and decreases in others. Of these areas, only one area had an appreciable decrease in CPUE. The average landing size of whelk since 2011 has been fairly stable across all fishing areas. The fishery appears sustainable at present; however, there are some concerns yet to be addressed. The selectivity of the gear currently results in the harvesting of immature individuals in some areas, with averages from 2005 to 2017 as high as 26%. In addition, the size-at-maturity for some areas is greater than the MLS and needs to be adjusted appropriately to ensure the chance for breeding in at least 50% of individuals. Another issue with this specific fishery is the unused licenses. These licenses often exceed the number of licenses being fished. It is unlikely that the stocks in many of the areas could support the entire potential effort should those licenses be used (DFO 2018).

More recent examinations of the potential for an offshore fishery in two areas in 2013 revealed insufficient quantities to support a fishery in those areas (Autef 2013). At this time there is no offshore fishery in the Quebec Region.

MARITIME REGION INSHORE WHELK FISHERIES

There have been several examinations into the potential of an inshore fishery for whelk within the Maritimes Region. In October 1995, a test fishery was conducted in the Tusket Shoals area of Lobster Bay (DFO 1996). A high degree of aggregation in the distribution of whelk catches and high variability in catch rates were observed, with 27% of traps having 0–1 whelk and 27% of traps having over 100 whelk. Examinations of morphometrics also indicated that the actual meat per size of snail was lower than other marketable fishing areas (DFO 1996). The resulting report on the test fishery suggested that the use of local management zones would provide a more biologically relevant unit for management given the low dispersal potential of the species. It was also suggested, given their patchy distribution, that the collection of whelk through Lobster bycatch may be more economical than a directed fishery (DFO 1996). Fishing in this area, however, did not continue.

In 1998, exploratory licenses were issued to inshore fishers in eastern Nova Scotia and in Cape Breton and assigned to fishing areas identified through observations from the Lobster fishery (Kenchington and Glass 1998); however, none of these areas progressed to further than exploratory fisheries. Research conducted on whelk populations along the Nova Scotia and New Brunswick coasts indicated strong local adaptation, consistent with the patterns of local variability exhibited in the Gulf of St. Lawrence and in Europe (Kenchington and Glass 1998). The study concluded that management of these resources would likely require the use of smaller local management zones, as necessitated by the biology of the species and evidenced by the high degree of local adaptation. The size at maturity for instance, varied among local populations as seen in previous studies across the geographic range of the whelk. The study was not able to determine if sufficient quantities to support directed fishing were present in any of these areas.

Further additional inshore scientific licenses were provided to fishers in 2006 to examine the potential for inshore fisheries of whelk and established protocols for data collection for the local morphology and biology of whelk in partnership with DFO and academia (DFO 2009). The results of research from this study showed similar patterns of spatial variability in morphology over relatively small spatial scales.

In 2008, fishers, researchers, and managers convened a meeting to discuss the available information that exists on whelk and whelk fisheries, the approaches that could be used for management of whelk in the Maritimes Region, and any potential future information needs (DFO 2009). Many of the presentations highlighted the potential for subpopulations existing over small spatial scales. This was evidenced by high variability in morphological and life-history traits and supported by known information on the dispersal potential of the species. The meeting identified three issues of priority:

1. *Distribute population component mortality as a percentage of component biomass*. It is important to determine the distribution and relative abundances of populations. The identification of population structure could be determined through basic biological sampling.
2. *Manage percentage of size/age/sex of capture*. Protocols need to be developed to monitor size-/age-at-maturity and growth rates, as well as catch composition to best inform management practices such as gear selectivity and MLS.
3. *Permit sufficient biomass to evade exploitation*. Given the differences in size-/age-at-maturity over small spatial scales and the potential senescence and parasite-induced sterility, there is need to monitor catch with regards to sex composition and reproductive state. Development of a population model is suggested to assess population growth and reproductive potential under various management regimes.

Over the years, fishers identified some areas with higher densities of whelk; however, most catches were minimal to zero and many license holders did not meet the implemented minimum participation requirements. Currently there are only two inshore whelk license holders, with all others notified in 2018 that their licenses would not be renewed. Further licenses are not currently being considered due to insufficient science data and resources to determine sustainability and resource abundance. The data available, however, indicate continued minimal landings.

OFFSHORE WHELK FISHERIES WITHIN NAFO DIVISIONS 4VS AND 4W

Fishing Year

The typical fishing season occurs between June and December, outside 50 nautical miles using conical traps consisting of a mesh over a metal frame with a weight. Each license is limited to 1,500 traps. The mouth of the trap must be no greater than 12.7 cm in diameter to minimize Lobster and crab bycatch. Each trap must also contain a biodegradable section to minimize ghost fishing in the event of a lost trap.

Species retained include Waved Whelk, Stimpson's Whelk (*Colus stimpsoni*), and Moon Snail (*Euspira heros*), although Stimpson's Whelk are not marketed. MLS for each area has been set based on current available data. Since it is difficult to measure all catch at sea, there is an allowance of only 5% of the landings to be undersized snails. The exception to these size restrictions is when whelk are collected for scientific purposes. Dockside monitoring is required to verify all catch prior to landing.

License holders must submit a fishing plan prior to each season, comply with SARA monitoring during the fishing season, and provide a report on the activities at the end of the fishing season.

4Vs

In 2009, an experimental fishery commenced for the offshore Banquereau area. After several successful commercial exploratory trips, the fishery evolved into an exploratory fishery in 2011. In 2012, after acquiring data on both catch and the biology of whelk in the area, the set 500 lbs (226 kg) TAC and 70 mm MLS were readjusted to levels that were more economical for the industry (350,000 kg = 350 t TAC). In 2013, 2014, and 2015, landings indicated a continual strong trend from this geographic area (as determined by data extracted from the Maritimes Fishery Information System [MARFIS] database, Table 1). Fishing occurred mainly within a delineated fishing area designated by industry as Area 1 (largest area fished as depicted in Figure 3). Further exploratory fishing outside of Area 1 were limited due to gear conflicts with Clearwater Seafood's Arctic Surfclam fleet. The following two years saw increased catches and in 2018, the TAC was increased from 350 to 700 t, with a 350 t cap on Area 1 (the first delineated management area within either division). With effective communication, gear conflicts between whelk and clam fishermen were avoided and exploratory fishing outside of Area 1 was successful in 2018 and onward. Fishing also commenced earlier in the summer of 2018 and traps were modified to include weights. With the increased TAC, the 2018 landings were the highest to date. Using a third vessel, the current catch for 2019, is similarly high.

4W

In 2011, an experimental fishery was conducted in the Middle Bank and Sable Bank areas where commercial exploratory trips identified reasonable quantities of whelk. In 2012, the quantities observed in the surveys were deemed sufficient to warrant expansion to an exploratory fishery with a TAC set at 350 t for each license holder. The 2012 landings, however, were low (Table 1) compared to other commercially viable areas. From 2013 to 2016, surveys yielded very few whelk with notably patchy distributions. In 2017, a joint venture between both license holders discovered a section of Middle Bank which contained much higher quantities of whelk, resulting in the highest total landings up to that date. In 2018, the MLS was adjusted based on information derived from research at Cape Breton University (CBU) and the TAC was reduced to 250 t per license holder. Landings in the 4W region further increased in 2018 and similar levels of catch have been observed in 2019 thus far.

FISHERIES DATA COLLECTION

Fishing activities are logged for each trip on the Whelk Monitoring Document provided by DFO. Aside from important identifying data relevant to the license holders and fishing vessels, these monitoring documents provide data on the temporal period of fishing (date set/hauled), the amount (traps set/lost/hauled) and spatial arrangement (position of traps) of fishing effort, the amount of catch (kept/discarded) for each species, and the discards of non-targeted species. CPUE can be calculated from these data.

Both offshore industry license holders have developed research plans to set goals and objectives for the fishery, guide research, and to establish a timeline to gauge the progress of the fishery. The license holders have partnered with academics to process samples and provide analyses of life-history traits and size-frequency that could inform management and ensure fishing continues at a sustainable level. A subset of whelk is collected from fishing trips and, in partnership with university researchers, several biological parameters are measured. Shell length, sex, sexual maturity, total weight, and shell characteristics, such as epibionts and fractures, are consistently measured by the industry members (Table 2). Other metrics such as tissue weight, shell weight, shell width, evidence of imposex, age, parasitism, and samples for DNA analysis are also collected by industry either inconsistently between the 4Vs and 4W divisions, or only when time allows. From these data, size-frequency distributions, size at sexual maturity, sex ratios, growth curves, age at sexual maturity, and population structure can be determined.

These metrics collected by industry cover the minimum required for monitoring and are also useful for DFO Science to more accurately determine the state of, and impacts to, the whelk populations within these areas. This information can be used to improve management of the resource by determining MLS values based on size at sexual maturity, the spatial extent of the resource based on catch, and population structure across fishing areas which can aid in the establishment of biologically relevant management units.

ALTERNATIVE DATA SOURCES FOR MONITORING

There are two other potential sources of data for monitoring whelk other than directed catch data from the fishery. The first is the DFO groundfish survey which catches some whelk. The utility of that data, however, is likely limited. The gear used in the survey is not designed to capture whelk, particularly those which would be quiescent and buried, thus sampling would underestimate abundance. The selectivity of the gear for particular sizes of whelk is also unknown, introducing more biases into the sampling. Finally, the stratified sampling is conducted randomly throughout the NAFO divisions and thus the spatial arrangement of sampling locations results in low coverage within fishing areas, if at all, and vary from year to year. Where these data may be useful is in determining broad-scale assessments of the spatial extent of whelk by identifying areas where large populations of whelk may exist (Figure 1).

The second potential source of data is the Banquereau Arctic Surfclam fishery, which also catches whelk as bycatch. The surfclam fishery, however, is not permitted to retain and land whelk. The proportion of the catch by weight that is whelk (sum of items identified as both Buccindae and Waved Whelk) is an average of 0.43% as observed by onboard sampling of the commercial surfclam fishery between 1999 and 2009 (DFO 2012). It should be noted, however, that these values do not specifically identify the whelk species, and that identification down to species occurs only for Silky Whelk (*Buccinum scalariforme*) (personal comm., Leslie Nasmith, DFO). Waved Whelk, therefore, likely only contributes a small proportion of the bycatch. Hydraulic clam dredges used in this fishery are capable of capturing whelk regardless of activity (i.e., it will capture buried whelk); however, the selectivity of the gear is uncertain. The utility of these data is restricted to particular areas of Banquereau and thus, would only be of value where fishing areas overlap between the two fisheries. Given the small proportion of whelk in the bycatch, of which the contribution of Waved Whelk is unknown, and the fact that there is only one observed trip for the Arctic Surfclam fishery per year, it is unlikely that these data will be of much value.

Other independent surveys are not currently conducted in this region; however, there are some additional methodologies that may be considered for independent surveys. Video and diving surveys (reviewed in Kideys 1993) both provide additional information such as habitat characteristics. Video tows have the added advantage over diver surveys in that they can be operated at depth for prolonged periods and the data can be processed at later dates. They are limited, however, by the resolution of the video, which can make it difficult to distinguish smaller whelk, particularly in more structurally complex habitats. Video also cannot distinguish live from dead whelk. Divers are able to more thoroughly examine the benthos compared to video analyses and this can be done without size bias. They also are more capable of distinguishing buried whelk. It should be cautioned, however, that the use of multiple divers can lead to discrepancies in the data which can be compounded by varying levels of diver experience. Despite these advantages to the accuracy of the information, the use of divers is unlikely to be fruitful given that the depth of fishing is typically > 20 m. These depths limit diver bottom time and may extend beyond recreational diving limits. Another independent survey method used in the Quebec Region is the use of a Digby scallop trawl. This method, much like the clam dredge, is more efficient at capturing quiescent whelk and thus the catch could provide a more accurate reflection of natural parameters such as size-frequency and abundance. At present there appears to be little scallop fishing activity on Banquereau; however, such an independent survey could be implemented.

LANDINGS, CPUE, AND EFFORT

Landings for the 4Vs region have shown continual growth as larger fishing areas have been identified with the increasing TAC since 2018 (Figure 2). The average annual landings is 224 t with a maximum landings to date of 665 t in 2018 (Table 1). Landings have been derived from three main fishing areas within the 4Vs region, with the greatest total landings coming from Area 1 (located in the middle of the three areas), followed by the newly explored easternmost area (Figures 3 and 7). The spatial distribution of landings from these two fishing areas exhibits some concentration which corresponds closely with fishing effort (Figures 4 and 8). Levels for CPUE in 4Vs have been relatively high at an average of 14.88 kg per trap (CPUE calculated as the sum of landings divided by the sum of effort). High mean CPUE values are exhibited across all three fishing areas (Figures 5 and 9). Only Area 1 has been fished sufficiently long enough to observe any temporal patterns in the spatial orientation of effort. For this area, prior to 2017, effort was greatest in the southwestern portion of the fishing area (Figure 6). In 2017, effort shifted and since then, effort has been greatest in the northeast portion of the fishing area.

The landings in the 4W region were initially very limited due to difficulties locating a fishing area with sufficient quantities of whelk. With continual searches, however, a fishing area was identified (Figure 10) and both effort and landings increased (Table 1). The average annual landings in this region is 49 t; however, in the later years, this region observed landings as high as 211 t in 2018. It is likely that if the resource remains stable, continued fishing will result in increased average annual landings (Table 1). These landings are derived primarily from a single fishing area (Figures 11 and 14) and like 4Vs, the spatial variability in landings corresponds with effort (Figures 12 and 15). CPUE, like landings, was very low initially but increased following the identification of the aforementioned fishing area. Currently, the average CPUE for this area is 3.56 kg per trap and the mean CPUE appears to vary greatly throughout this fishing area (Figures 13 and 16).

Comparing across both regions, 4Vs has exhibited higher landings (Figure 17) over the past decade, understandably, given the earlier discovery of an appropriate fishing area (Area 1). CPUE is also relatively greater in the 4Vs region (Figure 19), further contributing to the higher landings. Effort, however, has been far more concentrated in the 4W region (Figure 18).

CPUE for the 4Vs and 4W divisions were both comparable to those observed in the Quebec fishery. The average CPUE for 4Vs was higher than all fishing areas in the Quebec Region aside from one area with an average CPUE between 2003 and 2016 of 19.2 kg per trap. The average CPUE for 4W, however, was similar to the lower levels of CPUE observed among fishing areas in the Quebec Region (average CPUE from 2001 to 2016 of 3.6 kg per trap). Due to varying effort (amount and spatial extent) among regions and areas of access, comparisons of total landings are difficult to interpret. Levels observed in the 4Vs subdivision were comparable, however, to the higher levels observed while landings in the 4W Division were comparable to the lower levels observed.

Values for CPUE calculated in this document include only those instances in MARFIS with both effort and landings recorded. This excludes both instances where landings are recorded but are lacking values for effort (24.3% and 11.7% across all years in 4Vs and 4W, respectively) or where effort occurred but no landings were recorded (i.e., no catch). In the case of the latter, an inquiry was made to pull additional data on effort from the database; however, the data were not received in time for inclusion in this report. It should also be noted that samples of the Whelk Monitoring Documents were cross referenced with the effort database and indicated that effort with no landings was inconsistently entered into the database. Having an incomplete dataset reduces the ability to both properly estimate CPUE for any given area or year, and to determine the spatial extent of the resource. This should be easily remedied by determining the breakdown in the recording of this information and improving recording protocols to ensure effort is consistently included. CPUE was also calculated using only the number of traps. Valentinsson et al. (1999) found no evidence of saturation in catches of whelk after 18 days (although the death of whelk would render the catch unsaleable after 10 days) and thus, CPUE measures should account for soak days when calculating effort (i.e., kg whelk $trap^{-1}$ day^{-1}).

It is important to note that values of landings and CPUE are calculated for the entire regions (4Vs and 4W), which is not necessarily a relevant management unit given the biology of the species. For example, in the 4Vs region, where three areas of sufficient whelk density have been identified as potentially able to support fishing, a more appropriate analysis would consider catch within these areas separately. With further information on the biology of the whelk within each area, further subdivision into appropriate populations would be prudent for managing the resource.

BIOMASS, ABUNDANCE, AND SPATIAL EXTENT

Understanding the abundance and biomass of the targeted species can be used to set limits and monitor the status of the resource. In the case of the Waved Whelk, the difficulty of obtaining an accurate density measure has limited the estimation of both biomass and abundance for this species. The use of landings as a surrogate for abundance provides only relative densities. Absolute density requires knowledge of the area of attraction (area where some animals are attracted to the bait; Lapointe and Sainte-Marie 1992) and the effective area of the trap (theoretical area from which 100% of the whelk are caught; Miller 1975). Area of attraction, which influences the effective area of the trap, is dependent on current direction and speed (Lapointe and Sainte-Marie 1992) which can vary greatly in time and space. Mark-recapture experiments and diving surveys have provided some insight into how the area of attraction changes with varying hydrodynamic conditions. A study by Himmelman (1988) revealed significantly lower recapture rates at greater depths and under strong current conditions when compared to shallower sites. Under high flow conditions, bait is only perceived over small spatial scales, with most of the catches being the result of normal movement of whelk rather than directed movement towards bait. Thus, the area of attraction will expand and contract with changing current velocity. Another study showed that in the presence of bait, all whelk in 20^{o} downstream angle and 75.5% of whelk in the two flanking 20^{o} angles were found to move towards the bait. Whelk in the remaining 300^{o} angle exhibited similar activity to when no bait was available, moving with random orientations relative to current and bait (Lapointe and Sainte-Marie 1992). Area of attraction was found to be highly dependent on the current direction and thus, in situations of shifting current direction, area of attraction can increase. It is also important to note that the crawling speed of whelk will influence the effective area (Lapointe and Sainte-Marie 1992) which will also be dependent on soak time and persistent current direction. Unlike current speed, however, substrate was found to have little to no effect on movement of whelk towards food (Himmelman 1988). When assessing abundance and biomass based on landings, knowledge on the specific and situational effective area of any traps from which density is being estimated, will be necessary to provide an accurate estimate. Obtaining these data for each haul would be logistically impractical.

Another methodology for assessing local abundance is the use of a stock depletion model which industry has attempted to perform. In order for this to be successful, the stocks must show signs of depletion to calculate abundance which, unfortunately, they did not after multiple successive trips.

Industry has also proposed using a conservative estimate for the effective area of the trap by assuming that each trap represents 100% depletion. This will produce a purposely conservative underestimate of abundance. The issue with using a single effective area, whether conservative or not, is that the effective area changes depending on the situation. As an example, if there is a stable population and the actual effective area decreases compared to previous years due to strong current velocities in a persistent direction, then estimates of population would indicate a large decrease in the abundance when in fact the population was stable. As another example, if there is a decreasing population and the actual effective area increases compared to previous years due to variability in current direction at low velocities, then estimates of abundance would underestimate the change or fail to detect the change. Thus, the confidence bounds around any estimates using a single effective area could be considerably large.

Independent survey sampling using diver, video, or dredge have been shown to provide more accurate estimates of abundance and biomass for whelk. For determining these metrics, the development of an independent survey, perhaps using a Digby scallop dredge, would be more prudent.

Unlike biomass and abundance, there are fewer complications in determining the spatial extent of whelk. Both industry partners have identified in their research plans the determination of the spatial extent of populations within their respective NAFO divisions as research priorities. They plan to do this while maintaining fishing activities in previously explored areas. Understandably, the amount of exploration beyond known areas will depend on industry attaining sufficient catch in known areas to support the fishery. This exploration beyond current fishing divisions is not only to identify other potential areas of access but also to define the boundaries of the existing resource. This requires all data to be accurately recorded, including strings of traps where no catch was landed. While fishing effort in both divisions have provided data on the extent of whelk within areas of high density (i.e., areas with commercial quantities), further exploration is needed in many cases to define the boundaries of those areas of access.

BYCATCH, OBSERVER COVERAGE, AND SPECIES AT RISK

In 4Vs, bycatch has been reported as negligible and consisting mainly of hermit crab (Paguridae Family), toad crab (*Hyas* sp.), and sculpin. More infrequently, sea stars (Asteroidea), urchins (*Strongylocentrotus* sp.), sand dollars (Clypeasteroida Order), redfish, and even whelk egg masses have been found in traps (or attached to traps/lines in the case of eggs). None of the poisonous Ten-Ridged Whelk (*Neptunea decemcostata)*, or *Species At Risk Act* (SARA)-listed species were encountered. Stimpson's Whelk can be difficult to distinguish at sea and, therefore, are rarely reported separately. Recent investigations into the contribution of this species to the catch has been estimated to be less than 2%. This bycatch data was derived from observations by onboard researchers from CBU in 2016. Industry partners aim to improve bycatch reporting by vessel captains who have indicated that the Whelk Monitoring Document is not conducive to recording bycatch and is confusing. Industry would like to review the document to improve layout and information collected. At present, the document provides space to indicate the species, number, and estimated weights of discarded bycatch species from the entire trip. It could be beneficial to be able to record such bycatch by string to incorporate spatial variability. Bycatch data for 4W in 2017 was reported to be limited and largely consisted of hermit crab and toad crab.

Onboard-observer presence is based on request by DFO Resource Management and to date there are only 6 instances of at-sea observations in the 4Vs region during the years of 2011, 2014, and 2015. Bycatch consisted mainly of Snow Crab (*Chionoecetes opilio*), hermit crabs, Rock Crab, and toad crab. Total discarded from any one string was < 25 kg, and typically, these higher bycatch rates corresponded with low whelk landings. Other species caught include squid (*Pterygioteuthis* sp.), sand dollars, urchins, sea stars, and Sea Raven (*Hemitripterus americanus*) but all in very low quantities (< 5 kg discarded weight in any one string).

Prior to 2018, whelk license holders were only required to submit a single SARA log per season. In 2018, license holders were required to submit a SARA log for each trip, along with the Whelk Monitoring Document. Of the 58 trips logged in MARFIS that year, only 3 SARA logs were submitted, equating to a 5% compliance rate. In 2019, however, the compliance rate improved considerably, with 32 SARA logs submitted for the 60 trips submitted in MARFIS.

LIFE HISTORY TRAITS

SIZE AT SEXUAL MATURITY AND REPRODUCTIVE CYCLES

There are a number of different methods used to determine sexual maturity in whelk, including morphometrics, biometrics, visual assessments, and histological methods, the latter of which introduces the least error but is often a less viable option given the required expertise, expense, and time. Typically in fisheries biology, maturity is used to determine a size at which 50% of individuals are sexually mature (L_{50}). This metric is often used to set the MLS, which theoretically means that at least 50% of individuals caught at this minimum size have had the opportunity to mate (providing they are caught in seasons after egg laying has occurred). In males, a penis length of 50% of the shell length (PL_{50}) has been a reliable method to confirm or identify maturity for Waved Whelk and shows a good relationship with L_{50} (Martel et al. 1986b, Gendron 1992, Fahy et al. 2000, McIntyre et al. 2015). Another study observed that PL_{50} overestimated L_{50} when compared to the use of a GSI (Haig et al 2015), which may have inherent errors considering it was based on the weight of the entire eviscerated digestive whorl rather than the gonads alone. Another good indicator of maturity in males is the development of a vas deferens (McIntyre et al. 2015). Female maturity has been reported in studies less frequently, partly due to the increased difficulty in determining maturity compared to penis length in males. A common indicator is the clear differentiation of the gonad from the digestive gland within the digestive whorl (Martel et al. 1986b). As a visual indicator of maturity, the timing of sampling would enhance identification if samples are taken just prior to spawning season when there is the greatest differentiation between gut and gonad structures within the digestive whorl. The development of female egg capsule glands is also an indicator of maturity (McIntyre et al. 2015).

Thus far, biological information on size at maturity has been published for several discrete sites within the 4Vs and 4W divisions (Ashfaq et al. 2019) (sites and NAFO divisions displayed in Figure 20). This study used PL_{50} to determine maturity in males and a metric of gonad proportion (relative to digestive gland) to determine maturity in females and parasitized males. The authors also indicated that the methods for distinguishing maturity in females developed throughout the study and thus there are no data for female maturity for some of the earlier sampled sites. The authors found clear differences in L_{50} values among sites, with some differences occurring at very small spatial scales (e.g., 10.6 mm over 15 km; Table 3). Size at maturity for the eastern Banquereau, where commercial quantities have been identified, exhibited differences between a northern and southern site in the magnitude of 5.4 and 3.5 mm for males and females, respectively. In Area 1 of Banquereau, differences in size at maturity between a northern and southern site of 10.6 mm were observed for males. Whelk in the 4W division exhibited sizes at maturity of 64.3 and 65 mm for males and females, which was 8.7 and 7.9 mm greater than the highest L_{50} values among any of the 4Vs sites. From this information, the industry requested that MLS remain at 58 mm for Area 1 and remain at 65 mm for the rest of 4Vs until sufficient data is collected. Industry also indicated that the MLS of 65 mm for 4W remains appropriate given the current knowledge of biology for the one site in Middle Bank. There is still the need to refine methods for determining maturity and expand the data to include both sexes for each site, as differences in size at maturity do exist between sexes and could influence the setting of MLS for a particular population.

Ashfaq et al. (2019) also suggested that the large differences in size at maturity (and other metrics) over small spatial scales likely indicates local adaptation and possible genetic differentiation as observed in other studies throughout the geographic range of the species. This study suggests that the scale of these differences could indicate potential populations, which could guide the structure of management areas. It also highlights, as observed in other studies, that in the light of highly variable life-history traits at small spatial scales, a universal MLS will not protect all subpopulations. Such subpopulations should be managed separately with specific MLS values set by the L_{50} of that respective subpopulation. This strategy requires greater examinations into the spatial extent of subpopulations of whelk throughout the 4Vs and 4W divisions, which Ashfaq et al. (2019) suggests as a priority for future research.

Understanding temporal patterns in the reproductive cycle of whelk for both 4Vs and 4W could also aid in improving identification of sexual maturity. Given that most indices, including the index used by Ashfaq et al. (2019), rely on differentiating reproductive anatomy, ensuring sampling occurs prior to egg laying when differentiation is most pronounced, would improve the accuracy. This is particularly important for assessing reproductive status in females. There is substantial information on the timing of reproduction in the Gulf of St. Lawrence; however, no studies currently exist that can confirm whether whelk follow the same reproductive pattern in the Maritimes Region. This may also aid fishers in targeting periods when whelk are more actively feeding. In areas where reproductive cycles are seasonal, decreased feeding is observed during months when whelk are spawning. This has been identified as a potential cause of reduced capturing efficiency in the St. Lawrence Estuary (Villemure and Lamoureux 1975), England (Hancock 1963, 1967) and Brittany (Santarelli-Chaurand 1985) during spawning months. In the Gulf of St. Lawrence, for instance, increased catch rates/activity in whelk towards the end of summer/beginning of autumn coincided with both an increase in temperature and with the end of egg laying (Himmelman 1988). Given that whelk egg capsules are found attached to traps in the Maritimes Region, it can be presumed that fishing is occurring during, and potentially prior to, periods of egg laying. Excluding fishing during periods of the year when egg laying is occurring has been suggested as a means to ensure that whelk caught have had a chance to reproduce in that year, thereby increasing reproductive output.

AGE AND GROWTH

Determining age in Waved Whelk has historically been achieved by counting striae on the dorsal surface of the operculum (Santarelli and Gros 1985, Lawler 2013). Some studies, however, have indicated that the counting of opercula rings as an aging tool is currently unreliable (Kideys 1996). This is due to the low readability of rings which can reduce sample sizes considerably and potentially result in sampling bias. Counting of striae on the ventral surface has also proved unreliable due to the adventitious layers that constitute the rings accumulating as a function of growth to strengthen the opercula rather than as a function of age (Hollyman 2017b). Hollyman et al. (2018) reviewed a number of different methods for assessing age in gastropods, each of which vary in utility for different species. Internal and external growth rings on shells may provide reliable estimates of age; however, there are no external rings or lines on Waved Whelk (Santarelli and Gros 1985). Size-frequency can sometimes be used to assess age structure but it requires knowledge of growth rates. Mark-recapture experiments can be used to estimate growth of individuals that can in turn be used to infer growth and age for a population; however, this methodology would be difficult to implement in an offshore setting. The statolith, which is contained in the statocyst within the nervous system of the whelk, contains visible rings (either translucent or polished to the centre of the statolith) that correspond to the age of Common Whelk (*B. undatum*). This has been verified using a host of other aging methods (Hollyman 2017a, b). Chemical analysis can also be used to identify cycles of oxygen isotope ratios or trace element concentrations within the shell carbonate that correspond to annual cycles of water temperature, which influences the uptake of those chemicals. Samples of carbonate are taken along the growth axis of the shell to create a profile of the targeted chemicals which can be related to the seasonal changes in water temperature. This method, though highly accurate and reliable, is significantly more expensive, and likely better used as a means of validating other aging processes.

The research conducted at CBU in partnership with industry counted straie on the opercula to determine age-at-maturity (Ashfaq et al. 2019). Whether these represent the age based on the dorsal or ventral (adventitious layers) surface of the opercula is not reported. Age-at-maturity was not reported for all sites and sexes; however, the results did reveal spatial differences. For Banquereau sites within Area 1, age-at-maturity for whelk was determined to be 5.1 and 6.2 years for males at the northern and southern site, respectively (sites and NAFO divisions displayed in Figure 20). In eastern Banquereau, age-at-maturity for the southern site was 5.4 and 5.7 years for males and females, respectively. In 4W, age-at-maturity for females was found to be 6.4 years. These differences in age-at-maturity over small spatial scales, although incomplete in their spatial coverage and inclusion of both sexes, further suggest the potential for local adaptations within 4Vs and 4W. Differing age-at-maturity also indicates that these potential subpopulations may have differing capacities for recovery. As with length-at-maturity data, there is need for greater understanding of spatial differences throughout the fished areas as well as better coverage of both sexes.

The whelk industry partners have indicated that growth rates are currently being investigated but have not been published to date.

SIZE STRUCTURE

Size-frequency distributions can be obtained from fisheries data, typically using traps where the size selectivity has been removed through the inclusion of a fine mesh that inhibits the escape of smaller snails. Whelk fishers in the Maritimes Region have supplied researchers from CBU (Ashfaq et al. 2019) with whelk caught in standard traps of mesh size 25 mm across 5 sites in the 4W and 4Vs divisions (sites and NAFO divisions displayed in Figure 20). Whelk from each site were supplied in a single bag containing 100–300 individuals with no further sub-setting or sorting from the catch. It is important to note that the selectivity of the gear did not promote the capture of smaller individuals, and thus, the samples will be biased towards individuals with a shell width greater than 25 mm. The size-frequency distributions, therefore, are representative of the catch but not necessarily the population. The size-frequency distributions of whelk differed among the 5 sites. Statistical pairwise comparisons of the mean size of whelk showed significant differences between all sites within Banquereau, other than between the two easternmost sites. There were also significant size differences between Middle Bank and all sites in Banquereau, other than the southern site in Area 1. Mean shell lengths in eastern Banquereau (61.1 and 60.5 mm) were near or slightly below the MLS of 65 mm for eastern Banquereau but above the estimated size of maturity. The mean SL in Area 1 of Banquereau was below the MLS of 58 mm in the south (53.8 mm) but was above the MLS in the north (64.6 mm). Both populations exhibit mean sizes above the size at maturity, indicating the catch consists of a low proportion of immature individuals. For 4W, the mean size (55.6 mm) is below both the MLS of 65 mm and the size at maturity, which would indicate that the catch consists of a high proportion of immature individuals.

Improving estimates of size structure could be accomplished through increasing selectivity of gear for smaller individuals or through other independent survey methods such as the use of dredging gear. Similar to size- and age-at-maturity, differentiation between sexes should be considered when estimating size structure, particularly for females. Given that fecundity is relative to body size, a reduction in the proportion of larger mature females will lead to a lower reproductive output for the respective subpopulation.

NATURAL MORTALITY

To date, there have been no estimates or priority placed on assessing natural mortality but this would be a reasonable research priority if abundance or biomass-based models were to be developed.

PARASITE LOAD

Severe parasite loading can have influences on the fecundity of whelk potentially causing castration. The study by Ashfaq et al. (2019) identified the proportion of whelk parasitized across the 5 study sites and indicated considerable spatial variation. For instance, on Banquereau, there were higher proportions of parasitized whelk observed in southern than northern sites in both Area 1 (averages of 15.9% and 3.3% for southern and northern sites, respectively) and the eastern study area (averages of 25.5% and 11.7% for southern and northern sites, respectively). The authors concluded that this variability could further indicate potential isolation of populations. The degree of parasitism for individual whelk was not assessed.

POPULATION STRUCTURE

Assessing population structure in exploited whelk populations has received increasing attention given the likelihood of populations being effectively isolated due to low dispersal potential. For the Maritimes Region, there are several studies that indicate variability in morphometric and life-history traits over small spatial scales, including the research conducted in the Banquereau and

Middle Bank fishing areas (Ashfaq et al. 2019). These results strongly suggest there is local adaption and potential genetic differences. Population structure is likely more complex with isolation of subpopulations even within fishing areas, such as Area 1 on Banquereau which exhibited differences in size- and age-at-maturity, parasite load, and mean size of catch. There is need, however, for continued research in this area to expand our knowledge of the spatial arrangement of potential subpopulations. More specifically, these subpopulations need to be identified and their boundaries within fishing areas be clearly defined. This would produce more biologically relevant management areas to better ensure the sustainability of the resource.

In addition to using basic biology to assess potential differences in population structure, researchers at CBU are investigating patterns of genetic differentiation within these fishing grounds. An analysis of the 16S and CO1 haplotypes indicated little structure among sites; however, these particular genes may not be optimal for determining differences. A partnership venture, between the Bras d'Or Institute for Ecosystem Research and a researcher at New York University, is currently aimed at sequencing the full genome. With this information, more fine-scale differences may be detected to better inform population structure.

RISKS TO WHELK POPULATIONS WHEN DEVELOPING MANAGEMENT STRATEGIES

As identified in the previous meeting in 2008, and the conclusions of a considerable amount of scientific literature, understanding the population structure of whelk is of paramount importance to properly manage whelk resources. The low dispersal potential due to adult behaviour and lack of dispersive larval stages, coupled with their relatively low fecundity, have made this species vulnerable to over-exploitation and likely slow to recover. A lack of understanding with regards to spatially variable life-history traits such as size at maturity, has already resulted in the setting of standardized MLS values for different parts of the world which are inappropriate for some subpopulations that attain sexual maturity at considerably larger sizes. The implementation of management practices should be conducted at a biologically relevant scale (i.e., at the subpopulation level).

Whelk fishing using traps has been shown to have low impact on released whelk, with only minor damage (0–27%) and a survival rate of caught whelk greater than 95% (held in aquaria for 6 weeks; Mensink et al. 2000). Other fishing activities not necessarily targeting whelk, however, may also represent a source of mortality that could impact whelk populations. Beam trawl fishing for instance, resulted in greater damage (severe damage in 10–83%, minor damage in 17–75%) to caught whelk when compared to trap fishing, and lower survival (40%) regardless of damage (Mensink et al. 2000). Ramsay and Kaiser (1998) also showed that demersal fishing activities that might cause the "rolling" of whelk can also increase the predation risk of released whelk due to changes in their behaviour. Areas where fishing for whelk overlaps with demersal activities of other fishing gear may experience greater mortalities and this should be considered in management of the resource.

Another potential impact of the removal of whelk is the shift in dominance among whelk species. Stimpson's Whelk is considered to be more dominant in parts of Banquereau and the depletion of Waved Whelk may result in a shift to a Stimpson's Whelk dominated system (Kenchington and Glass 1998). Although differentiation has been minimal between these two species in the past, with established protocols for identification, going forward there will be a need to determine the relative proportion of each species within the catch.

RESEARCH RECOMMENDATIONS AND CONCLUSIONS

In both 4Vs and 4W subdivisions, industry has identified areas considered to have economically feasible quantities of whelk. Industry regularly collects several metrics associated with fishing activities, specifically landings, effort, spatial positioning, and bycatch and discards. The Whelk Monitoring Document provides adequate space to record the aforementioned information on each string other than bycatch. Although the limited observer data indicates potentially low levels of bycatch with no species of particular concern, it would be informative to have spatial information on bycatch, so that the occurrence of changes in species composition could be detected.

The Whelk Monitoring Document itself is adequate for the recording of metrics that will undoubtedly be used when developing a monitoring framework, particularly the spatial extent of the resource, total landings, and CPUE. Examinations of the MARFIS database for whelk catches revealed missing effort data due to a potential combination of insufficient reporting on the Whelk Monitoring Documents and insufficient recording of that data into the database. CPUE could not be calculated for instances with no recorded effort and thus the use of CPUE as an indicator of the fishery will not be accurate at present. The degree of accuracy is presently unknown. The use of soak time should also be incorporated into those calculations and should be obtainable from appropriately reported documents. In addition, the inconsistent reporting/recording of instances when there were no landings, reduces the ability to identify the spatial extent of whelk which will aid in developing relevant management areas. It is as important to know where whelk are as it is to know where they are not. Moving forward, there is a need to ensure consistent reporting/recording of data, and that the data is recorded at the lowest reasonable resolution (e.g., ensure each string is recorded, rather than a set of strings).

Development of these and other indicators for monitoring are further complicated by the lack of accurate differentiation between whelk species within the catch. Stimpson’s Whelk appear to constitute a low proportion of the catch; however, this should be monitored regularly and the spatial variability determined.

Abundance and biomass estimates continue to be logistically difficult to determine but would aid in the development of future assessment models. At present, complications with determining the effective area of the trap limit the use of catches as a reliable indicator of these metrics. It will likely require a different methodology to refine these estimates and improve confidence. The development of an independent survey, such as that conducted in certain areas of the Quebec Region, would likely be necessary to provide a more accurate way to estimate abundance. This may involve potentially using video analysis or a stratified dredge survey within areas of access.

Unbiased sampling by ensuring there is no selectivity for any size class of whelk is needed to determining the size-structure. This is particularly important when populations exhibit small sizes at maturity that approach the selectivity of the gear. Unbiased sampling could be accomplished by lining traps with fine mesh to prevent the escape of small individuals. Alternatively, if an independent survey were to be developed, such as the use of a dredge, the gear selectivity should similarly be modified to collect representative samples of the population.

For the analyses of age-at-maturity and size-at-maturity, the researchers working with industry have used viable methods described in the primary literature. Penis length, for instance, has a long-standing reliability for indicating maturity and, based on the current literature, should continue to be used. Female maturity, however, is far more complicated to determine. Histological analysis is by far the most reliable, but it is far more expensive and time-consuming. Like most gonadosomatic indices, the one used by Ashfaq et al. (2019) requires differentiation between reproductive organs and digestive glands. This method is sound but requires targeting of sampling to periods when differentiation is greatest (i.e., prior to spawning) to reduce potential error in identifying reproductive organs. It would also be beneficial to validate these methods using histological methods on a subset of samples. Using straie on the opercula as a means of ageing whelk has been done historically, although it is less reliable than observations of statolith, or chemical analyses. These latter methods could provide a means of validating the method and should be considered for future monitoring. If straie are to be used as a means of ageing, then researchers should ensure that the dorsal surface of the opercula is used for counting rather than the ventral surface. It is also beneficial to ensure consistency in these measures between industry users, as variability can occur among different methods for ageing and determining maturity.

The research plans proposed by industry have identified a number of important priorities towards the development of a monitoring framework. Of those, the following are two priorities that, given our understanding of the biology of the species, are likely of highest priority for accurately monitoring and managing the whelk fishery.

Determining the temporal patterns of the reproductive cycle for whelk in this geographic region will have several benefits including improving the quality of data collection and management of the fishery. Firstly, identifying when whelk are spawning will provide a more appropriate temporal window when sampling for size- and age-at-maturity. Knowing the spawning time will allow the fishery to maximize the differentiation of reproductive organs and improve the accuracy of the gonadosomatic indices. Secondly, it will identify the periods when catches are likely to be minimized due to decreased feeding activities during reproduction. This could be used to set a start date for the season which could decrease the amount of effort required to meet TACs (which could currently be impacting CPUE). This will also ensure that all females within the population have the opportunity to breed that season, thereby increasing the potential reproductive output of the species.

The most critical priority, however, will be establishing biologically appropriate management units. This species exhibits indications of population structure over small spatial scales both throughout its range and within the Canadian populations of the 4Vs and 4W divisions. They also exhibit a limited capacity for connectivity between populations; hence, the identification of potential subpopulations—informed by spatially variable life-history characteristics and/or genetics—should be of high priority. Routine fishing coupled with exploratory fishing outward from fishing areas can identify the specific boundaries of abundant whelk populations; however, population structure within those fishing areas needs to be described and the extent of subpopulations mapped. Ideally, whelk subpopulations would be managed rather than divisions or areas of access based on the extent of all whelk. Areas of access could potentially be delineated based on the extent of each subpopulation. This would represent a unit of whelk that does not receive significant or potentially any recruitment from adjacent subpopulations, even when there are no obvious boundaries between subpopulations. Knowledge of this could be gained through genetic analysis as prioritized by industry, but should also be accompanied by stratified sampling within areas of high whelk abundance for metrics such as sex-ratio, size- and age-at-maturity, and size-frequency.

It will also be necessary to conduct regular assessment of life-history characteristics (sex-ratio, and age- and size-at-maturity), size-structure (frequency distribution), and the extent of subpopulations throughout any established management units to monitor changes in subpopulations that could impact their sustainability. For instance, a reduction in size-frequency of females would indicate a reduction in overall reproductive output. Size-at-maturity, particularly for females, should be used to set MLS for each respective area and be monitored for changes to prevent unnecessary levels of immature females being removed (i.e., removing whelk before they are able to contribute to reproductive output of the species). Monitoring age- and size-at-maturity will continue to validate the separate management of subpopulations. These metrics in turn could eventually be used for population modelling as part of a monitoring framework. Additional information that would also be of high value for assessing the reproductive output of the population include evidence of imposex and levels of parasitism. Management and industry should consider establishing a standardized protocol for assessing these metrics and a sampling design that would allow for the description of subpopulations within areas of high whelk density.

Whelk are vulnerable to overexploitation and local depletion leading to the loss of subpopulations. Recovery of those subpopulations is likely to be very slow and could even be inhibited by the expansion of other species such as Stimpson's Whelk. To properly ensure sustainability in the fishery, these populations cannot be treated as a single stock for 4Vs or for 4W. It would be more prudent to manage the use of areas of access associated with those subpopulations, with individual MLS and trends in independently monitored metrics of CPUE and landings. The extent of fishing effort within each of these areas of access should also be dispersed across the entire area rather than concentrated, to ensure there is no local depletion. Concentrated fishing effort could also result in reducing the ability to detect decreases in CPUE, a potential monitoring indicator, particularly in situations where the positioning of effort changes yearly.

REFERENCES CITED

Ashfaq, U., Mugridge, A. and Hatcher, B.G. 2019. Size at sexual maturity of waved whelk (*Buccinum undatum*) on the Eastern Scotian Shelf. Fish. Res. 212: 12–20.

Autef, S. 2013 Feasibility study for a deep-water whelk fishery on the North Shore. Merinov. R&D Report nº 13–02. 8 pp.

Bauvin, Y., Larrivée, D.H. and Himmelman, J.H. 1986. Reproductive cycle of the subarctic brooding asteroid *Leptasterias polaris*. Mar. Biol. 92: 329–337.

Bell, M.C. and Walker, P. 1998. Size at Maturity in Common Whelks *Buccinum undatum* L. in England and Wales. ECES Document CM 1998/CC: 9.

Borsetti, S., Munroe, D., Rudders, D.B., Dobson, C. and Bochenek, E.A. 2018. Spatial variation in life history characteristics of waved whelk (*Buccinum undatum* L.) on the U.S. Mid-Atlantic continental shelf. Fish Res. 198: 129–37.

Brulotte, S. 2012. Assessment of whelks stocks of Québec's coastal waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/058. xi + 106 pp.

Brulotte, S. 2015. Whelk Stock Assessment in Québec's Inshore Waters – Methodology and Results. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/045. xii + 80 pp.

Caddy, J.F. and Chandler, R.A. 1968. Accumulation of paralytic shellfish poison by the rough whelk (*Buccinum undatum* L.). Proc. Natl. Shellfish Assoc. 58: 46–50.

Crisp, M. 1978. Effects of feeding on the behavior of *Nassarius* species (Gastropoda: Prosobranchia). J. Mar. Biol. Assoc. U.K. 58: 659–669.

Crisp, M., Davenport, J. and Shumway, S.E. 1978. Effects of feeding and chemical stimulation on the oxygen uptake of *Nassarius reticulatus* (Gastropoda: Prosobranchia). J. Mar. Biol. Assoc. U.K. 58: 357–399.

Dakin, W.J. 1912. L.M.B.C. Memoirs on Typical British Marine Plants and Animals: *Buccinum* (the Whelk). Liverpool Marine Biology Committee, London. 107 pp.

de Jonge, V.N., Essink, K. and Boddeke, R. 1993. The Dutch Wadden Sea: a changed ecosystem. Hydrobiologia. 265: 45–71.

DFO. 1996. Waved whelks in Tusket Shoal. DFO Atlantic Fisheries Stock Status Report 96/79E.

DFO. 2009. Proceedings of a Workshop on Canadian Science and Management Strategies for Whelk; 3–4 June 2008. DFO Can. Sci. Advis. Sec. Proc. Ser. 2009/024.

DFO. 2012. Assessment of the Arctic Surfclam (*Mactromeris polynyma*) Stock on Banquereau in 2010. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/068.

DFO. 2013. Subdivision 3Ps offshore whelk: a preliminary assessment of male size at maturity. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2013/066.

DFO. 2018. Assessment of the whelk fishery in Québec's inshore waters. DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2018/028.

Drinkwater, K.F. and Gilbert, D. 2004. Hydrographic variability in the waters of the Gulf of St. Lawrence, the Scotian Shelf and the Eastern Gulf of Maine (NAFO Subarea 4) during 1991– 2000. J. Northwest Atl. Fish. Sci. 34: 83–99.

Dumont, C.P., Jean-Sebastien, R. and Himmelman, J.H. 2008. Predation by the sea urchin *Strongylocentrotus droebachiensis* on capsular egg masses of the whelk *Buccinum undatum*. J. Mar. Biol. Assoc. U.K. 88(5): 1025–1031.

Fahy, E., Masterson, E., Swards, D. and Forrest, N. 2000. A Second Assessment of the Whelk Fishery *Buccinum undatum* in the Southwest Irish Sea with Particular Reference to its History of Management by Size Limit. Marine Institute, Dublin. 52 pp.

Flight, J. 1988. The 1987 Whelk Fishery in the Newfoundland Region. Can. Tech. Rep. Fish. Aquat. Sci. 1630: 43 pp.

Galbraith, P.S. 2006. Winter water masses in the Gulf of St. Lawrence. J. Geophys. Res. 111: C06022: 1–23.

Gaymer, C.F., Dutil, C. and Himmelman, J.H. 2004. Prey selection and predatory impact of four major sea stars on a soft bottom subtidal community. J. Exp. Mar. Biol. Ecol. 313: 353–374.

Gaymer, C.F. and Himmelman, J.H. 2013. Chapter 18: *Leptasterias polaris*. In: Asteroidea: Biology and Ecology of Starfish (J.M. Lawrence, ed.), pp.181–190. Johns Hopkins University Press, Baltimore, MD.

Gendron, L. 1991. Gestion de l'exploitation du buccin *Buccinum undatum* au Quebec : determination d'une taille minimal de capture. Rapp. Tech. Can. Sci. halieut. Aquat. 1833: 47 pp.

Gendron, L. 1992. Determination of size at sexual maturity of the waved whelk *Buccinum undatum* Linnaeus, 1758, in the Gulf of St Lawrence, as a basis for the establishment of a minimum catchable size. J. Shellfish Res. 11: 1–7.

Gros, P. and Santarelli, L. 1986. Méthode d'estimation de la surface de pêche d'un casier à l'aide d'une filière expérimentale. Oceanologia Acta. 9: 81–87.

Haig, J.A., Pantin, J.R., Salomonsen, H., Murray, L.G. and Kaiser, M.J. 2015. Temporal and spatial variation in size at maturity of the common whelk (*Buccinum undatum*). ICES J. Mar. Sci. 72(9): 2707–2719.

Hamel, J.-F. and Mercier, A. 1995. Prespawning behavior, spawning and development of the brooding sea star *Leptasterias polaris*. Biol. Bull. 188: 32–45.

Hancock, D.A. 1963. Marking experiments with the commercial whelk (*Buccinum undatum*). Spec. Publs. Int. Commn. NW. Atlant. Fish. 4: 176–187.

Hancock, D.A. 1967. Whelks. Ministry of Agriculture, Fisheries and Food, Laboratory Leaflet No. 15, Fisheries Laboratory, Brunhan of Crouch, Essex.

Hansson, H.G. 1998. NEAT (North East Atlantic Taxa) database. Tjärnö Marine Biological Laboratory.

Henderson, S. and Simpson, C. 2006. Size at sexual maturity of the Shetland Buckie *Buccinum undatum*. NAFC Marine Centre, Fisheries Development Note 20: 1–4.

Heude-Berthelin, C., Hégron-Macé, L., Legrand, V., Jouaux, A., Adeline, B., Mathieu, M. and Kellner, K. 2011. Growth and reproduction of the common whelk *Buccinum undatum* in west Cotentin (Channel), France. Aquat. Living Resour. 24: 317–327.

Himmelman, J.H. and Hamel, J.-R. 1993. Diet, behavior and reproduction of the whelk *Buccinum undatum* in the northern Gulf of St. Lawrence, eastern Canada. Mar. Biol. 116(3): 423–430.

Himmelman, J.H., Lavergne, Y., Cardinal, A., Martel, G. and Jalbert, P. 1982. Brooding behavior of the northern sea star *Leptasterias polaris*. Mar. Biol. 68: 235–240.

Himmelman, J.H. 1988. Movement of whelks (*Buccinum undatum*) towards a baited trap. Mar. Biol. 97: 521–531.

Himmelman, J.H. and Dutil, C. 1991. Distribution, population structure and feeding of the subtidal seastars in the northern Gulf of St Lawrence. Mar. Ecol. Prog. Ser. 76: 61–72.

Hollyman, P.R., Chenery, S.R.N., EIMF, Ignatyev, K., Laptikhovsky, V.V. and Richardson, C.A. 2017a. Micro-scale geochemical and crystallographic analysis of *Buccinum undatum* statoliths supports an annual periodicity of growth ring deposition. Chem. Geol. 526: 153–164.

Hollyman, P.R., Leng, M.J., Chenery, S.R.N., Laptikhovsky, V.V. and Richardson, C.A. 2017b. Statoliths of the whelk *Buccinum undatum*: a novel age determination tool. Mar. Ecol. Prog. Ser. 596: 261–272.

Hollyman, P.R., Laptikhovsky, V.V. and Richardson, C.A. 2018. Techniques for estimating the age and growth of molluscs: Gastropoda. J. Shellfish Res. 37(4): 773–782.

Jalbert, P. and Himmelman, J.H. 1989. Whelks (*Buccinum undatum*) and other subtidal invertebrate predators in the northern Gulf of St. Lawrence. Naturaliste can. Rev. Écol. Syst. 116: 1–15.

Kenchington, E. and Glass, A. 1998. Local adaptation and sexual dimorphism in the waved whelk (*Buccinum undatum*) in Atlantic Nova Scotia with applications to fisheries management. Can. Tech. Rep. Fish. Aquat. Sci. 2237: iv +43 pp.

Kideys, A.E. 1993. Estimation of the density of *Buccinum undatum* (Gastropoda) off Douglas, Isle of Man. Heglolånder Meeresuntersuchengen. 47: 35–48.

Kideys, A.E. 1996. Determination of age and growth of *Buccinum undatum* L. (Gastropoda) off Douglas, Isle of Man. Helgoländer Meeresuntersuchungen. 50: 353–368.

Kideys, A.E., Nash, R.D.M. and Hartnoll, R.G. 1993. Reproductive cycle and energetic cost of reproduction of the negastropod *Buccinum undatum* in the Irish sea. J. Mar. Biol. Assoc. U.K. 73: 391–403.

Lapointe, V. and Sainte-Marie, B. 1992. Currents, predators, and the aggregation of the gastropod *Buccinum undatum* around bait. Mar. Ecol. Prog. Ser. 85: 245–257.

Lawler, A. 2013. Determination of the Size of Maturity of the Whelk *Buccinum undatum* in English Waters-Defra Project MF0231. 39 pp.

Magnúsdóttir, H. 2010. Konksneglens (*Buccium undatum*) biologi og udbredelse I farvandet ved Island og Færøerne. Konksnegle II Journal 282: 1–74.

Martel A., Larrivée, D.H. and Himmelman, J.H. 1986a. Behaviour and timing of copulation and egg-laying in the negastropod *Buccinum undatum* L. J. Exp. Mar. Biol. Ecol. 96: 27–42.

Martel A., Larrivée, D.H., Klein, K.R. and Himmelman, J.H. 1986b. Reproductive cycle and seasonal feeding activity of the neograstropod *Buccinum undatum*. Mar. Biol. 92: 211–221.

McIntyre, R., Lawler, A. and Masefiled, R. 2015. Size of maturity of the common whelk, *Buccinum undatum*: Is the minimum landing size in England too low? Fish. Res. 162: 53–57.

Mensink, B.P., Fischer, C.V., Cadée, G.C., Fonds, M., Ten Hallers-Tjabbes, C.C. and Boon, J.P. 2000. Shell damage and mortality in the common whelk *Buccinum undatum* caused by beam trawl fishery. J. Sea Res. 43: 53–64

Miller, R.J. 1975. Density of the commercial spider crab, *Chionoecetes opilio*, and calibration of effective area fished per trap using bottom photography. J. Fish. Res. Board Can. 32: 761–768.

MMO (Marine Management Organisation). 2019. UK sea fisheries statistics 2018. Office for National Statistics, London. 156 pp.

Nielsen, C. 1975. Observations on *Buccinum undatum* L. attacking bivalves and on prey responses, with a short review on attack methods of other prosobranchs. Ophelia. 13: 87–108.

Nicholson, G.J. and Evans, S.M. 1997. Anthropogenic impacts on the stocks of the common whelk *Buccinum undatum* (L.). Mar. Environ. Res. 44: 305–314.

OBIS. 2019. Distribution records of *Buccinum undatum* (Lamarck, 1758). Ocean Biogeographic Information System. Intergovernmental Oceanographic Commission of UNESCO. www.iobis.org.

Pálsson, S., Magnúsdóttir, H., Reynisdóttir, S., Jónsson, Z.O. and Örnólfsdóttir, E.B. 2014. Divergence and molecular variation in common whelk *Buccinum undatum* (Gastropoda: Buccinidae) in Iceland: A trans-Atlantic comparison. Biol. J. Linn. Soc. 111: 145–159.

Ramsay, K. and Kaiser, M.J. 1998. Demersal fishing disturbance increases predation risk for whelks (*Buccinum undatum* L.). J. Sea Res. 39: 299–304

Rochette, R., Tétreault, F. and Himmelman, J.H. 2001. Aggregation of whelks, *Buccinum undatum*, near feeding predators: the role of reproductive requirements. Anim. Behav. 61: 31–41.

Santarelli, L. and Gros, P. 1985. Determination de l'âge et de la croissance do *Buccinum undatum* L. (Gastropoda : Prosobranchia) á l'aide des isotopes stables de la coquille et de l'ornemantation operculaire. Oceanologica Acta. 8 : 221–229.

Santarelli-Chaurand, L. 1985. Les pêches du buccin (*Buccinum undatum* L.: Gastrapoda) du golfe Normand-Breton. Eléments de gestion de la ressource. Ph.D. thèse, Univ. Aix-Marseille II, Faculté des sciences de Luminy Marseille. 194 pp.

Shelmerdine, R.L., Adamson, J., Laurenson, C.H. and Leslie, B. 2007. Size variation of the common whelk, *Buccinum undatum*, over large and small spatial scales: Potential implications for micro-management within the fishery. Fish. Res. 86: 201–206.

Shrives, J.P., Pickup, S.E. and Morel, G.M. 2015. Whelk (*Buccinum undatum* L.) stocks around the Island of Jersey, Channel Islands: Reassessment and implications for sustainable management. Fish. Res. 167: 236–242.

Siddall, R., Pike, A.W. and McVicar, A.H. 1993. Parasites of *Buccinum undatum* (Mollusca: Prosobranchia) as biological indicators of sewage-sludge dispersal. J. Mar. Biol. Assoc. U.K. 73: 931–948.

Skerritt, D. and Durrance, S. 2018. Management recommendations for English non-quota fisheries: Common whelk. Report to Blue Marine Foundation.

Smith, K.E. and Thatje, S. 2013. Nurse egg consumption and intracapsular development in the common whelk *Buccinum undatum* (Linneaus 1758). Helgol. Mar. Res. 67: 109–120.

Staaland, H. 1972. Respiratory rate and salinity preference in relation to the ecology of three marine prosobranchs *Buccinum undatum* (L.), *Neptunea antiqua* (L.) and *Neptunea despecta* (L.). Norweg. J. Zool. 20: 35–51.

Taylor, J.D. 1978. The diet of *Buccinum undatum* and *Neptunea antiqua* (Gastropoda: Buccinidae). J. Conchol. 29: 309–318.

Tétreault, F., Himmelman, J.H. and Measures, L. 2000. Impact of a castrating Trematode, *Neophasis* sp., on the Common Whelk, *Buccinum undatum*, in the Northern Gulf of St. Lawrence. Biol. Bull. 198: 261–271.

Thomas, M.L.H. and Himmelman, J.H. 1988. Influence of predation on shell morphology of *Buccinum undatum* L. on Atlantic coast of Canada. J. Exp. Mar. Biol. Ecol. 115: 221–236.

Torroglosa, E.M. and Giménez, J. 2010. Temporal variation in size at maturity of the snail *Zidona dufresnei* from the southwestern Atlantic Ocean after ten years of fishery exploitation. Aquat. Biol. 11: 163–167.

Valentinsson, D., Sjodin, F., Jonsson, P.R., Nilsson, P. and Wheatley, C. 1999. Appraisal of the potential for a future fishery on whelks (*Buccinum undatum*) in Swedish waters: CPUE and biological aspects. Fish. Res. 42: 215–227.

Valentinsson, D. 2002. Reproductive cycle and maternal effects of offspring size and number in the neogastropod *Buccinum undatum* (L.). Mar. Biol. 140: 1139–1147.

Villemure, L. and Lamoureux, P. 1975. Inventaire et biologie des populations de buccins (*Buccinum undatum* L.) sur la rive sud de l'estuaire de Saint-Laurent en 1974. Min. Ind. Comm. Québec, Cahier d'information No. 69.

Weetman, D., Hauser, L., Bayes, M.K., Ellis, J.R. and Shaw, P.W. 2006. Genetic population structure across a range of geographic scales in the commercially exploited marine gastropod *Buccinum undatum*. Mar. Ecol. Prog. Ser. 317: 157–169.

Włodarska-Kowalczuk, M. 2007. Molluscs in Kongsfjorden (Spitsbergen, Svalbard): a species list and patterns of distribution and diversity. Polar Res. 26: 48–63.

TABLES

Table 1. Reported annual landings and CPUE for the offshore whelk fishery within 4Vs and 4W divisions. Dashes (-) indicate no fishing in those years. There were no fishing records for 2010.

Year	4Vs				4W			
	Landings (tonnes)	CPUE (kg/trap)	Total Effort (no. of traps)	TAC (tonnes)	Landings (tonnes)	CPUE (kg/trap)	Total Effort (no. of traps)	TAC (tonnes)
2009	0.19	0.97	200	0.22	-	-	-	-
2011	60.46	9.35	6430	0.22	-	-	-	-
2012	0.23	0.39	585	350	0.34	0.49	697	700
2013	113.11	14.22	4820	350	0.01	0.06	225	700
2014	111.12	12.16	8000	350	0.18	0.24	750	700
2015	103.62	15.80	4399	350	1.14	2.28	500	700
2016	287.77	15.22	18905	350	0.12	0.10	1210	700
2017	352.43	17.15	20550	350	8.96	8.00	1120	700
2018	664.73	16.34	31777	700	211.23	3.97	36815	500
2019	549.16	13.81	23050	700	169.99	3.35	45250	500
Avg.	224.28	14.88	11872	n.a.	49.00	3.56	10821	n.a.

Table 2. Biological sampling metrics taken by industry as part of respective research plans. "A" denotes that the metric is always taken, "O" denotes a metric measured opportunistically (when funding and timing allow) and a dash (-) denotes a metric not currently measured as part of the license holder's research plan.

Metrics for Biological Sampling	License Holder 1 (4W)	License Holder 2 (4VS), (4W)	Comments
Shell length	A	A	Important for size frequency
Shell width	A	O	
Total Weight	A	A	
Shell Weight	A	O	
Tissue Weight (including foot)	A	O	
Exterior shell characteristics (epibionts and shell fractures)	A	O	
Sex	A	A	Important for sex ratio
Sexual maturity	A	A	Important for setting MLS and describing spatial structuring of populations
Evidence of imposex	-	A	Implications for determining fecundity
Parasitism	-	O	Implications for determining fecundity
Genetics	-	O	Important for describing spatial structuring of populations
Age	-	O	Important for growth, age-at-maturity, and describing spatial structuring of populations

*Table 3. Sex ratio, parasite loading (% prevalence), smallest size at maturity, size at which 50% of whelk are mature (LM_{50}), and age at LM_{50} of Waved Whelk (*Buccinum undatum*) sampled at five sites on the Scotian Shelf between 2016 and 2017. Reproduced from Ashfaq et al. 2019. ND = no data.*

Site	Sex Ratio (M:F)	Parasitic Prevalence (%)		Smallest Mature (mm)		LM_{50} (mm)		Age at LM_{50} (yrs.)	
		M	F	M	F	M	F	M	F
Southern Area 1 (4Vs)	1:1.3	16.3	15.6	50	ND	55.6	ND	6.2	ND
Northern Area 1 (4Vs)	1.8:1	2.3	5.2	50	ND	45.0	ND	5.1	ND
Southeastern Banquereau (4Vs)	1:1.4	25.6	24.5	45	46	55.2	57.1	5.4	5.7
Middle Bank (4W)	1:1	11.3	15.7	56	63	64.3	65.0	ND	6.4
Northeastern Banquereau (4Vs)	1:2.0	6.0	14.6	48	54	49.6	53.6	ND	ND

FIGURES

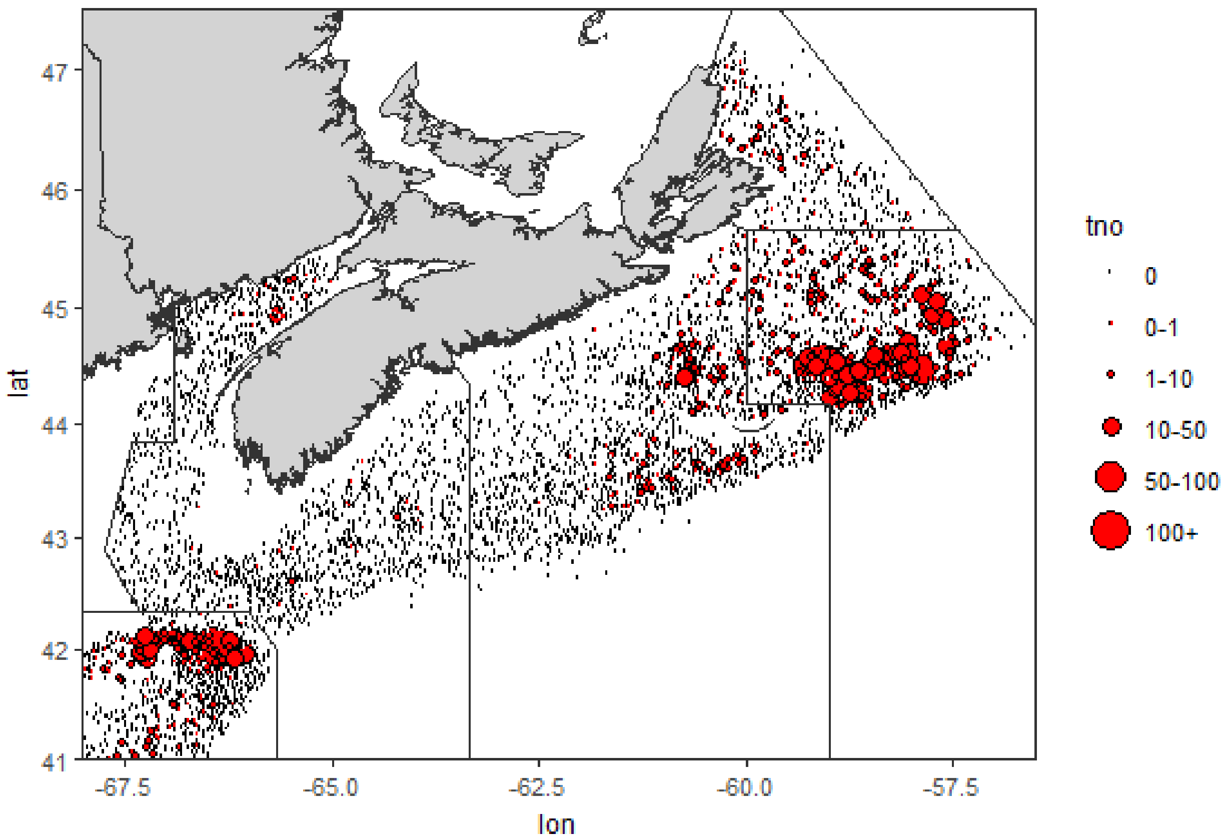

Figure 1. The spatial distribution of whelk found in the DFO Ecosystem Survey from 2007–2018 (number/tow). Whelk are not well captured with the ecosystem survey gear, however, patterns over time are considered representative of the general species distribution. Three categories used in the DFO Ecosystem Survey capture Buccinum undatum: *Waved Whelk, Whelks, and Buccinidae. These categories were summed per tow from 2007–2017, to account for the increasing tendency of identifying invertebrates to species since 2000. tno = total number.*

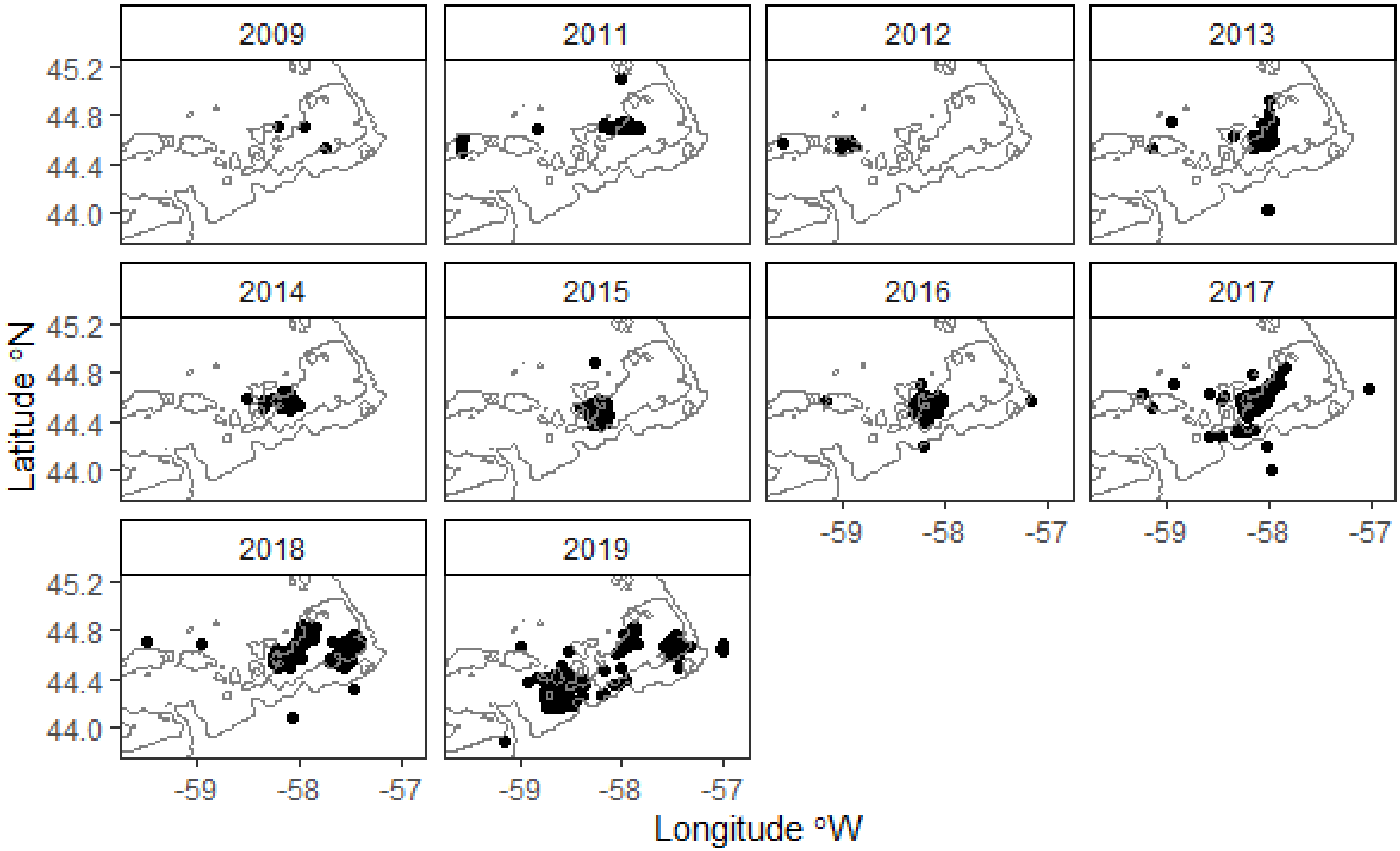

Figure 2. Spatial distribution of effort by year for fishing within the 4Vs subdivision. Only years with fishing effort are presented.

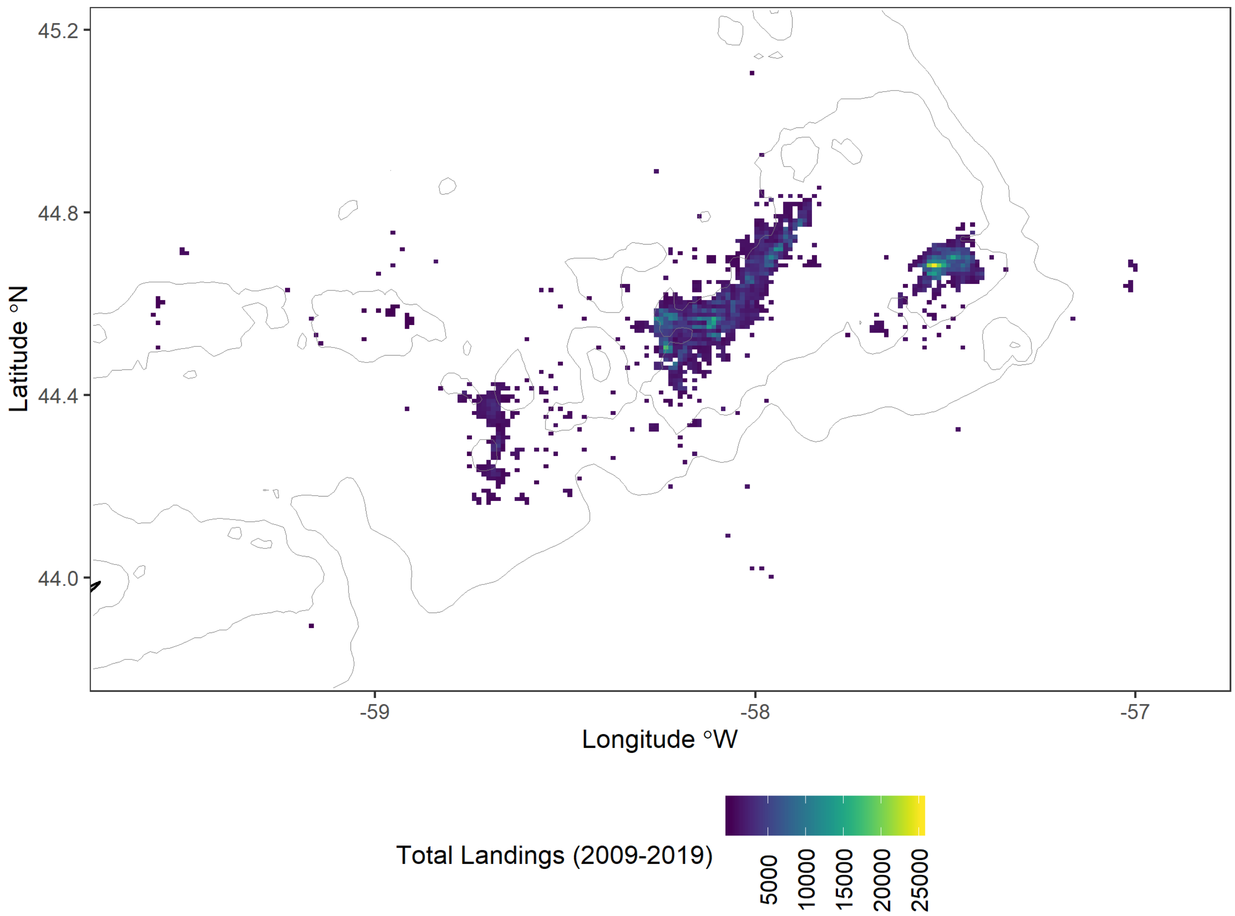

Figure 3. Spatial distribution of landings (kg) for whelk fishing within the 4Vs subdivision between 2009 and 2019. Values for cells are summed at a resolution of 1 km. White = no data.

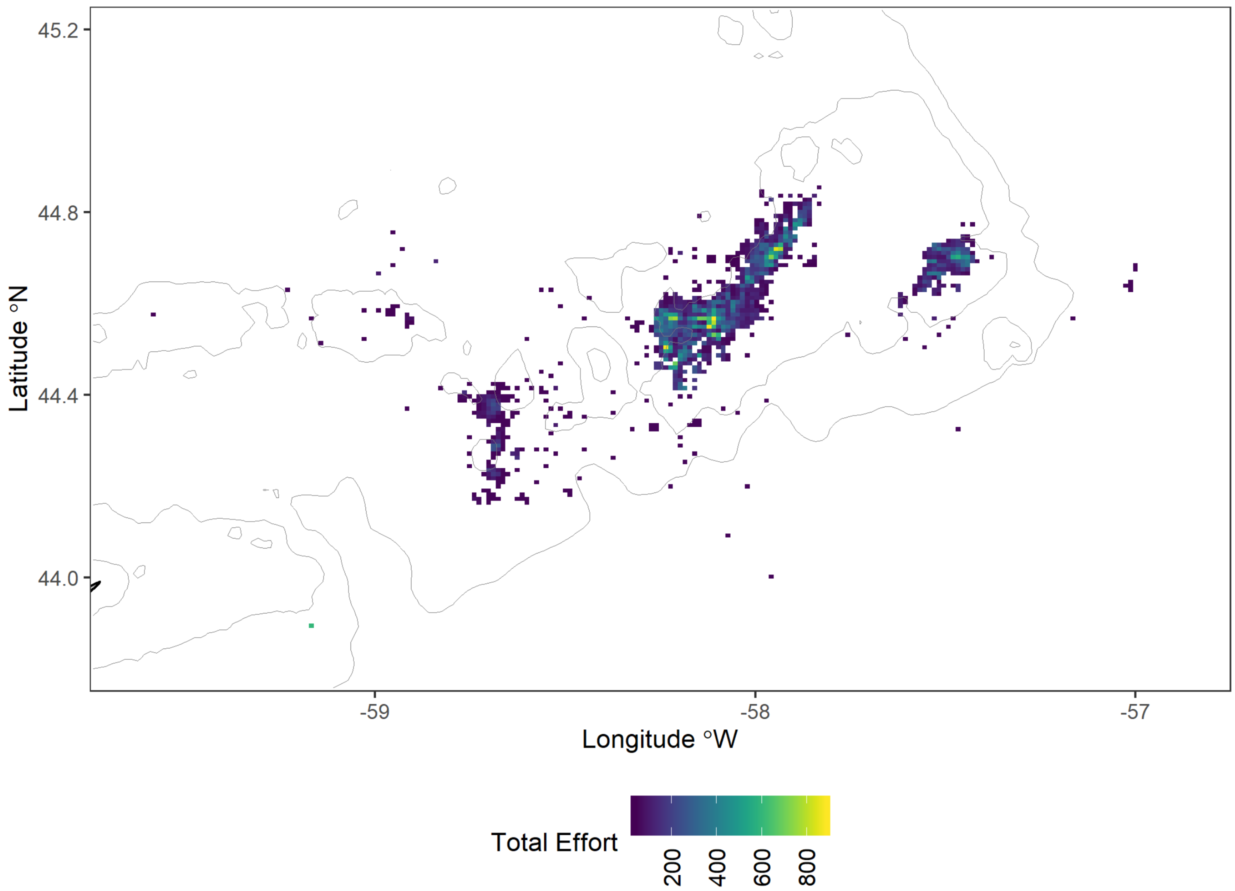

Figure 4. Spatial distribution of effort (number of traps) for whelk fishing within the 4Vs subdivision between 2009 and 2019. Values for cells are summed at a resolution of 1 km. White = no data.

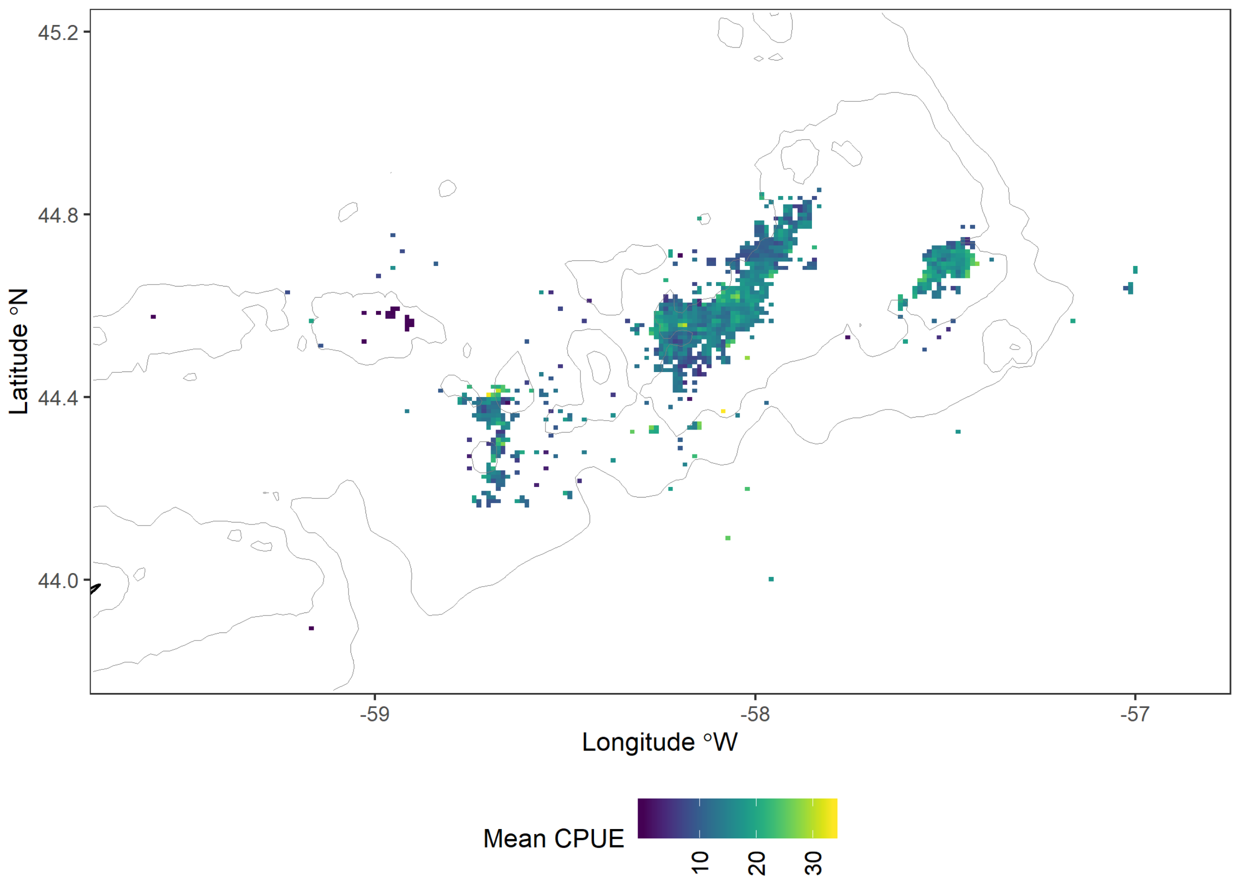

Figure 5. Mean CPUE (kg/trap) for whelk fishing within the 4Vs subdivision between 2009 and 2019. Values for cells are summed at a resolution of 1 km. White = no data.

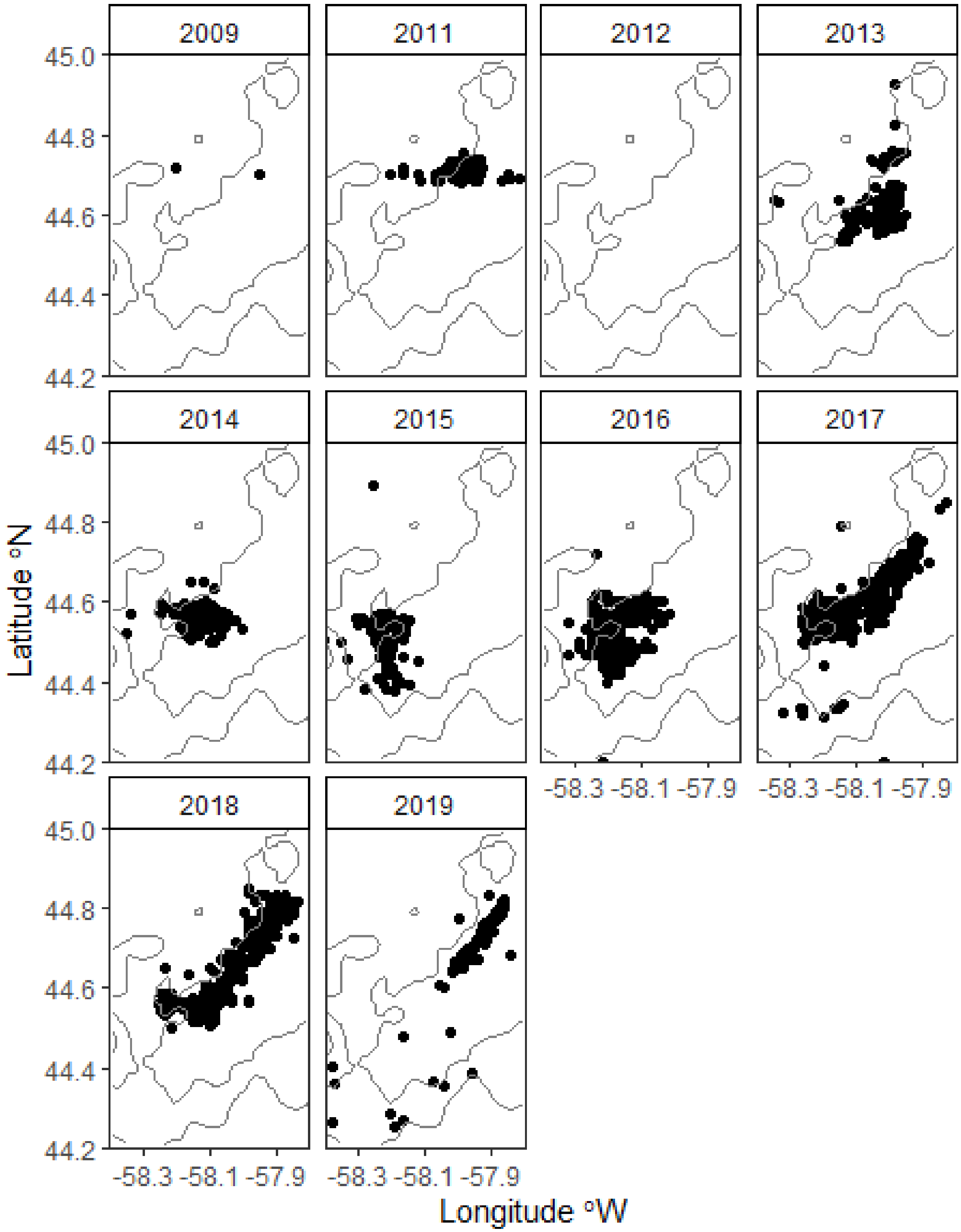

Figure 6. Spatial distribution of effort by year for whelk fishing within Area of access 1 of the 4Vs subdivision. Only years with fishing effort are presented.

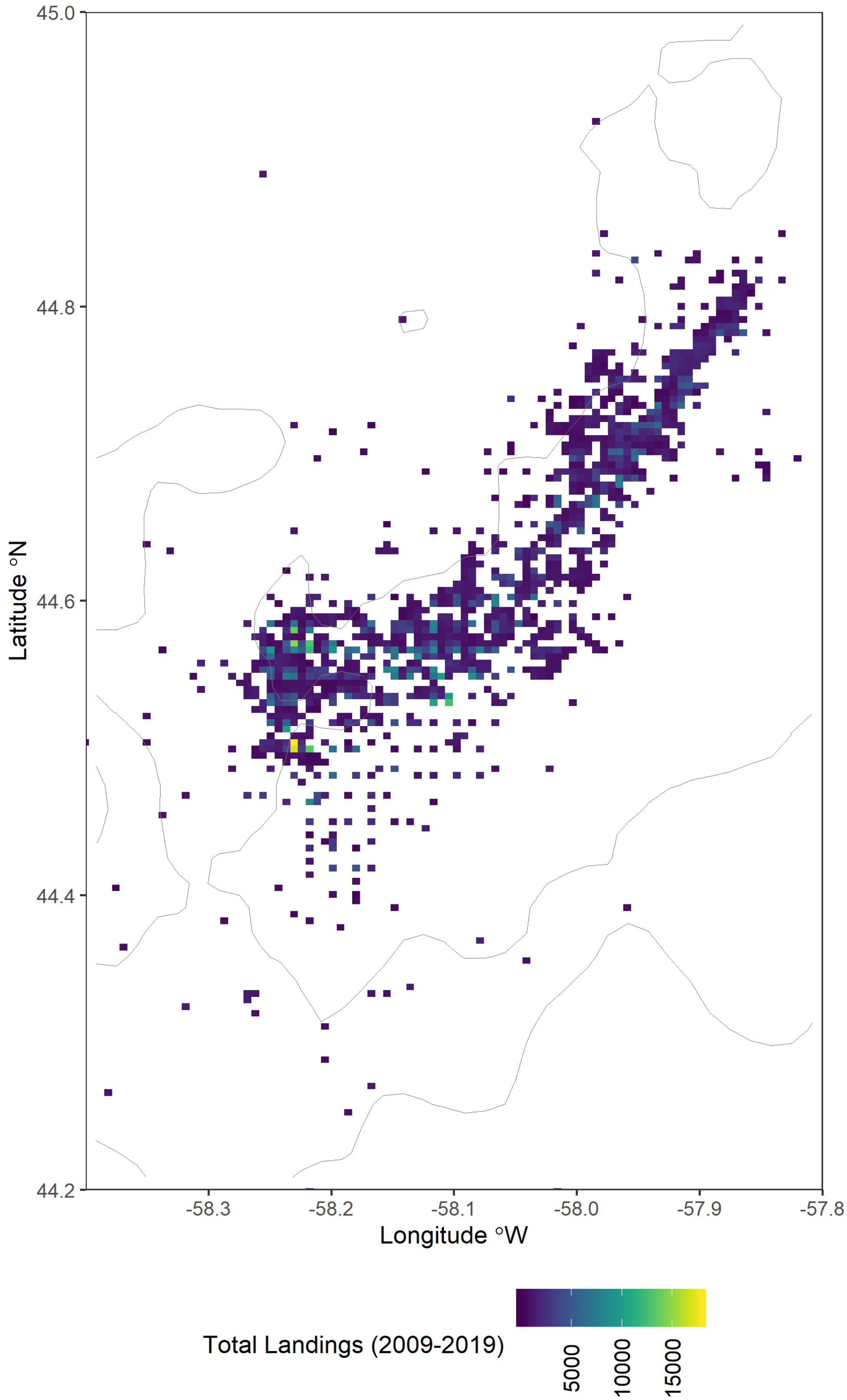

Figure 7. Spatial distribution of landings (kg) for whelk fishing within Area of access 1 of the 4Vs subdivision between 2009–2019. Values for cells are summed at a resolution of 0.5 km. White = no data.

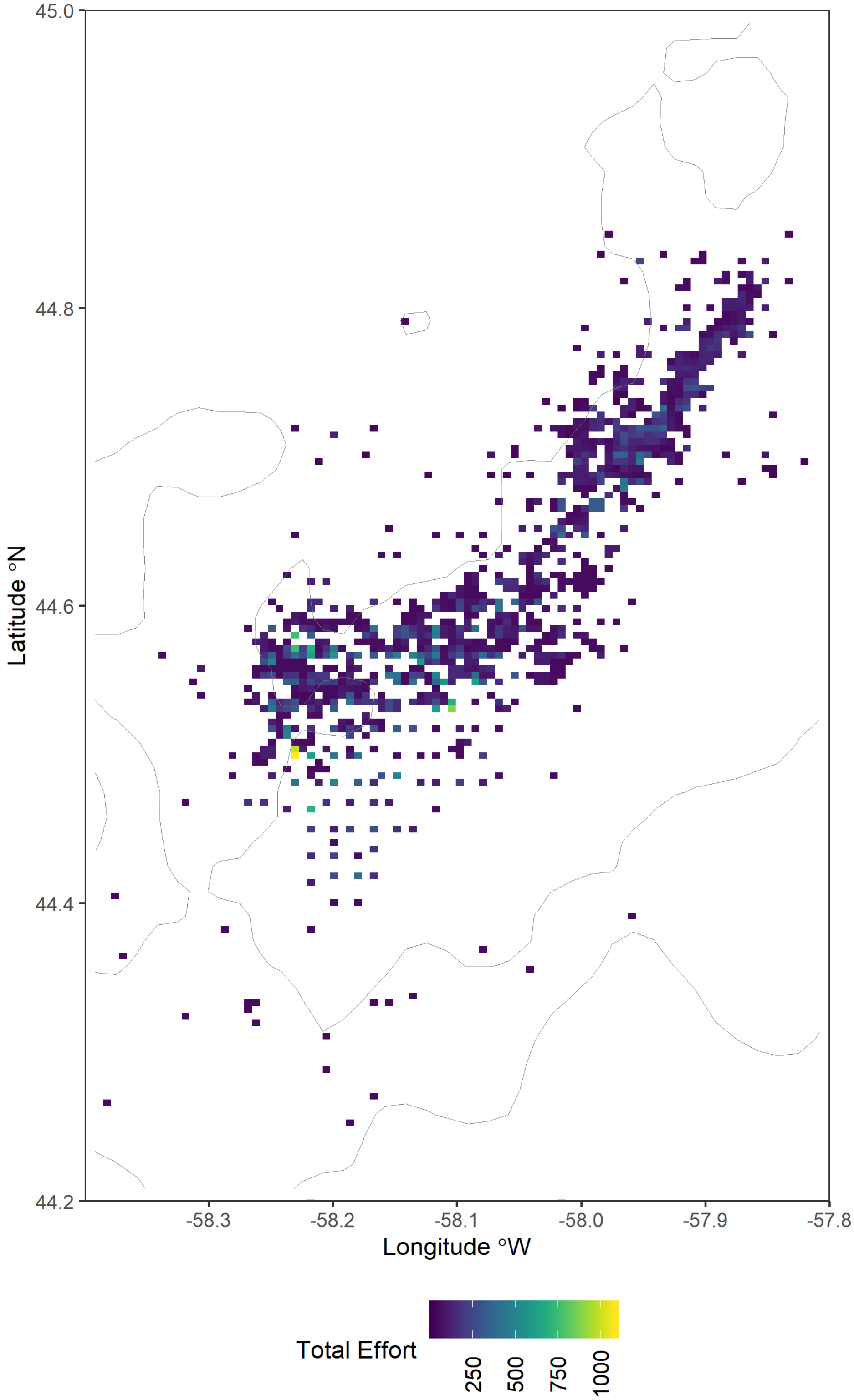

Figure 8. Spatial distribution of effort (no. of traps) for whelk fishing within Area of access 1 of the 4Vs subdivision between 2009 and 2019. Values for cells are summed at a resolution of 0.5 km. White = no data.

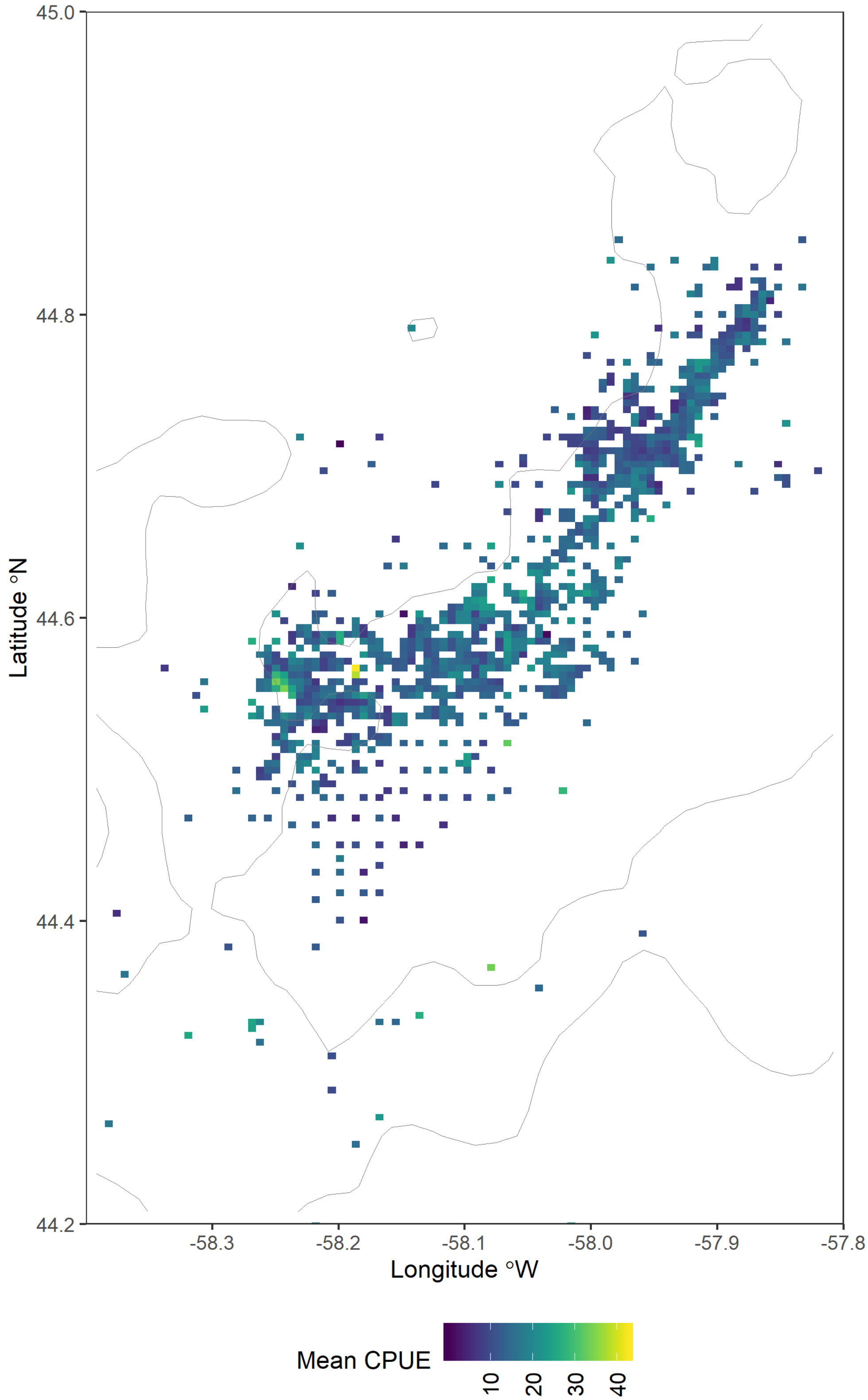

Figure 9. Mean CPUE (kg/trap) for whelk fishing within Area of access 1 of the 4Vs subdivision between 2009 and 2019. Values for cells are summed at a resolution of 0.5 km. White = no data.

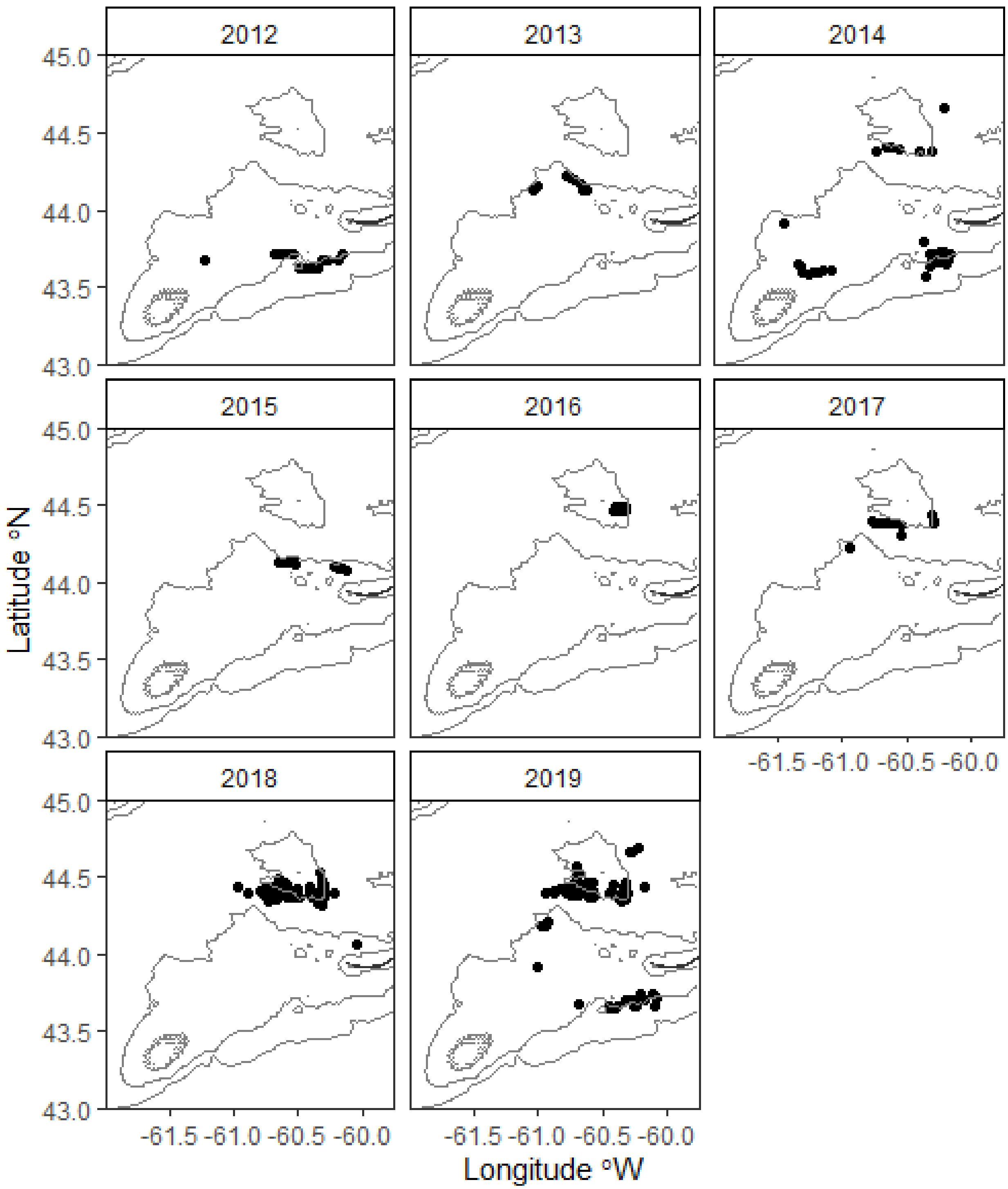

Figure 10. Spatial distribution of effort by year for whelk fishing within the 4W Division between 2012 and 2015. Only years with fishing effort are presented.

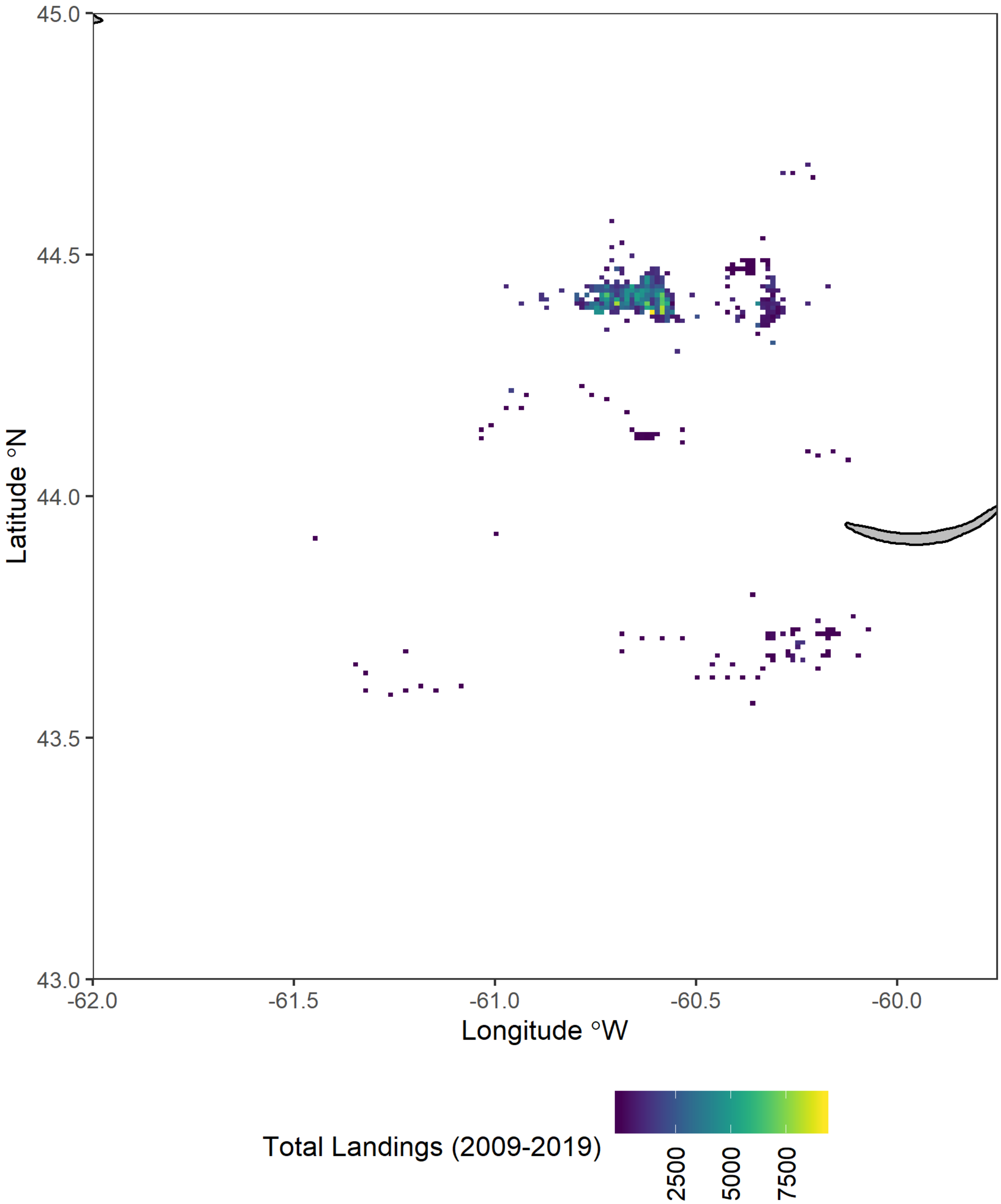

Figure 11. Spatial distribution of landings (kg) for whelk fishing within the 4W Division between 2012–2019. Values for cells are summed at a resolution of 1 km. White = no data.

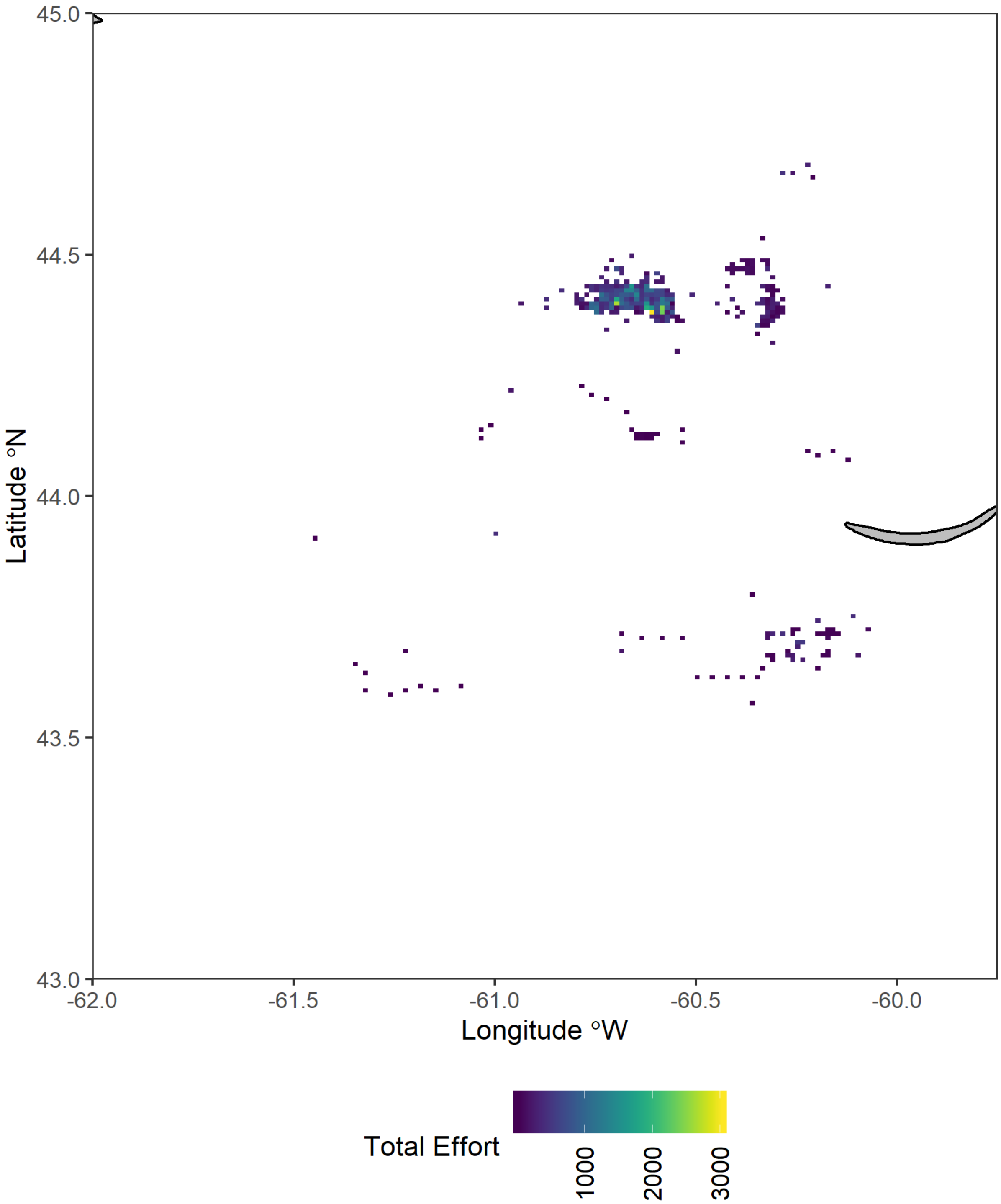

Figure 12. Spatial distribution of effort (no. of traps) for whelk fishing within the 4W Division between 2012–2019. Values for cells are summed at a resolution of 1 km. White = no data.

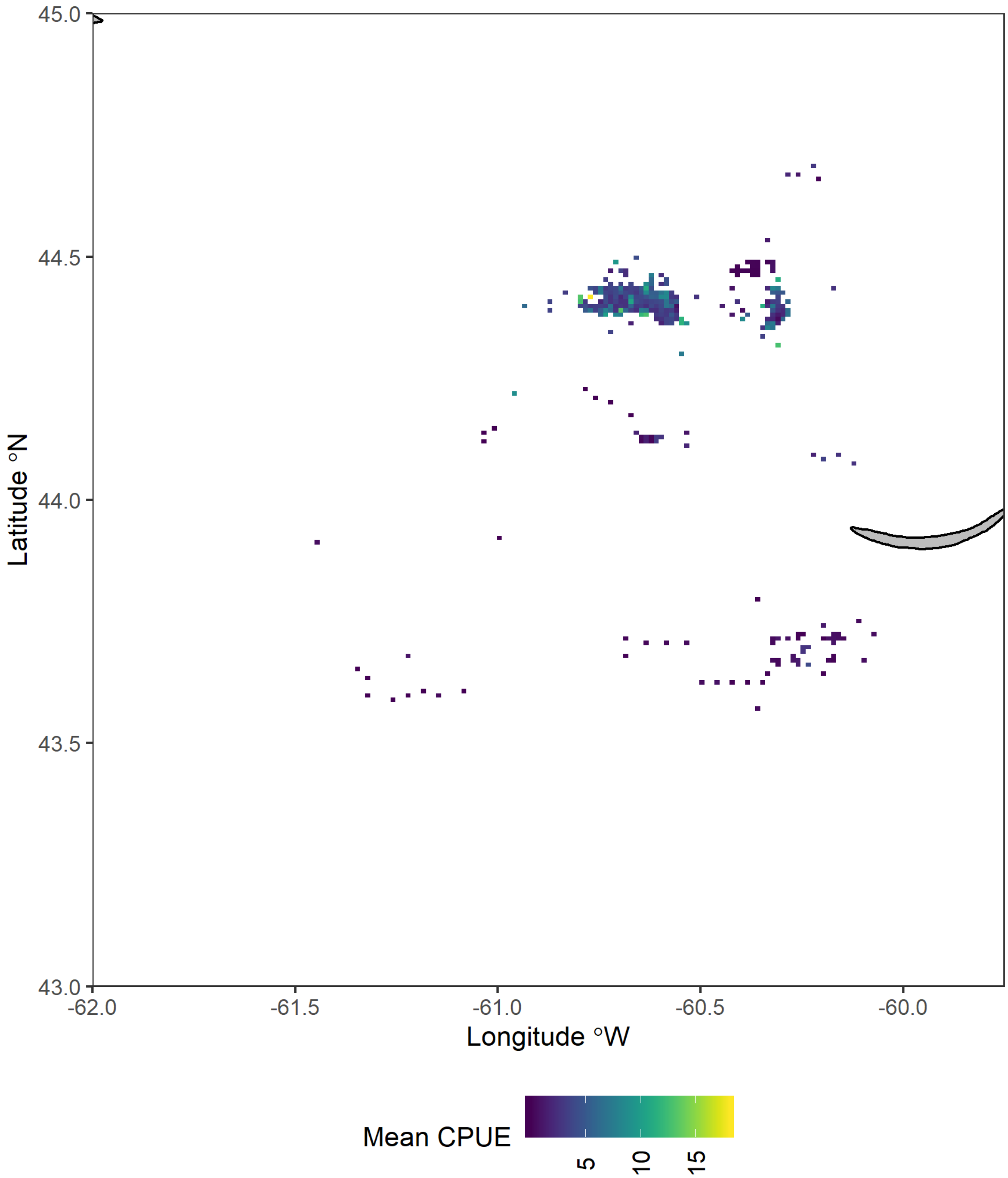

Figure 13. Mean CPUE (kg/trap) for whelk fishing within the 4W Division between 2012–2019. Values for cells are summed at a resolution of 1 km. White = no data.

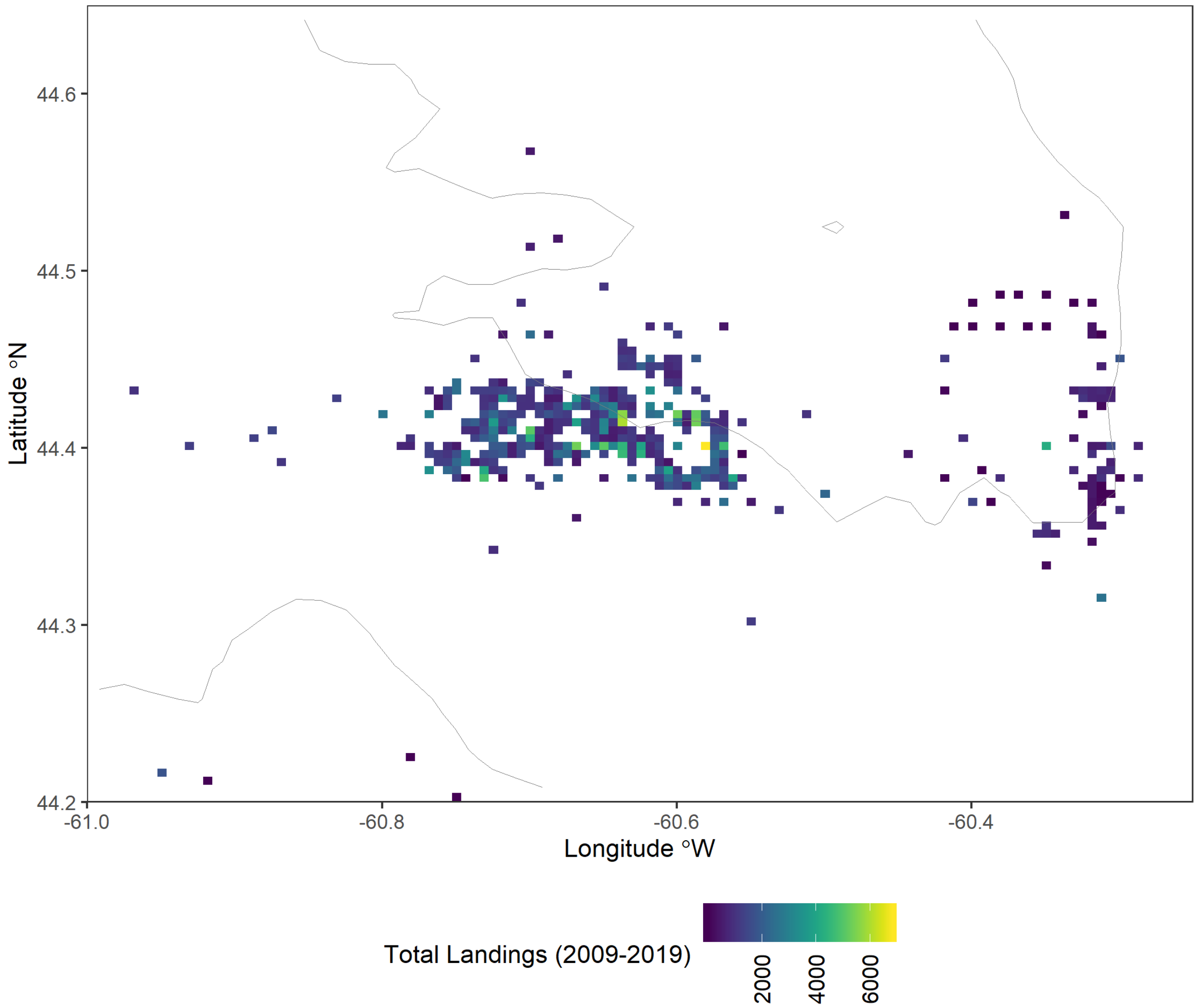

Figure 14. Spatial distribution of landings (kg) around the Middle bank area of the 4W Division between 2014 and 2019. Values for cells are summed at a resolution of 0.5 km. White = no data.

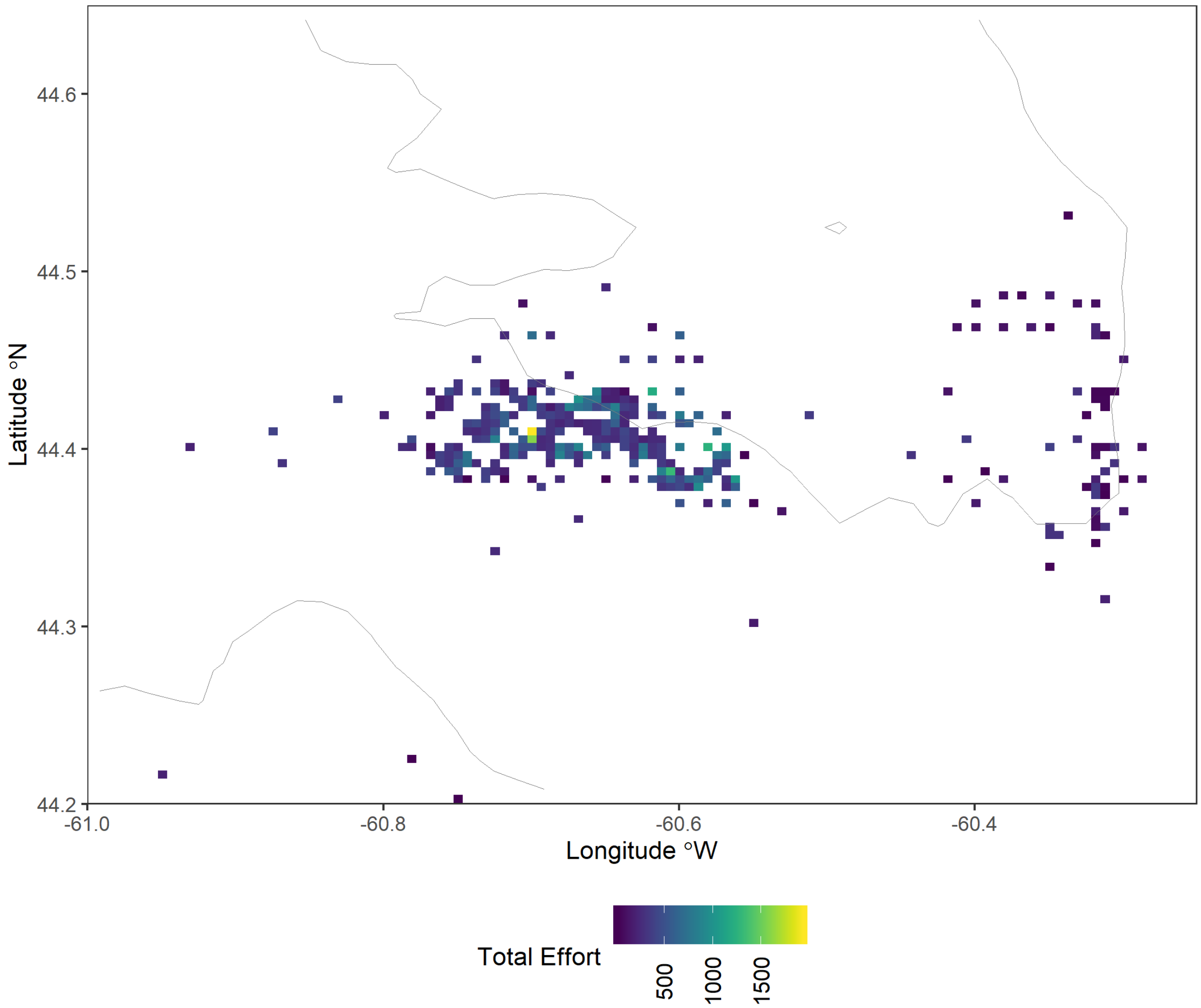

Figure 15. Spatial distribution of effort (no. of traps) around the Middle bank area of the 4W Division between 2014 and 2019. Values for cells are summed at a resolution of 0.5 km. White = no data.

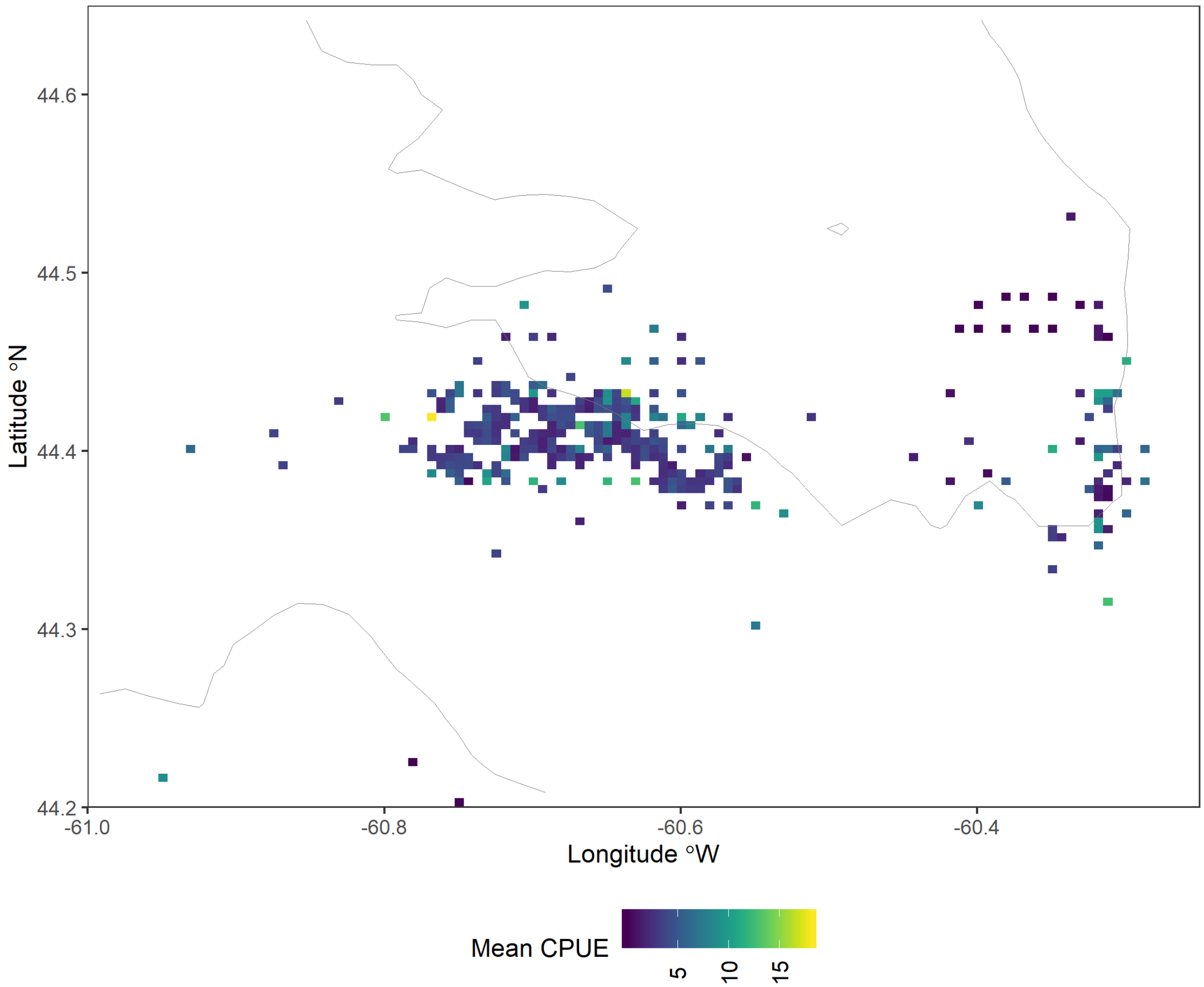

Figure 16. Mean CPUE (kg/trap) around the Middle bank area of the 4W Division between 2014 and 2019. Values for cells are summed at a resolution of 0.5 km. White = no data.

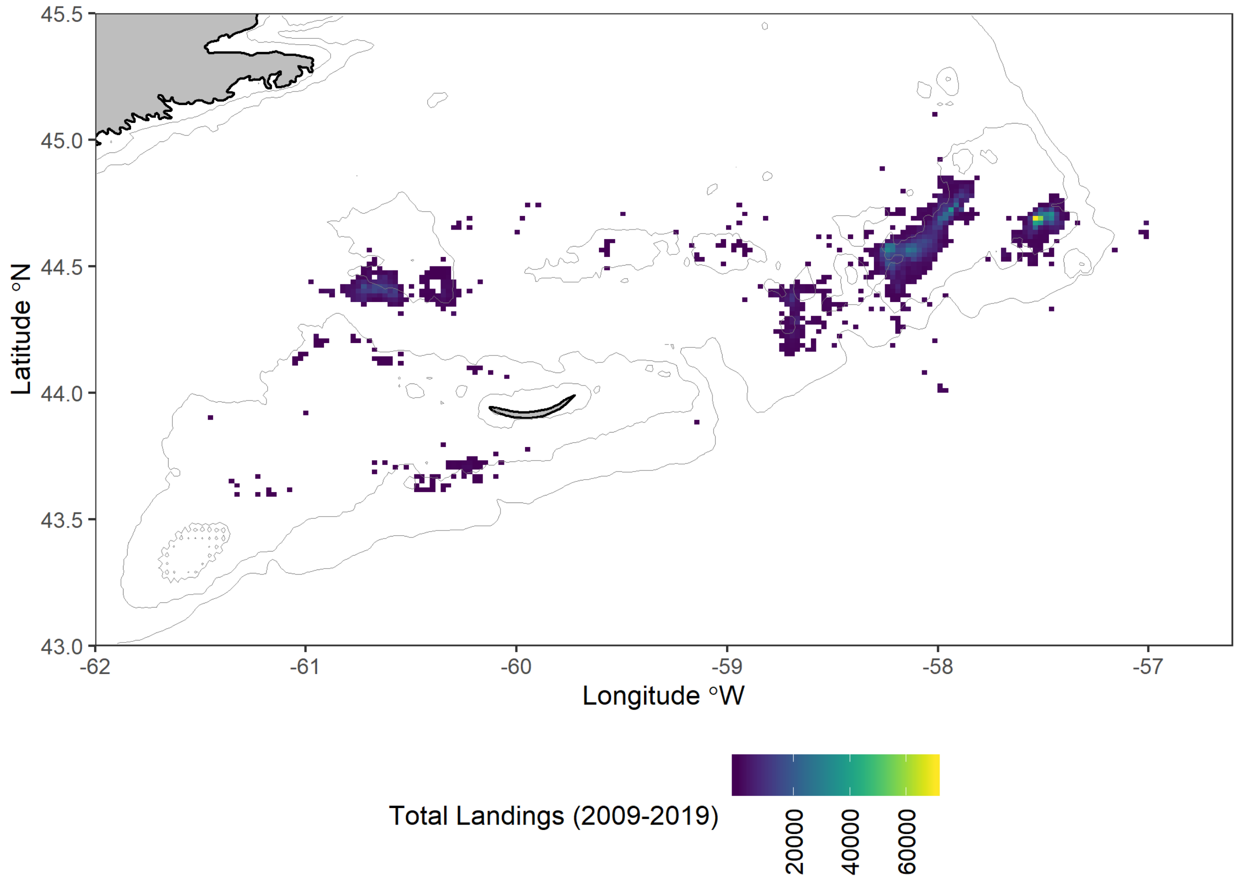

Figure 17. Spatial distribution of landings (kg) for all offshore whelk fishing in the Maritime region between 2009 and 2019. Values for cells are summed at a resolution of 2 km. White = no data.

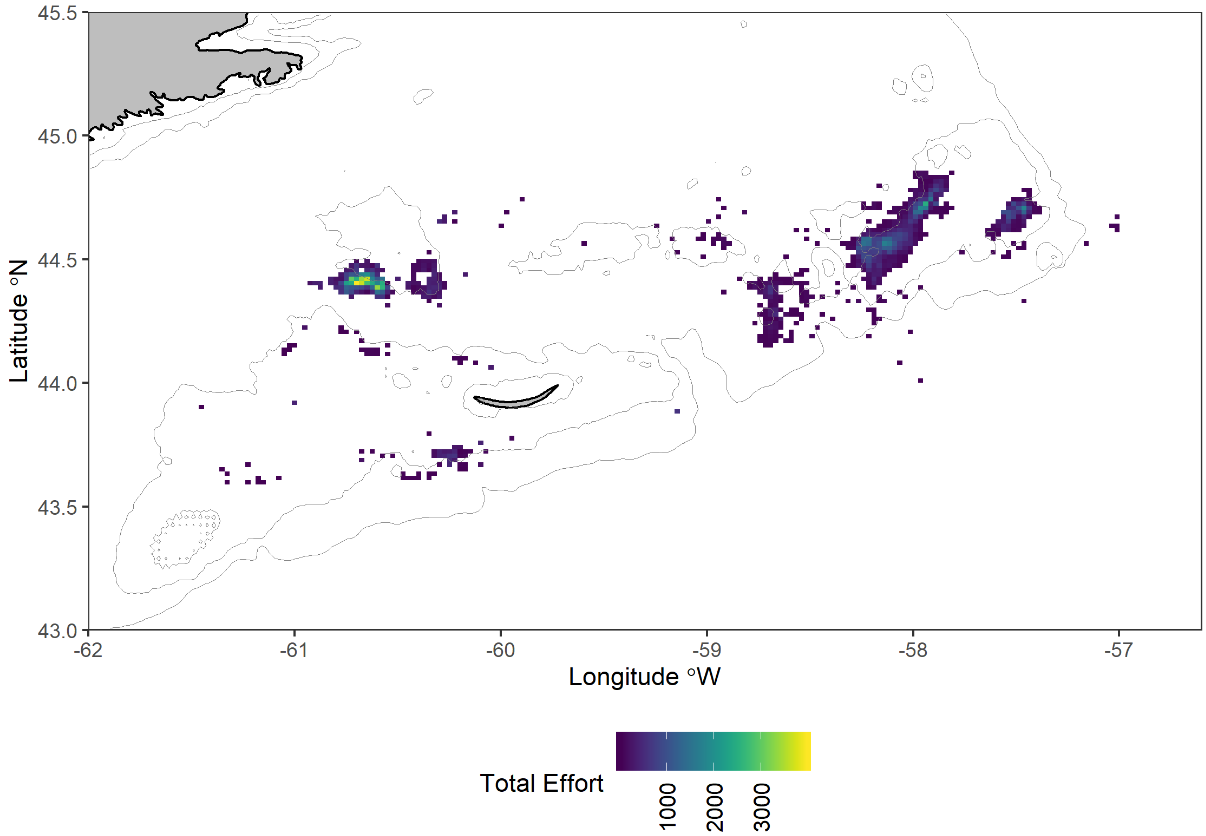

Figure 18. Spatial distribution of effort (no. of traps) for all offshore whelk fishing in the Maritime region between 2009 and 2019. Values for cells are summed at a resolution of 2 km. White = no data.

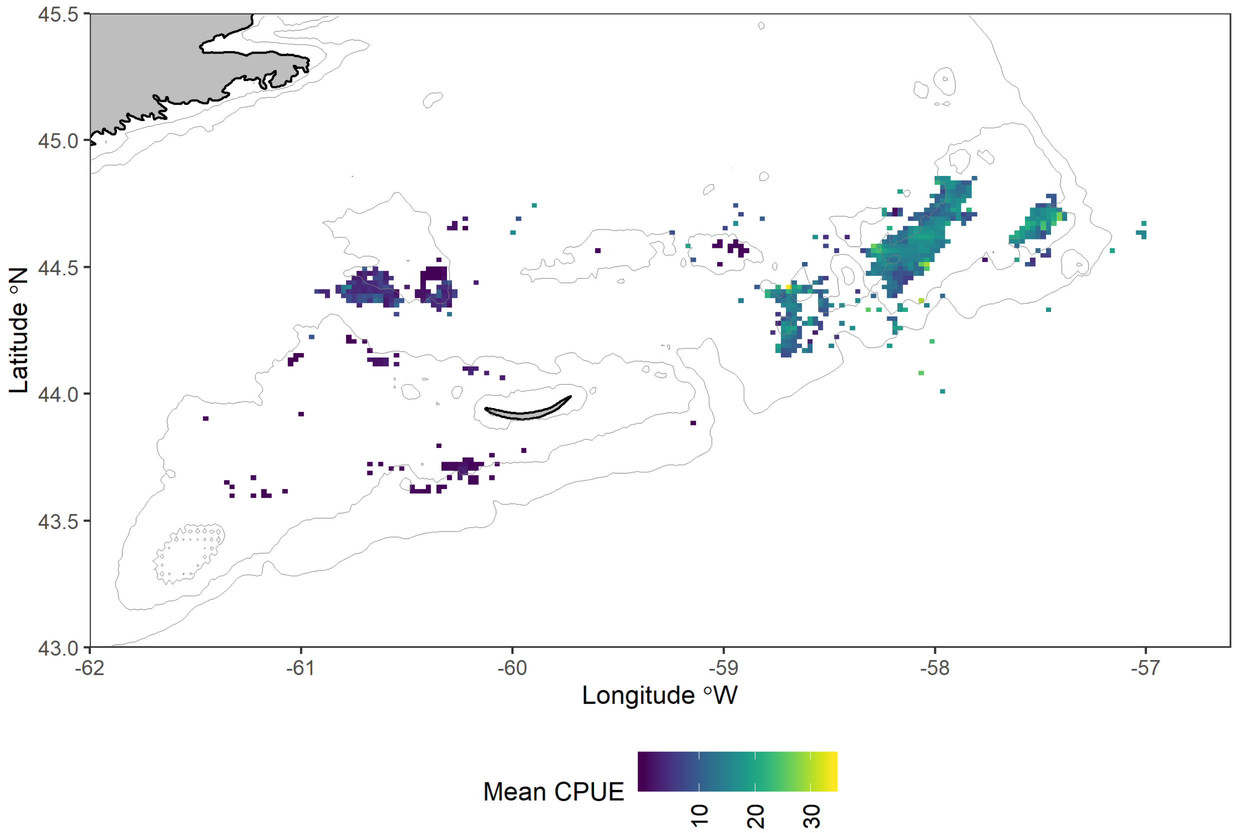

Figure 19. Mean CPUE (kg/trap) for all offshore whelk fishing in the Maritime region between 2009 and 2019. Values for cells are summed at a resolution of 2 km. White = no data.

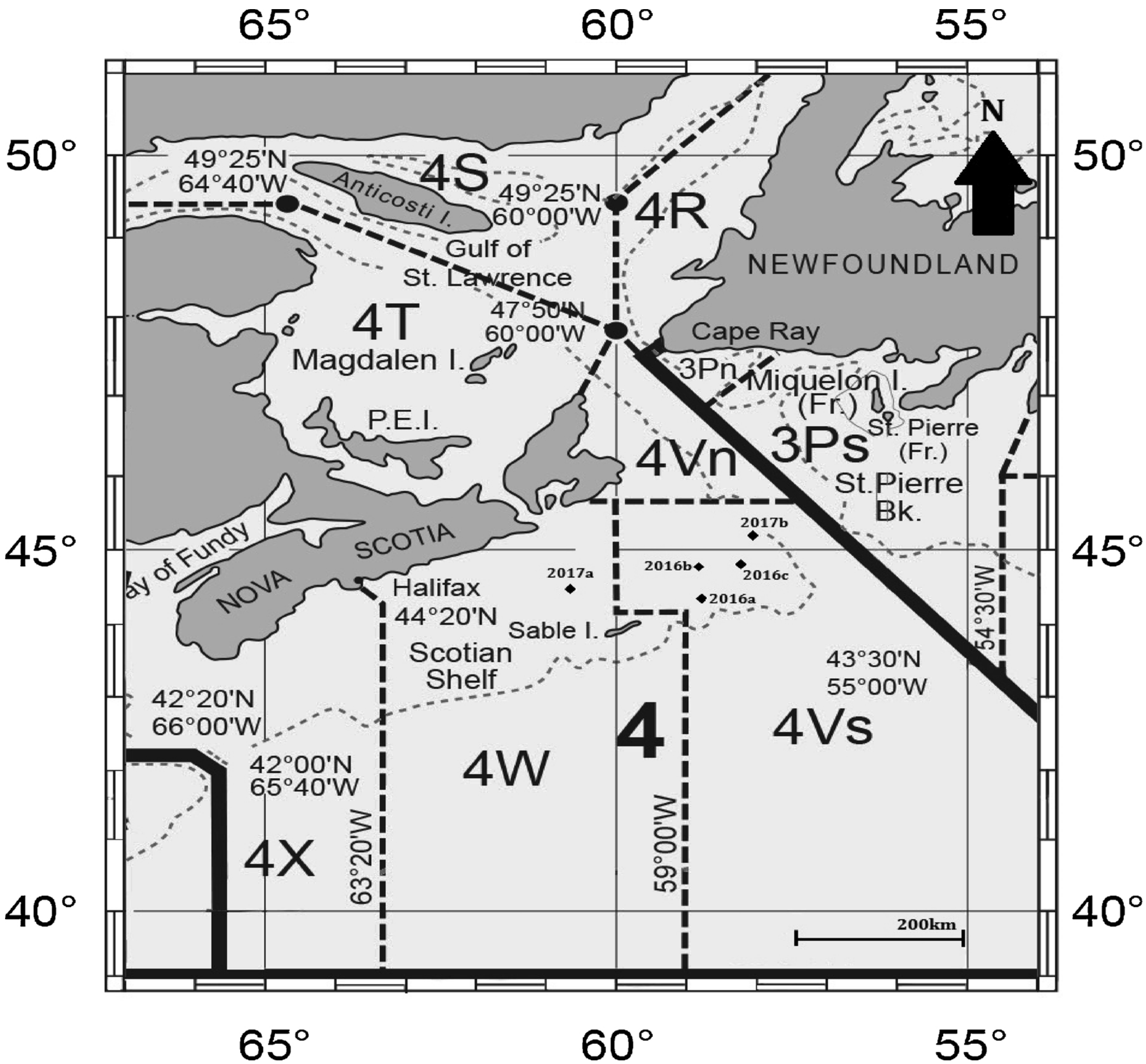

Figure 20. From Ashfaq et al. 2019. The North Atlantic Fishing Organization (NAFO) convention area map showing the commercial fishing subareas (bold solid lines), divisions (bold dotted lines) and sampling locations (diamond markers) of the waved whelks that were collected from the commercial fishing catch on sample trips 2016a to 2017b to the Eastern Scotian Shelf.