[Short title:] *Cancer pagurus* in deep water

Some observations of *Cancer pagurus* Linnaeus, 1758 (Decapoda, Brachyura) in deep water

by

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ABSTRACT

Available species information pages and fact sheets define 100 to 200 metres as the maximum depth of occurrence for *Cancer pagurus.* We here present some observations from video transects conducted in Sognesjøen, Norway, where numerous individuals of adult *C. pagurus* were observed at more than 400 m depth. Within the area investigated, 81 live crabs, 3 dead crabs/exuviae, and 32 areas with concentrated shell remnants were counted. In addition, several areas were covered with obvious crawling tracks from crabs. Spatial variation in the density of live crabs, remnants, and tracks varied between 0 and 52 crabs/100 m^2. Size estimations based on 19 individuals showed an average carapace width of 14.5 cm. Possible explanations for why the crabs are present at these depths, are discussed.

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INTRODUCTION

The brachyuran crab *Cancer pagurus* Linnaeus, 1758, commonly named the edible crab, has a widespread latitudinal distribution in the eastern Atlantic Ocean, from Morocco to the northern parts of Norway (FAO, 2015). Several popular sources of species information or fact sheets report 100 or 200 metres as the maximum depth for the occurrence of *C. pagurus* (cf. Hayward & Ryland, 1990; Lloris & Rucabado, 1998; Bay-Nouailhat, 2004; Neal & Wilson, 2008; FAO, 2015). Although a reference to this maximum depth is not specified, it is likely that the numbers originate from mark-recapture studies, where data on depth for the recaptured individuals are available. Data from recaptured individuals are, however, restricted by the operational depth of the fishing gear, which in the edible crab fishery is limited to inshore or offshore areas with depths less than 200 metres (Brown & Bennett, 1980; Le Foll, 1982; Woll et al., 2006; Bannister, 2009). In d'Udekem d'Acoz (1999), who cited Clark (1986), the author reported 520 m as the deepest observation for *C. pagurus*, and a search through online biological databases shows that a few individual crabs have been caught at greater depths during surveys off the coast of Ireland (table I). However, there is no evidence suggesting that deep water is an important habitat for *C. pagurus*. We here present some results from video transects in Sognesjøen, Sogn og Fjordane, Norway, where a high abundance of *C. pagurus* was observed at ~400 metres depth. Our observations add information to the limited available data on the depth distribution of this species.

MATERIAL AND METHODS

The video material used is from an ongoing project supported by the Norwegian Biodiversity Information Centre, mapping nature types and species in Sognefjorden (Norway) one of the world's longest and deepest fjords (insert in fig. 1). The current paper reports on the video observations of edible crab from a station located in Sognesjøen, just outside Sognefjorden (fig. 1, Pos. 60°55'35"N 4°39'12"E) conducted 27 March 2014. At the station two video transects were made (fig. 1), one in a north-eastern direction, ~700 m long (S1VL1), followed by a second, ~450 m long transect in a west/north-western direction (S1VL2). The video-rig, called “Chimaera”, was equipped with a high definition colour video camera (Sony HDC-X300) tilted forward at an angle of approximately 45°. Laser beams denote 10 cm distance in the picture frame. The rig also has a standard definition video camera for navigation purposes, lights (2 × 400 W, Hydrargyrum Medium-Arc Iodide (HMI)), and a depth sensor. The videos were recorded on hard-drives on board the vessel. The width of the video image covers ~1.5 - 2.0 metres of seabed. The video platform was towed behind the survey vessel at a speed of 0.7 knots [ca. 1.2 $km.h^{-1}$] and controlled by a winch operator providing a near-constant altitude of 1.5 m above the seabed. To provide the best view, the video rig was towed uphill in steep terrain. Geo-positioning of the video data is provided by a hydro-acoustic positioning system (Simrad HIPAP and Eiva Navipac software) with a transponder mounted on the frame, giving a position accuracy of approximately 2% of the water depth. Navigational data (date, UTC time, positions, and depth) were recorded automatically at 10-second intervals using the software CampodLogger made at the Institute of Marine Research (IMR), Bergen. This software was also used to systematically take field notes of fauna, bottom types, signs of fishing impact, occurrence of litter, and local geological seabed features during video recording.

The videos from the transects were analysed by counting all *Cancer pagurus* within the picture frame. Both live crabs (observed moving), and dead crabs/or intact exuviae as well as areas with accumulation of shell remnants, were counted. Dead crabs/exuviae were scored when non-moving intact crabs either on their back or in an unnatural position on the seabed, were observed; in other words, the crabs were determined as dead/exuviae, as it was not possible to determine if these were crabs that had died, or if it was the complete exoskeleton of a crab that had moulted. When counting shell remnants, only aggregations clearly identifiable as the edible crab were counted, and where at least one claw and the carapace were identifiable. Abundance (n/100 m^2) of live crabs, shell remnants, and tracks from crabs along video transects S1VL1 and S1VL2 were calculated based on the numbers of observations within the video sequences. The sequences varied in distance between 5 and 20 m, with an average on 10.8 m. Areas for these sequences were calculated by multiplying the distance with the average field view, indicated by two parallel laser pointers.

Estimates of the size of crabs were conducted by the formula 10 × *cw/lw*, where *cw* is the measured carapace width of the crab, and *lw* the measured distance between the laser points. Only crabs that were positioned in a way that allowed for good on-screen measurements were used in size estimates. Carapace width was rounded off to the nearest 0.5 cm.

Vertical profiles of salinity and temperature (CTD) were collected from the Institute of Marine Science's data base, who have a hydrographic station at Sognesjøen where measurements are taken every second week. The data used were from 24 March 2014, three days prior to the date of making the video transects.

RESULTS

The temperature and salinity profiles for Sognesjøen in the current period are presented in fig. 2, showing cold water (~5-6°C) from the surface down to about 30 m depth, and with a constant temperature of about 7°C deeper than 150 m. The salinity was 30.8‰ at the surface, and gradually increased to about 35‰ at around 150 m depth.

The average depth of the surveyed area was 423 meters (maximum depth: 488 m, minimum depth ~300 m). In transect 1 (S1VL1) the seabed consisted mostly of sandy mud, occasionally interrupted by cobble and boulders, while transect 2 (S1VL2) was dominated by a muddy bottom and some bedrock with detritus. The deepest observation of a live crab, *Cancer pagurus*, was at 406 m, but with shell remnants found as deep as 450 m. In the two video transects a total of 81 live crabs, 3 dead crabs/exuviae, and 32 areas with concentrated shell remnants were counted. In addition, several areas with obvious tracks from crabs were found. A video from the first transect is included in this paper as supplementary material (S1 – Video S1VL1 [please see link on last page]).

Fig. 3 presents the density of live crabs, shell remnants, and crab tracks along the two transects. In fig. 4, the density of live crabs is plotted against the depth profile of the transects. The highest density of crabs was found in the last half of transect 1 and at the beginning of transect 2. The estimated total area covered by the video transects was 1648 m^2, yielding a mean density of ~4.9 live crabs/100 m^2. If dead crabs/exuviae and crab remnants are included, the density was ~7.0 crabs/100 m^2, on average. The highest density of crabs was found in the first transect, where 55 live crabs and 30 dead crabs/exuviae were counted (density: ~ 5.4 live crabs/100 m^2; ~8.7 crabs/100 m^2 remnants included). The highest local abundance of crabs was found at the end of S1VL2, with 52.04 crabs/100 m^2 (fig. 3). This transect included the ascent towards shallower water, where several crabs were observed, including an aggregation of about 20 crabs on a ledge at about 330 meters depth. At S1VL1 a cluster was found of high crab density, with 37.3 crabs/100 m^2.

Making reliable size estimates of 19 crabs was possible based on the laser measurements. The average carapace width for these crabs was ~14.7 cm, with the largest crab measuring ~19.5 cm and the smallest ~12 cm.

Adult females and males have different morphological characteristics (Hartnoll, 1974; Edwards, 1979; Tallack, 2002), where besides the obvious difference in abdomen size (females have wider and larger abdomens), males have proportionally larger chelipeds and a less dorsally extruding carapace. The three dead crabs/exuviae observed in the video where on their back or had their abdomen extended. All these were clearly identifiable as female crabs. Most of the crabs observed in the video appeared to be female, although a few crabs looked to have male characteristics (a flatter carapace and with large chelae). However, based purely on the visual observations it was not possible to determine the sex of the various crabs with certainty.

DISCUSSION

Except for a few individuals caught in ground fish surveys (table I), the result we present constitutes, as far as we can find in the literature, the first time a high abundance of *Cancer pagurus* has been observed in deep water. The large number of crabs observed also shows that we not merely have observed the migration of some random individuals to these depths. Bell et al. (2003) conducted a mark-recapture study in a commercially fished offshore area (Race Bank, U.K.) and estimated the population at 2100 crabs/km^2 (= ~0.2 crabs/100 m^2). In a study by Hall et al. (1991), where diving observations were conducted in shallow waters, a density of 16-20 crabs/5000 m^2 (= ~0.4 crabs/ 100 m^2) was estimated. This is a much lower density of crabs than what was estimated for the area observed in our study (an average of 4.9 and locally up to 52 crabs/100 m^2). Due to methodological differences and the aggregational densities in our observations, it is not possible to directly compare our findings with other studies. However, the overall high abundance of crabs observed shows that these depths probably constitute an important winter habitat for the species in this area.

The reason for the aggregation of crabs along transects is not clear. The variation in abundance could be related to depth, as most crabs were observed in the shallower areas of the transects (fig. 4). The deeper waters were, however, also associated with different types of sediment: where, for instance, along transect 2, in places where fewer crabs were found, these were dominated by mud, while transect 1 had more dense, sandy bottom, which latter condition represents a more common substrate for *C. pagurus* (cf. Neal & Wilson, 2008).

As regards the reason why the crabs are at these depths, more detailed studies are needed: our observations give no clue in this respect. Some considerations for future studies can, however, be made based on the biological knowledge of the species. In Norway, the main season for crab fishery is between July and November (Woll et al., 2006). Statistics on commercial landings show that from November to the time of the study only 85 kilograms of crabs were fished in the region where the study was conducted (pers. comm. Ann Dorthe Kråkenes, Fishermen's sales organisation "Vestnorge"). It is therefore unlikely that the crabs observed in the video are crabs that have been discarded by boats. Further, since crabs and tracks were observed over such a large area, that supposition would mean postulating a substantial amount of crabs being discarded. It is therefore safe to assume that the crabs have migrated to these depths. We hypothesize that the topography of the area plays an important role, where crabs have limited possibilities for horizontal movement without venturing into waters of great depth (fig. 1). The large number of crabs filmed on the steep cliffs leading down to the area observed, indeed indicates a vertical migration. It is well known that crabs migrate to deeper and warmer waters in response to cooling surface water temperatures during winter (Brown & Bennett, 1980; Karlsson & Christiansen, 1996). Given the low surface water temperature in the area (~5-6°C, fig. 2) it is thus possible that we have observed a thermally driven migration.

The estimation of crab sizes based on the laser measurements indicates that the crabs spotted were adults. Assuming they where predominantly females, these individuals could be migrating to suitable spawning grounds. Such migrations have been documented in several studies (Williamson, 1904; Meek, 1914; Bennett & Brown, 1983; Le Foll, 1986; Ungfors et al., 2007; Hunter et al., 2013). Tagging experiments of *C. pagurus* conducted by the Institute of Marine Science in the 1960's at Kjeldosen, just 40 km south of the location of our study, demonstrated a primarily southward directional movement of mature female crabs in the area (Gundersen, 1977, 1979). Future studies should therefore involve physically collecting crabs using pots or gillnets, in order to enable researchers to accurately determine the sex and maturity stage of the crabs found.

Determining if the shell remnants observed in the video were exuviae originated from moulting, that had been disintegrated (e.g., dismembered by scavengers or conspecifics), or actual remnants of dead crabs, appeared not to be possible. Soft-shelled crabs are caught by fishermen year-round (Williamson, 1904; Edwards, 1967), but the most prominent period for moulting (and for females, concurrently mating) is from late spring to autumn, when the crabs migrate to shallower water (Williamson, 1900; Edwards, 1967, 1979; Bennett, 1995; Tallack, 2007; Bakke et al., 2018), i.e., a period several months later than that when the study was conducted. The three dead crabs/exuviae that were observed, were without visual damage. Collecting of such specimens intact, would help to determine if moulting actually occurs at these depths, or that we have observed the remains of dead crabs. Both explanations (moulting or mortality) would have significant implications for our biological understanding of the species. If crabs are moulting, it suggests an extension of, or a separate period for, growth. If we, however, observed remains from dead crabs, the large quantities suggest that the stay in deep water during the winter months could contribute significantly to the species' natural mortality.

CONCLUSIONS

An accurate understanding of a species' biogeographical range as well as of its bathymetric limitations is important when conducting biological studies, especially at the population level. Our findings show that *Cancer pagurus* show a higher degree of eurybathy than noted in current fact sheets and information pages, and that deep water possibly constitutes an important habitat in the species' life cycle. Studies on *C. pagurus* are often concerned with the biology of the species in shallow water, while the period when crabs overwinter in deeper water are more or less overlooked and, in fact, silently assumed to be a dormant phase in the seasonal cycle. Given the high density of crabs observed in our study, it is, however, clear that an effort should be made to answer some of the questions raised above, in order to gain a more complete understanding of the biology of *Cancer pagurus*.

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[LEGENDS TO FIGURES]

Fig. 1. Bathymetry of Sognesjøen. Different tones of grey or hatching show different depths as denoted in the scale. The square-outlined area, magnified in the inserted figure, showing the transects of the video rig. Transect 1 (S1VL1) from Start to Turn, Transect 2 (S1VL2) from Turn to Stop. Insert with map of Norway showing location of Sognesjøen, with the station marked with a filled black square.

Fig. 2. Temperature and salinity at Sognesjøen from 0 to 300 m depth. Measurements taken from the hydrographic station operated by the Institute of Marine Science. Data from 24 February 2014, 3 days prior to the day of making the video transects.

Fig. 3. Density of: a, live *Cancer pagurus* Linnaeus, 1758; b, shell remnants; and c, tracks from crabs; along the two transects S1VL1 and S1VL2.

Fig. 4. Density of live *Cancer pagurus* Linnaeus, 1758 along the depth profile of the transects S1VL1 and S1VL2.

TABLE I

Some registrations of *Cancer pagurus* Linnaeus, 1758 in deep water originating from fishery surveys. The table only presents registrations with a maximum depth deeper than 400 m

Max depth (metres)	N	Sex	Location	Observation date (dd.mm.yyyy)	Ref.
568	1	NA	55°33.5'N 09°33.5'W Tory Island, Donegal, Ireland	19.vi.1973	(1)
435	NA	NA	51°42'36"N 11°39'00"W (2) Celtic Sea, off SW Ireland	11.xi.2006	(3)
430	2	F	55°10'48"N 10°03'00"W (2) Off coast of Doneagal, Ireland	10.xi.2009	(4)
400	2	M	55°10'48"N 10°03'00"W (2) Off coast of Donegal, Ireland	10.iii.2010	(4)
400	2	M	55°10'48"N 10°03'00"W (2) Off coast of Donegal, Ireland	18.iii.2009	(4)
400	2	F	55°10'48"N 10°03'00"W (2) Off coast of Donegal, Ireland	18.iii.2009	(4)

[1]) Natural History Museum (2014), Data Portal. Dataset: Collection specimens. Resource: Specimens. http://data.nhm.ac.uk/object/b874f965-ed05-41fd-9ba0-84fb7690713e

[2]) Converted from given decimal degrees to classical degrees, minutes, and seconds

[3]) Fish trawl survey: Irish Ground Fish Survey for commercial fish species. Data obtained from European Marine Observation and Data Network (EMODnet), Data Portal.

http://www.emodnet-biology.eu/portal/

[4]) Fish trawl survey: Scottish West Coast Survey for commercial fish species. Data obtained from European Marine Observation and Data Network (EMODnet), Data Portal. http://www.emodnet-biology.eu/portal/

[FIGURES]

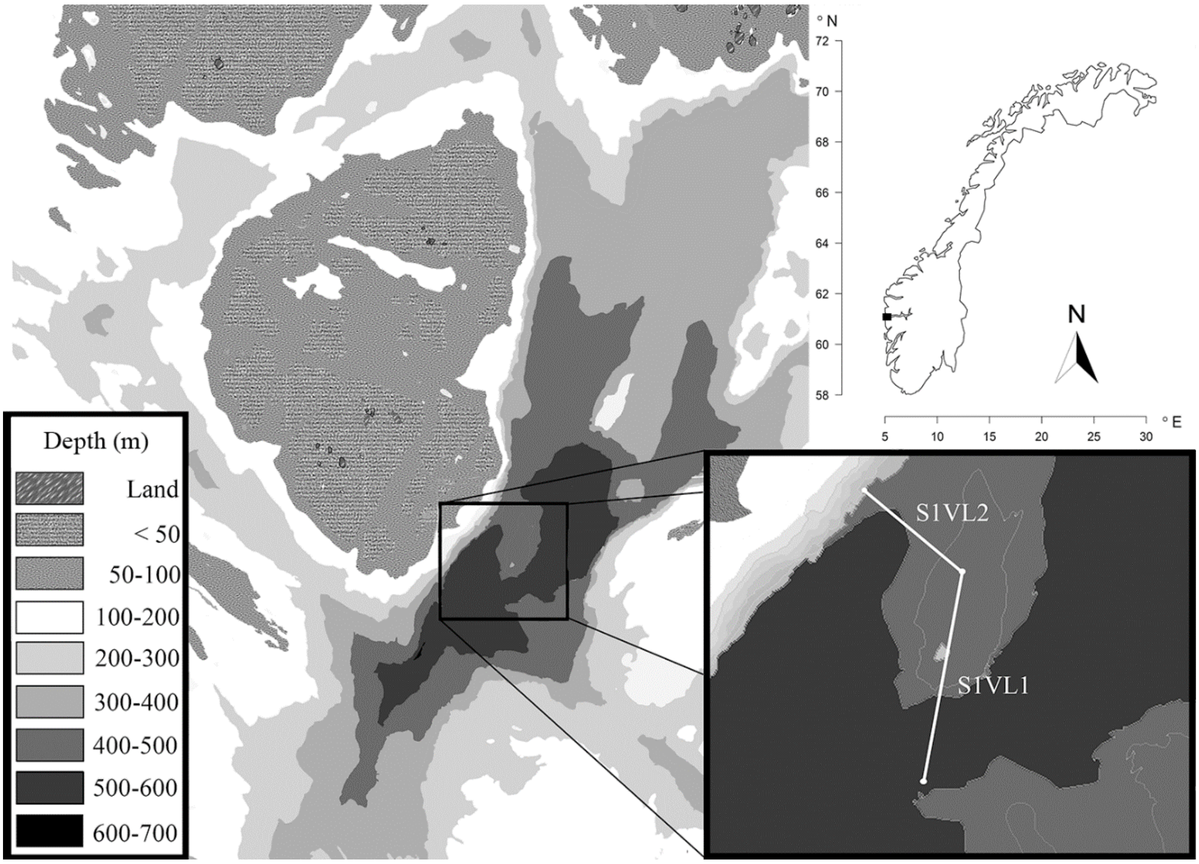

Fig. 1.

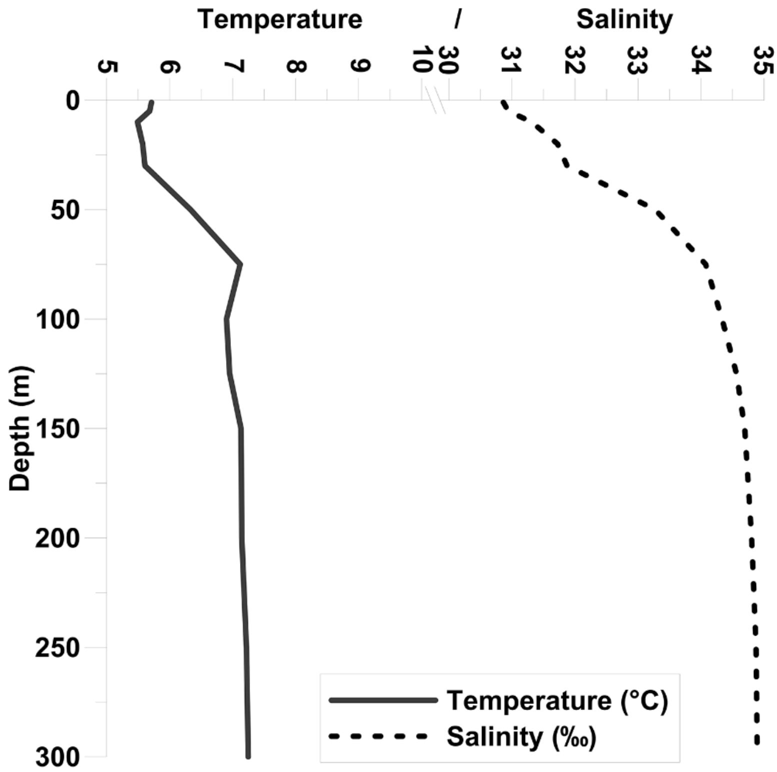

Fig. 2.

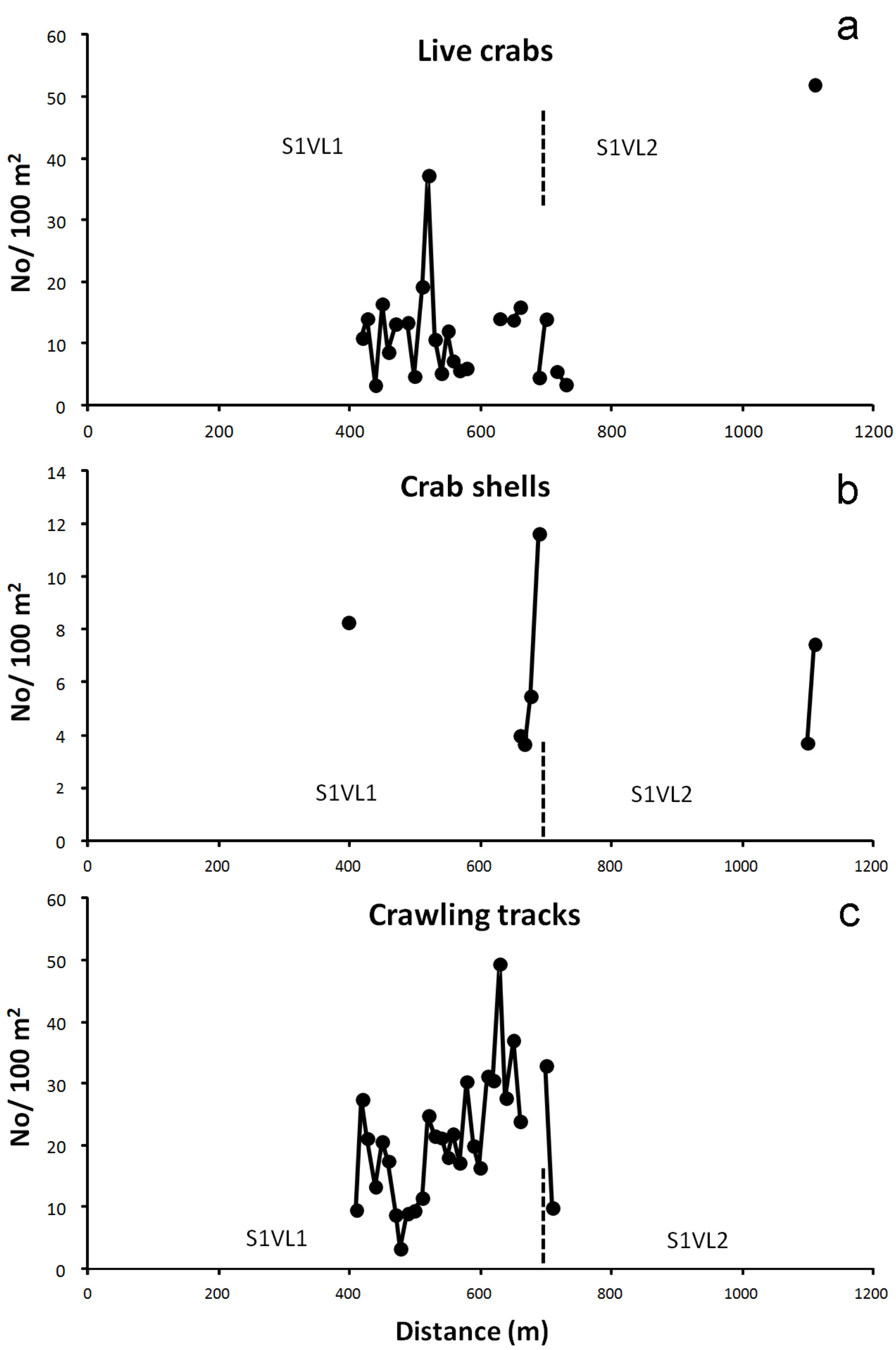
a
Live crabs
S1VL1
S1VL2
No/ 100 m²
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
b
Crab shells
14
12
10
8
6
4
2
0
S1VL1
S1VL2
c
Crawling tracks
S1VL1
S1VL2
Distance (m)

Fig. 3.

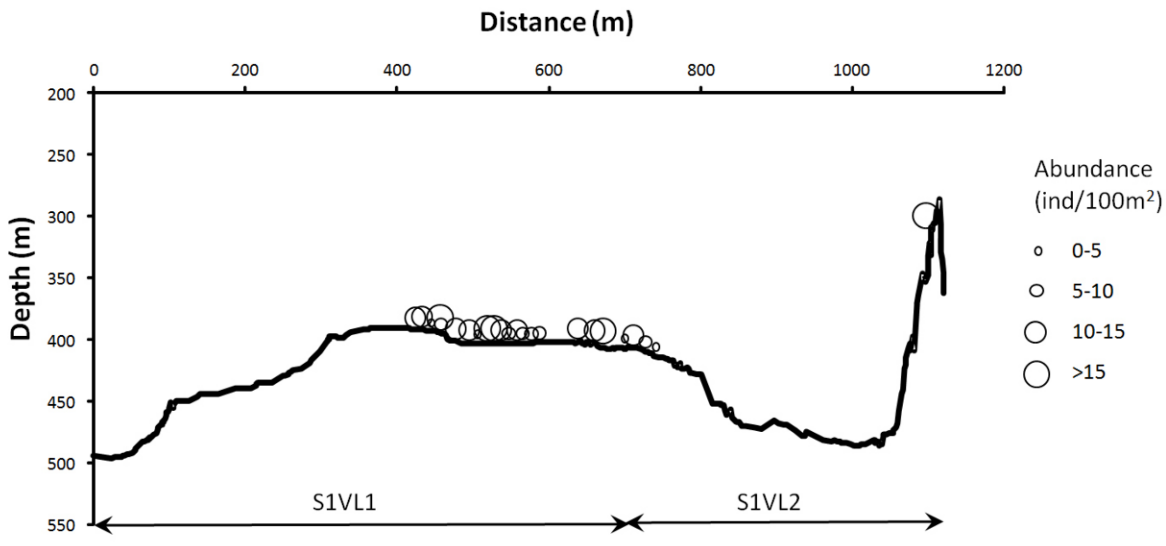
Distance (m)
0
200
400
600
800
1000
1200
Depth (m)
200
250
300
350
400
450
500
550
Abundance (ind/100m²)
0-5
5-10
10-15
>15
S1VL1
S1VL2

Fig. 4.