Effects of reefs on fish communities in the southern North Sea

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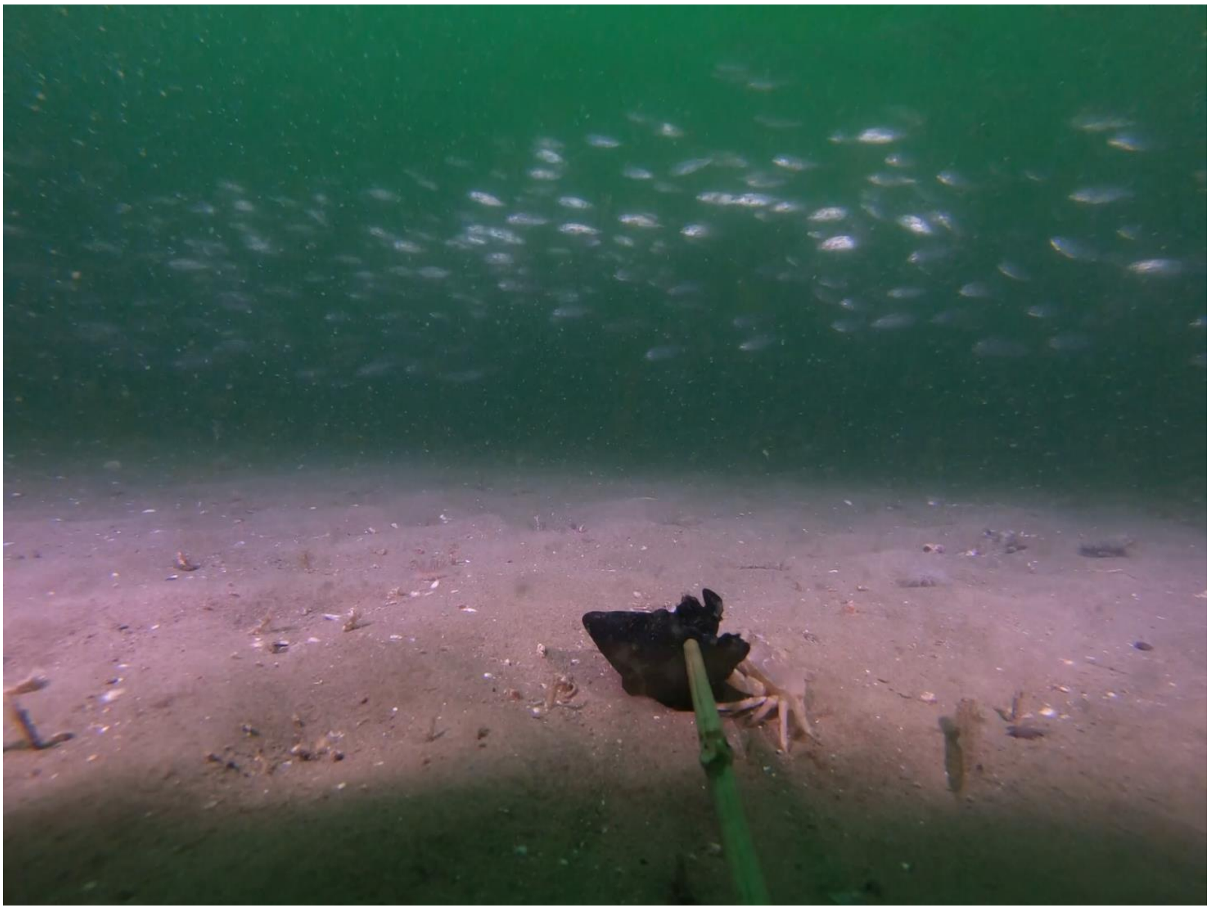

Note: Screenshot of footage from station B07 in the Borkum area, with goby right of bait and school of horse mackerel in the background.

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Abstract

This research investigates the effects of reefs on fish communities in the southern North Sea and indicates whether there could be spillover of fish species of commercial interest. Knowledge on these effects is important to provide background information for projects on oyster reef restoration and can be used in the design of offshore wind farms, which is a relevant topic with various of such projects being executed. To answer the research questions, video footage was analysed from cameras on baited remote underwater video systems placed on sampling stations inside and outside the Voordelta shellfish reef and the Borkum stones area. For each station the number of different species and the maximum number of individuals per species present on the footage was noted. The stations inside the reef were then compared to the stations outside of the reef. In the Voordelta, the species richness and the total abundance was greater inside the reef than outside of the reef. In the Borkum area the species richness and abundance were slightly higher outside of the reef compared to inside of the reef, but not significantly. However, the results of the PERMANOVA of both areas demonstrate that there is a clear distinction between the stations located inside of the reef and outside of the reef. This study concludes that shellfish reefs, like the one in the Voordelta, enhance species richness and abundance, and provide nursery or foraging areas for juvenile horse mackerel and seabass, which are commercial species. In a rocky reef like the Borkum stones area the difference between inside and outside of the reef is less pronounced, but the rocky reef still provides a higher diversity in the entire area and attracts species such as cod and whiting.

Contents

1. Introduction

1.1 Background

The North Sea is the shallow shelf sea off the coasts of The Netherlands. This dynamic system has been under the influence of anthropogenic activities, such as bottom trawling, for centuries (Beaujon, 1885; Lindeboom et al., 2008). As a result, in many areas the seabed substrate that used to consist of rocks, gravel, or vast oyster beds, has changed to soft and sandy (Olsen, 1883; Lindeboom et al., 2008). This is strikingly visible when comparing the maps of Olsen (1883) to maps of the seabed today (figure 1 and 2).

Such hard substrates like rocks or shellfish can form reefs, as by the definition of the European Commission (2013) of reefs. Already 30 years before Olsen made his maps in the 19th century, there were warnings about the declining oyster stocks by Sowerby and Jeffreys (cited in Coolen, 2017). Halfway through the 20th century, oyster stocks were depleted so much that larval recruitment failed and they were not able to sustain themselves anymore, leading to the disappearance of natural oyster reefs in the North Sea (Korringa, 1946). Rocky reefs were also impacted by anthropogenic activities, like trawling or collection by fishermen, who used to move them into deeper water or brought them ashore (Reid, 1913).

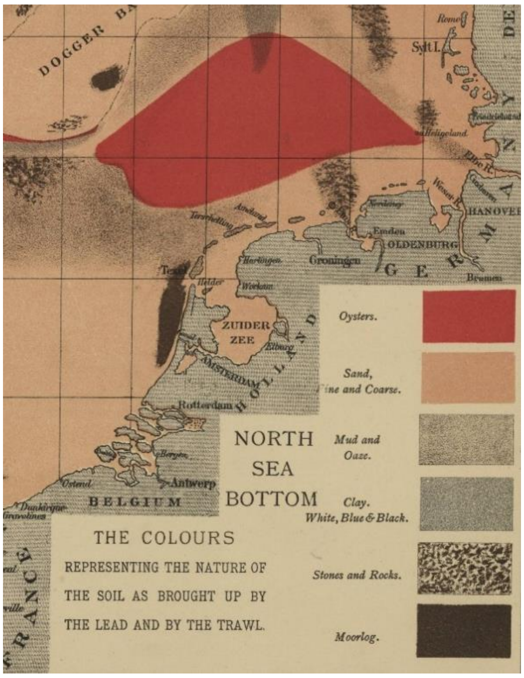


Figure 1: *Part of map by Olsen (1883) showing the North Sea seabed substrate. Red: oysters; pink: sand; fine grey: mud; coarse black: stones and rocks; black: moorlog.*

Figure 2: Map of North Sea seabed substrate today (EMODnet Geology, z.d.). Blue: mud to muddy sand; yellow: sand; dark yellow: coarse substrate; pink: mixed sediment; white and black: no data available.

The disappearance of these natural hard substrates likely had a large impact on fish communities in the North Sea. Shellfish reefs are known to have a significant positive effect on biodiversity and population numbers in fish communities compared to soft seabed, and rocky reefs in an otherwise sandy environment have shown to be able to more than double the local biodiversity (Gilby et al., 2021; Peterson et al., 2003; Bahr et al., 1981; Arve, 1960; Coolen, 2017). These effects on the fish communities in the North Sea were lost with the decline of these substrates. Today, rocky reefs in the North Sea are extensive in the United Kingdom's part, but in the Dutch North Sea they are only present on the Texel Rough, Cleaver Bank and Borkum reef grounds (Beschermde gebieden in de Noordzee, 2019; Veenstra, 1969). There is only one known natural shellfish reef in the Dutch North Sea, which was discovered in the Voordelta in 2016 (Sas et al., 2016).

Similar effects on biodiversity are observed in the presence of artificial reefs, such as shipwrecks and windmills, as they attract species that normally inhabit rocky reefs (Zintzen, 2007; Stenberg et al., 2015; Krone et al., 2017). Seven offshore windfarms have been installed in the Dutch North Sea in the last 15 years, and a lot more are planned for the next decade (Ministry of Economic Affairs and Climate Policy, 2021; Ministerie van Volkshuisvesting, Ruimtelijke Ordening en Milieubeheer, 2022). This could provide new opportunities for the restoration of marine biodiversity and fish populations, also because bottom trawling is not allowed within the windfarms (Rijkswaterstaat, 2020). However, stakeholders from the commercial fishing industry are seeking to explore future possibilities for allowing of fishing activities close to or within offshore windfarms (Schupp et al., 2021).

Reefs can benefit commercial fisheries by providing new adult individuals to the surrounding environment, known as spillover effect, or by serving as nursery and spawning areas increasing larval stocks, known as recruitment effect (Arve, 1960; Di Lorenzo et al., 2016; Reubens et al., 2013; Leitão et al., 2009). In addition, reefs can provide food and shelter for other commercial species (Degraer et al., 2020). Therefore, it is crucial to protect such reefs habitats, as this can ultimately benefit fish stocks. However, what ecosystem services reefs in the southern North Sea provide, and the effect they have on fish communities, is not known.

1.2 Objectives

This study is executed as part of the North Sea Reef Vitalization For Ecosystem Services (ReViFES) project and aims to contribute to the knowledge about the ecosystem services provided by reefs in the southern North Sea. The research questions are the following:

- What is the effect of reefs on fish communities in the southern North Sea?
- To what extent radiates the influence of the reef on fish outwards the reef to the surrounding environment?
- Does this influence lead to spillover of species of commercial interest and how?

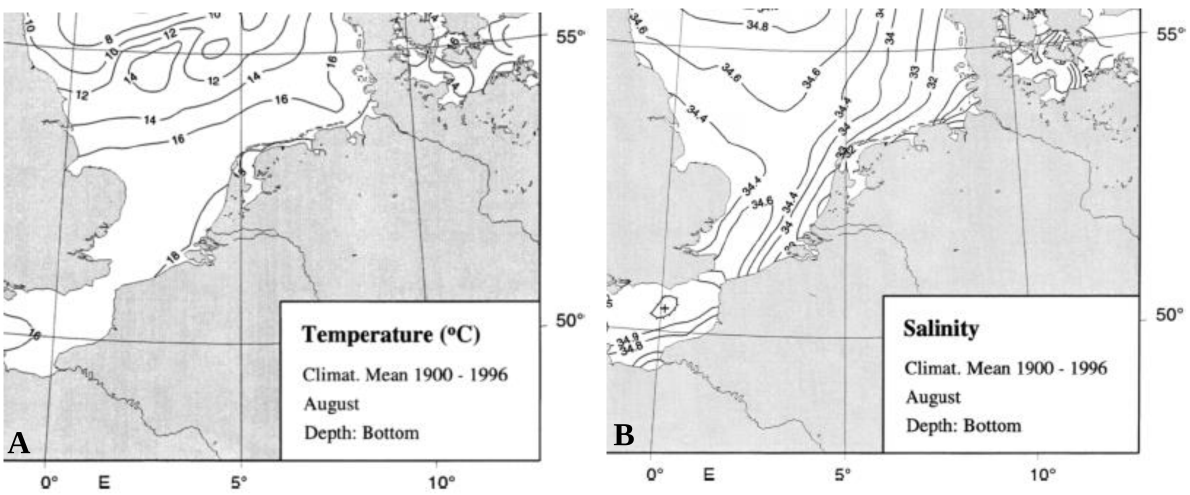
To answer the research questions and assess any effect of the reef on spillover of adult individuals, video footage made with baited remote underwater video systems (BRUVS) from shellfish and rocky reef areas and bare sandy areas was compared. It is expected that the reefs attract fish by providing food and shelter, so species diversity and abundance will be higher inside of the reefs than outside of the reefs. The species that are expected to be present are discussed in the paragraph 'fish species' further down the introduction. Presence of juveniles would be an indication of spillover.

1.3 Research Area

The research was executed in the Voordelta shellfish reef and the Borkum stones area. These areas are located on the Dutch continental shelf, in the southern part of the North Sea where the maximum depth is 50 metres (figure 3 and 4). The shellfish reef is located in the Voordelta, which is a protected Natura 2000 area located off the coast of Zeeland and Zuid-Holland (Voordelta | natura 2000, z.d.). The Borkum reef grounds are located north of Schiermonnikoog, in an area with water depth ranging between 10 and 40 metres (Coolen, 2017).

Figure 3: Aerial view of the Netherlands and the North Sea (Google Earth, 2015-a), with zoom in on the research areas and outline in red of the Borkum stones area at the top (Google Earth, 2015-b) and Voordelta shellfish reef at the bottom (Google Earth 2020-a).

Environmental factors temperature, salinity, and water depth are displayed in figure 4. In the Voordelta, the water depth ranges between 3 and 6 metres. The temperature is between 16 and 18°C and the salinity around 33 PSU during the months of July and August, in which the data collection for this research took place. The water depth in the studied part of the Borkum area ranges between 20 and 25 metres, the temperature is between 14 to 18°C and the salinity is around 32 to 33 PSU in the months of July and August.



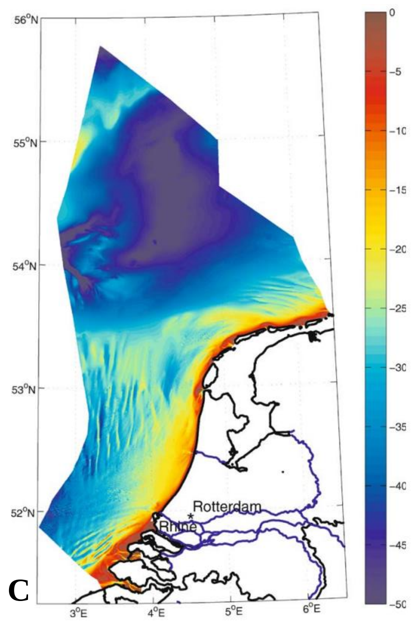


Figure 4.A: Map that displays the bottom temperature in the southern North Sea (Janssen et al., 1999).
Figure 4.B: Map that displays the salinity in the southern North Sea (Janssen et al., 1999).
Figure 4.C: Map that displays the depth in the Dutch North Sea (Knaapen, 2008).

1.4 Fish species

Fish species with commercial interest that are expected to be visible on the video footage are cod (*Gadus morhua*), whiting (*Merlangius merlangus*), herring (*Clupea harengus*), horse mackerel (*Trachurus trachurus*), mackerel (*Scomber scombrus*), seabass (*Dicentrarchus labrax*), sole (*Solea solea*), and plaice (*Peuronectes platessa*). The expectation that these species are visible on the footage and present in the study areas is based on catch rates discussed by Heessen et al. (2015) (figure 5, 6 & 7) and observations of the species in the study areas by Kamermans et al. (2022) and Coolen (2017) (table 1).

Cod and whiting are both demersal fish species of the familie Gadidae (Heessen et al., 2015). Cod is quite an important commercial fish. It is targeted and caught as bycatch and was subject to overfishing in the 1990’s and 2000’s (Heessen et al., 2015; ICES, 2005). It is likely to be present in both the Voordelta and Borkum area based on the catch rates that are displayed in figure 5 and the function of the German Bight as a nursery for juvenile cod (Daan et al., 1990; Heessen et al., 2015). The same applies to whiting, although whiting is less important as a commercial fish species, and generally caught in mixed trawl fisheries with cod and haddock or as bycatch. It is exploited for human consumption, but a substantial part of the catch is discarded at sea as bycatch (Heessen et al., 2015; ICES, 2005). Both species feed on fish among other things, so it is also expected that they will be attracted to the bait, which is mackerel.

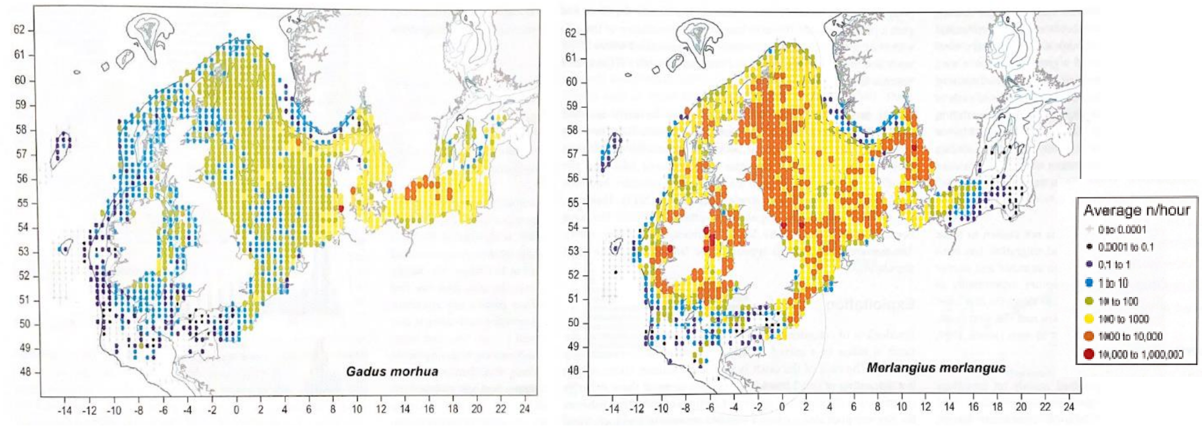


Figure 5: Catch rates of cod (Gadus morhua) and whiting (Merlangius merlangus) in the Celtic Sea, North Sea, and Baltic Sea by Heessen et al. (2015).

Herring, horse mackerel, mackerel, and seabass are pelagic fish species that are of considerable economic value. Herring stocks even collapsed in the 1970s due to overfishing. Seabass is one of the most valuable fish species caught in Europe, and a key species for Ireland, the United Kingdom, France, Belgium, and the Netherlands (European Market Observatory for Fisheries and Aquaculture Products (EUMOFA), 2021). Horse mackerel fisheries on the other hand mainly target the western stock, which is distributed from the Bay of Biscay, west of the United Kingdom, to the Norwegian Sea. Still, horse mackerel of the North Sea stock overwinters in the English Channel, within the boundaries of the western stock, so it is hardly possible to assign landings to the specific stocks (Heesen et al, 2015; ICES, 2005). These 4 species could be visible on the video footage based on their distribution (figure 6). However, these species are pelagic, and the video systems are deployed on the bottom of the sea, so this could result in them not being in the vertical range of the camera. In addition, herring is not expected to be attracted to the bait, since herring feeds on zooplankton instead of other fish.

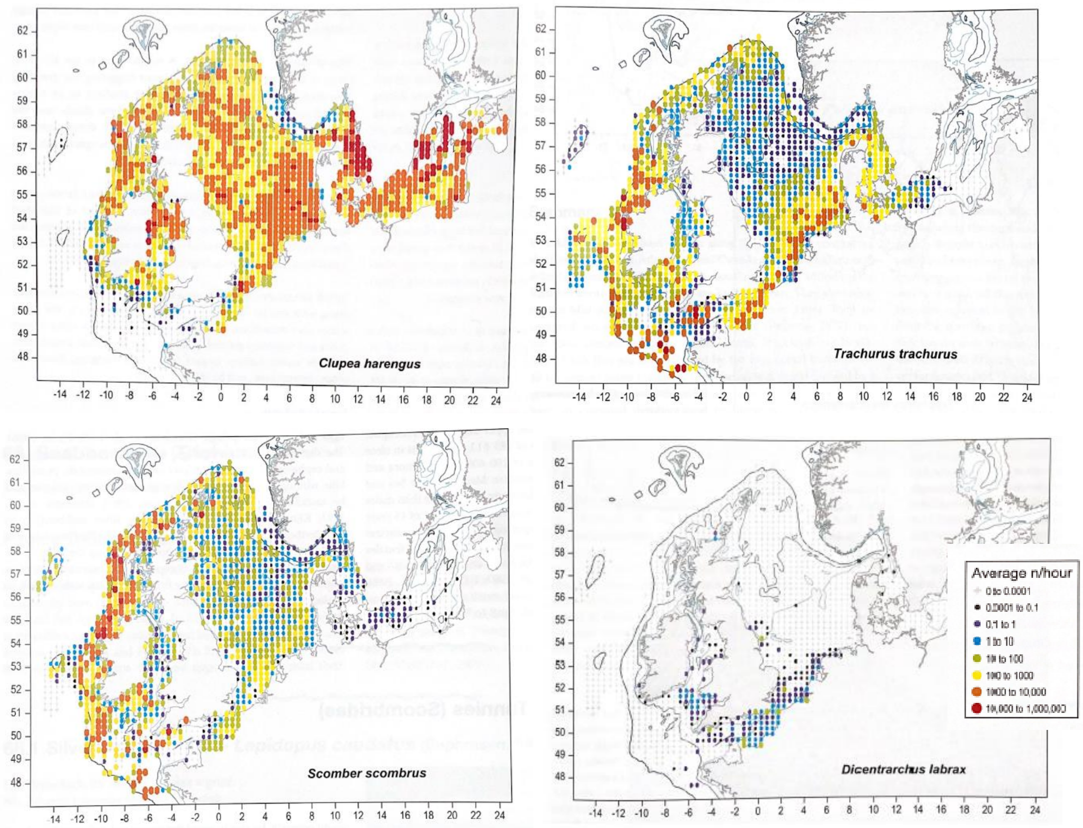


Figure 6: Catch rates of herring (Clupea harengus), horse mackerel (Trachurus trachurus), mackerel (Scomber scombrus) and seabass (Dicentrarchus labrax) in the Celtic Sea, North Sea, and Baltic Sea by Heessen et al.

Plaice is a very important species for Dutch fisheries and is quite abundant in the southern North Sea, so based on catch rates shown in figure 7 it is expected to see plaice on the footage (Plaice - NIOZ, z.d.). In addition, the Borkum area falls in the so called ‘plaice box’, which is an area where fishing is partially prohibited to protect juvenile plaice. Sole is also a fish species of commercial interest, but it is less abundant in the southern North Sea. However, the catch rates in figure 7 could underestimate the true abundance, because sole are active during night and buried in the sediment during the day, and the surveys were done during the day (Heessen et al., 2015). This behaviour could also result in sole not being visible on the footage. In addition, these species generally inhabit sandy bottoms, so they are likely not positively influenced by the reef.

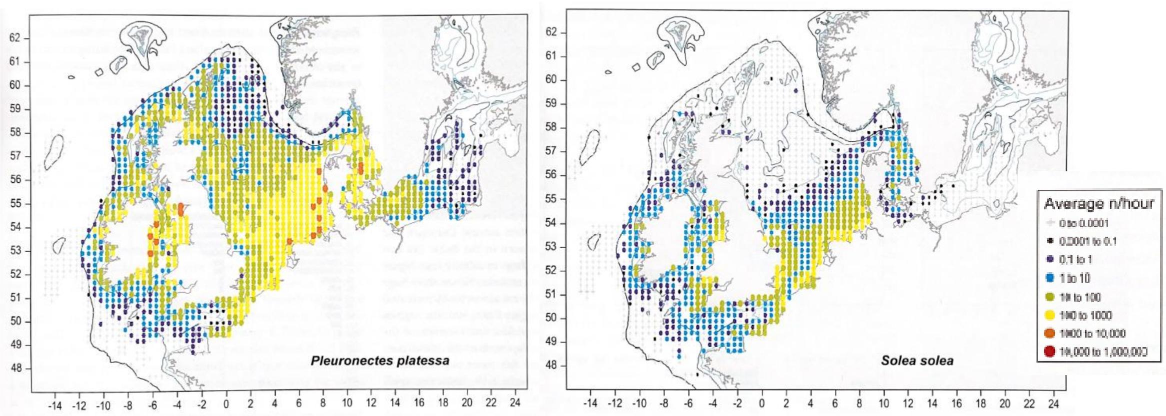


Figure 7: Catch rates of plaice (Pleuronectes platessa) and sole (Solea solea) in the Celtic Sea, North Sea, and Baltic Sea by Heessen et al. (2015).

In addition to these commercial species, there are over 200 fish species in the North Sea, part of which could be present in the research areas and on the video footage (Daan et al., 1990; Teal, 2011). Species that have been observed before in the Voordelta and Borkum area are listed in table 1.

Table 1: Fish species that have been observed in the Voordelta by Kamermans et al. (2022) and Borkum reef area by Coolen (2017).

Scientific name	Common name	Area of occurrence
Raja clavata	Thornback ray	Voordelta
Aphia minuta	Transparant goby	Voordelta
Gobius Niger	Black goby	Voordelta
Gobius paganellus	Rock goby	Voordelta
Gobiusculus flavescens	Two-spotted goby	Voordelta
Pomatoschistus spp.	Sand gobies	Voordelta and Borkum
Atherina boyeri	Big-scale sand smelt	Voordelta
Atherina presbyter	Sand smelt	Voordelta
Callionymus reticulatus	Reticulated dragonet	Voordelta
Callionymidae	Dragonet family	Borkum
Dicentrarchus labrax	Sea bass	Voordelta
Entelurus aequoreus	Snake pipefish	Voordelta
Syngnathus acus	Greater pipefish	Voordelta
Syngnathus rostellatus	Nilsson’s pipefish	Voordelta
Myoxocephalus scorpius	Short-spined sea scorpion	Voordelta
Taurulus bubalis	Long-spined bullhead	Voordelta
Parablennius gattorugine	Tompot blenny	Voordelta
Pholis gunnellus	Butterfish	Voordelta
Platichtys flesus	Flounder	Voordelta
Microstomus kitt	Lemon sole	Borkum
Symphodus melops	Corkwing wrasse	Voordelta
Ctenolabrus rupestris	Goldsinny wrasse	Borkum
Trisopterus luscus	Bib	Voordelta
Zoarces viviparus	European eelpout	Voordelta
Agonus cataphractus	Pogge	Borkum
Liparis liparis	Sea-snail	Borkum

2. Materials and Methods

There are multiple methods to sample fish communities, such as trawling (Wassenberg et al., 1997), longlining (Løkkeborg & Bjordal, 1992), underwater visual census (Sale & Douglas, 1981; Samoilys & Carlos, 2000; Stewart & Beukers, 2000), and baited remote underwater video systems (BRUVS) (Priede et al., 1994). Which method is most suitable depends on the habitat and size of the fish. BRUVS are most suitable when the habitat is difficult to access, such as in the deep sea (Priede & Bagley, 2000), when the habitat is sensitive or protected and traditional fishing gear is too destructive, such as a reef (Farnsworth et al., 2007), and/or when the fish species are small or cryptic (Stoner et al., 2008). Because BRUVS are a non-invasive method, the research areas are reefs, and the Voordelta shellfish reef is a protected area, BRUVS are the most suitable method to sample the fish communities in this research.

The video footage for this study was taken during two research cruises: one from the 4th to the 17th of July 2022 at the Borkum Reef grounds and one from the 2nd to the 9th of August 2022 at the Voordelta shellfish reef (figure 3). The video footage was taken using GoPro Hero 7 and GoPro 9 cameras, baited with frozen mackerel. The bait was placed into a nylon stocking and attached to the camera structure using a bamboo stick. The system was combined with 2 lights and attached to a crab cage used to sample other mobile species on the cruise to the Borkum reef (figure 4). In the Voordelta a construction made of PVC pipes filled with gravel was used (figure 5). The PVC pipe construction was attached with a line to a floating device in the form of plastic PET bottles spray painted with fluorescent green paint. Because the depth at the Borkum reef ranges from 10 to 40 metres, and the depth at the Voordelta does not exceed 5 metres, the camera systems are different and lamps were only necessary at the Borkum reef.

Figure 8: GoPro and bamboo stick with bait attached to the bottom of the cage, and two LetonPower lights attached right and left to the top of the cage.

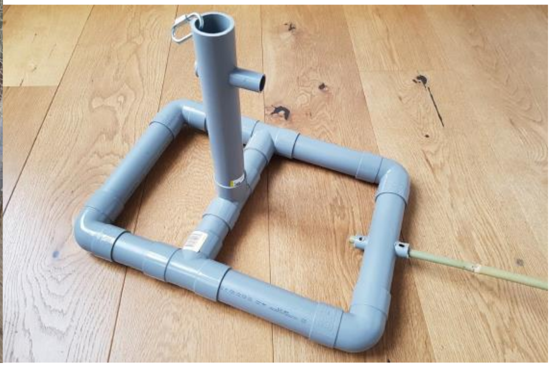


Figure 9: Frame of PVC pipes with bamboo stick to attach bait on the right and smaller pipe through the vertical pipe to attach the camera.

In the Borkum reef, footage was taken in 2 transects consisting of 8 stations. The first 3 stations were located inside the reef, and the others were located outside of the reef with increasing distance from the reef. In the Voordelta, footage was taken from 6 transects (A, B, C, D, E and F) with 10 stations each. Of transects A, B, C and D, stations 1 to 3 are located on the reef, station 4 on the edge of the reef, and stations 5 to 10 are located outside of the reef with increasing distance from the edge of the reef. Transects E and F are located north of the reef, parallel to the other transects, to assess the influence of distance from shore on the results. Footage was taken in two ways: in- and outside the reef and along the transects. For the in- and outside method 12 cameras were deployed on station 1, 3 and 10 of transect A, B, C and F. This was repeated 5 times, twice with low water, twice with high water, and once in between the high and low water. This method was used to be able to easily analyse whether there is an effect of the reef on fish communities. The along transects method was executed once on all transects, and twice on transect A, on stations 1, 3, 5, 7, 9 and 10. The tidal conditions were low water every time. The cameras recorded for 60 to 120 minutes. After retrieval of the cages and constructions, the content of the SD memory card of the cameras was downloaded and emptied and the batteries charged. Due to time constraints, in this research only in- and outside footage taken on the 5th of August in 2022 in the Voordelta, and footage taken in stations 1, 3, 7 and 10 of both transects on the 12th and 14th of July in 2022 in the Borkum area, was analysed. As a result, the question regarding the extent of reef influence cannot be answered in this thesis. The transects and deployment stations are displayed in figure 10.

Figure 10: Aerial view of the transects in the Voordelta on the left (Google Earth, 2020-b) and the Borkum area on the right (Google Earth, 2015-c). Dots indicate the stations, with station 1 on the right and station 10 on the left. Yellow line indicates transect A and blue line indicates transect B in both areas, and in the Voordelta transect C is red and transect F is green.

To analyse the footage, the number of fish species and number of individuals per species in view was noted for each second of footage. For each station an hour of footage was analysed, because this was the minimum amount of footage that was available for each station. In addition, certain behaviour was noted, such as baiting, protective behaviour over bait, and shoaling behaviour. Protective behaviour means that an individual would chase others away from the bait, and shoaling behaviour means that multiple individuals would swim together and form a shoal. From this information, the species richness, the maximum number of individuals per species in view during the entire length of the video (MaxN), and the time of first arrival of the species (T1st) was extracted for statistical analysis. MaxN is the most common metric used in studies with BRUVs and is useful for assessing the relative abundance of species and comparing spatio-temporal differences in aquatic assemblages (Stoner et al., 2008; Whitmarsh et al., 2016). T1st is the measure of how fast species are first observed in the video. T1st is short when the abundance and MaxN of a species is high (Stobart et al., 2015; Parker & DeMartini, 1995). However, it needs to be considered that T1st can be influenced by the distance the organisms have to travel to get to the BRUVS and how attracted they are to the bait, which can vary between species (Whitmarsh et al., 2016).

The species were identified with help of the Fish atlas of the Celtic Sea, North Sea, and Baltic Sea by Heessen et al., (2015) and help of Dennis Mosk of the department of Coastal Systems at NIOZ. The data of the different stations were compared to detect differences between species richness, which species are present, and the abundance of the species. These variables were analysed by permutational analysis of variance (PERMANOVA), based on the Bray-Curtis distance and with MaxN as abundance per species in RStudio. The results were visualised in non-metric multidimensional scaling plots (nMDS) in which each dot represents a station and the distance between the dots represents how different the diversity between the stations is. The differences and similarities were explained by analysing the species richness and abundance with a T-test or Wilcoxon test, depending on the distribution of the data. In addition, these variables were visualised in barplots. The abundance of horse mackerel in the Borkum area was very high, so was halved in all stations to display the relative distribution, while also keeping the barplots readable. T1st was visualised in a scatterplot and also analysed with T-test and Wilcoxon test. The relationship between T1st and MaxN was determined with a kendall test. In addition, the abundance of species was plotted over the time of the video to visualise what happened in the footage (appendix A).

3. Results

3.1 Voordelta shellfish reef

In the Voordelta there were 4 fish species present on the camera footage. These species were gobies (*Pomatoschistus spp.*), horse mackerel (*Trachurus trachurus*), seabass (Dicentrarchus labrax) and sand smelt (*Atherina sp.*) (figure 11). The presence and abundance of the species is displayed in figure 12.

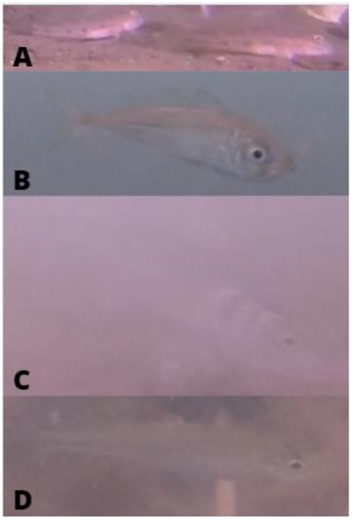


Figure 11: Best available screenshots of the species present in the Voordelta shellfish reef.
A: Gobies. Image is from Borkum area, because no clear screenshots of gobies could be taken from Voordelta footage.
B: Juvenile horse mackerel.
C: Sea bass.
D: Sand smelt.

Gobies were present in all stations, except for station F10, with a MaxN of 1 to 6 inside of the reef and 1 to 3 outside of the reef. The group 'gobies' consists of species within the group Gobiidae, likely species of the genera *Pomatoschistus Gobius* and *Gobiusculus*. They were grouped together because individuals were not always clearly visible on the footage, which made recognition of different species impossible in these cases, and individuals of different species within the group Gobiidae are difficult to identify accurately (Heessen et al., 2015). Juvenile horse mackerel were present in all stations inside of the reef in school of up to 10 individuals. They were present in 2 out of 6 stations outside of the reef, with a MaxN of 2 in station F03, and MaxN of 23 in station A10. Seabass was present in 5 stations inside of the reef, with a MaxN of 1. Sand smelt was only present in station A01, with a MaxN of 2.

The median of the total abundance was not significantly different inside the reef compared to outside the reef ($p = 0.17$). However, the abundance of horse mackerel was exceptionally high in station A10 compared to the other stations. When this outlier was removed from the analysis, there was a significant difference in median abundance between the inside and outside stations ($p = 0.034$). Except for station A10, the general abundance was lower outside of the reef than inside the reef.

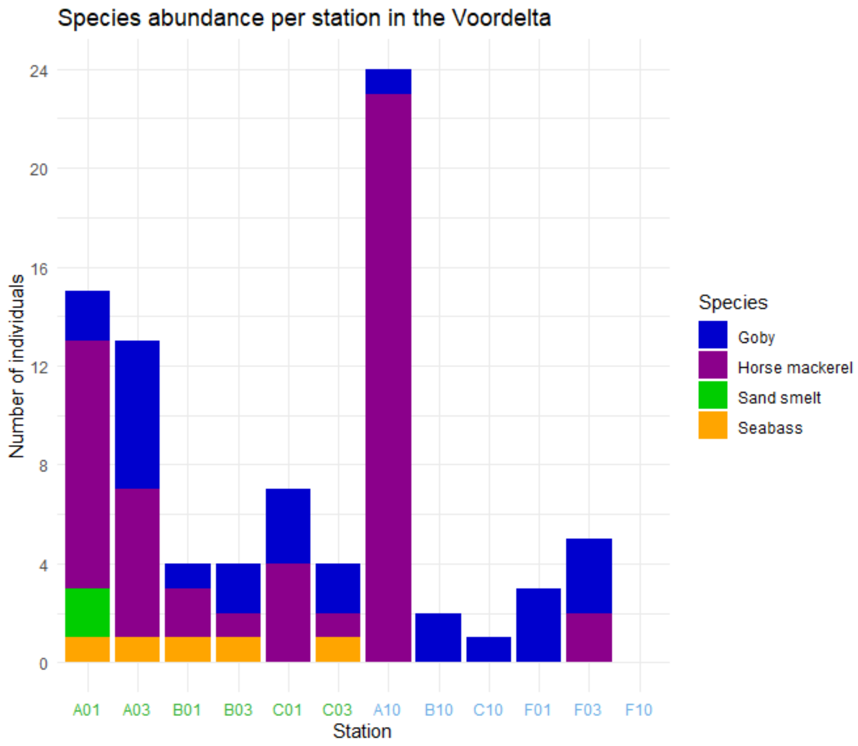


Figure 12: Number of individuals per species and per station in the Voordelta area. Axis labels in green are stations inside of the reef and labels in blue are stations outside of the reef.

The time of first arrival of the species is displayed in figure 13. There was a large variance in the T1st of the species per station. Inside the reef, the T1st of gobies varied between 01:51 (mm:ss) and 41:35, and outside of the reef between 01:35 and 16:58. The T1st of horse mackerel inside of the reef varied between 04:35 and 57:15, and 05:21 and 28:22 outside of the reef. The T1st of seabass ranged between 07:16 and 51:18 and that of sand smelt was 48:09. There was a significant difference in median T1st between the inside and outside of the reef ($p = 0.01$).

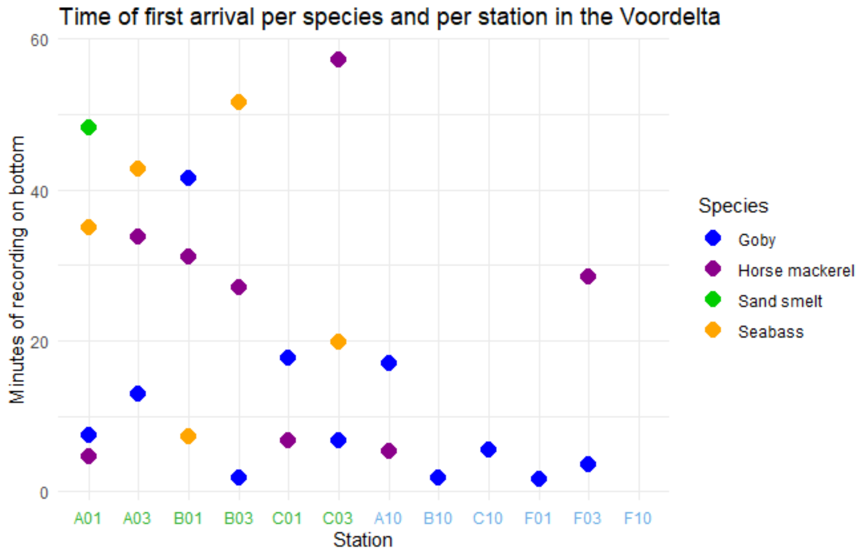


Figure 13: Time of first arrival in minutes per species and per station in the Voordelta area. Axis labels in green are stations inside of the reef and labels in blue are stations outside of the reef.

The species richness per station is displayed in figure 14. There was a significant difference between mean species richness inside and outside of the reef (p = 0.001). Richness was generally higher inside the reef, where it ranged from 2 to 4 different species, than outside the reef, where it ranged from 0 to 2 species.

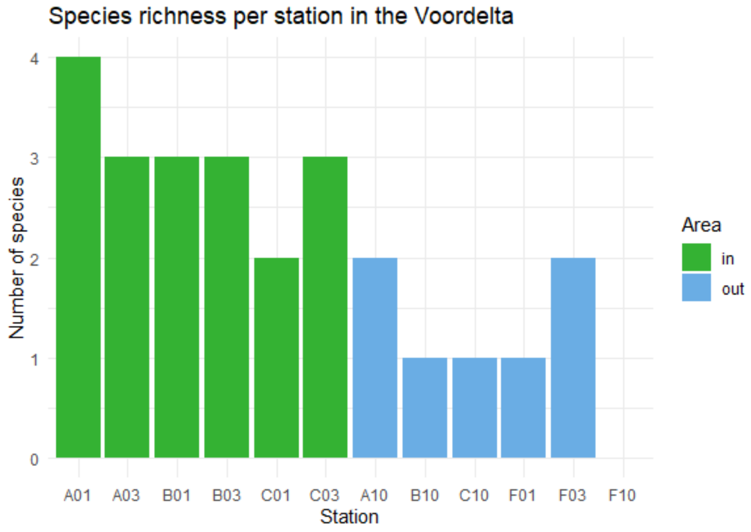


Figure 14: Number of species per station in the Voordelta area.

3.2 Borkum stones area

There were 10 fish species present on the footage in the Borkum stones area which are shown in figure 15. These species were gobies (*Pomatoschistus spp.* and *Gobius spp.*), horse mackerel (*Trachurus trachurus*), whiting or cod (*Gadus morhua* or *Merlangius merlangus*), flatfish (Pleuronectidae), crystal goby (*Crystallogobius linearis*), goldsinny wrasse (*Ctenolabrus rupestris*), gurnard, bib or poor cod (*Trisopterus sp.*), Butterfish (*Pholis gunnellus*) and pipefish (*Syngnathus sp.*). Their presence and abundance in and outside of the Borkum reef is displayed in figure 16.

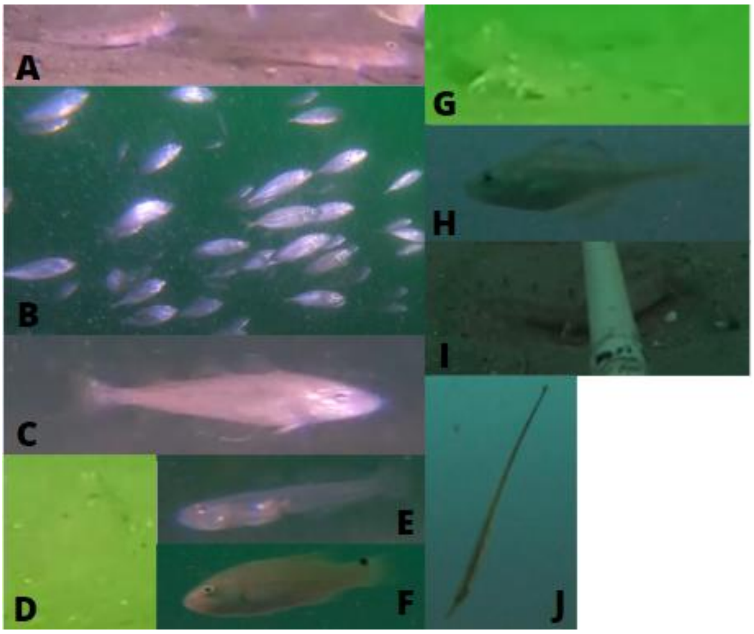


Figure 15: Best available screenshots of the species present in the Borkum area.
A: Gobies; B: Horse mackerel; C: Whiting/cod; D: flatfish; E: Crystal goby; F: Goldsinny wrasse; G: gurnard; H: Bib/poor cod; I: Butterfish; J: Pipefish

Like in the Voordelta, the group 'gobies' is a combination of species of the group Gobiidae, and genera *Pomatoschistus* and *Gobius.* Gobies were present in all stations in the Borkum area, and their MaxN ranged from 3 to 6 inside of the reef, and 1 to 4 outside of the reef. The horse mackerel were adults and present in schools of up to 96 individuals. They were present in 6 out of 8 stations, of which 3 inside the reef and 3 outside the reef. Another fish that was quite abundant is whiting or cod (D. Mosk, personal communication, February 7, 2023). They were present in 6 stations, of which 4 inside the reef and 2 outside the reef. The MaxN was 1 or 2 inside the reef, and 1 and 4 outside of the reef. Like the gobies, these individuals were not always clearly visible and whether they are cod or whiting is difficult to determine. Flatfish were present in 1 station inside the reef and 3 stations outside of the reef, with a MaxN of 1 each time. They were visible from the side, thus hard to identify, but they were all likely of the family Pleuronectidae (D. Mosk, personal communication, February 7, 2023). The other species were less abundant. Crystal goby was present in 1 station inside the reef and 2 stations outside the reef, with a MaxN of 1. Goldsinny wrasse was present in 2 stations inside of the reef with a MaxN of 1. A fish gurnard (Triglidae) was present in 2 stations outside of the reef, with a MaxN of 1. One individual of juvenile *Trisopterus sp.* was present in one station inside of the reef. Butterfish and *Syngnathus sp.*, which is a genus of pipefish, were present together in 1 station outside of the reef.

There was no significant difference between the total abundance inside the reef and outside the reef ($p = 0.967$). The total abundance ranged from 7 to 89 inside the reef, and 7 and 101 outside of the reef, so it was higher outside of the reef, but not significantly.

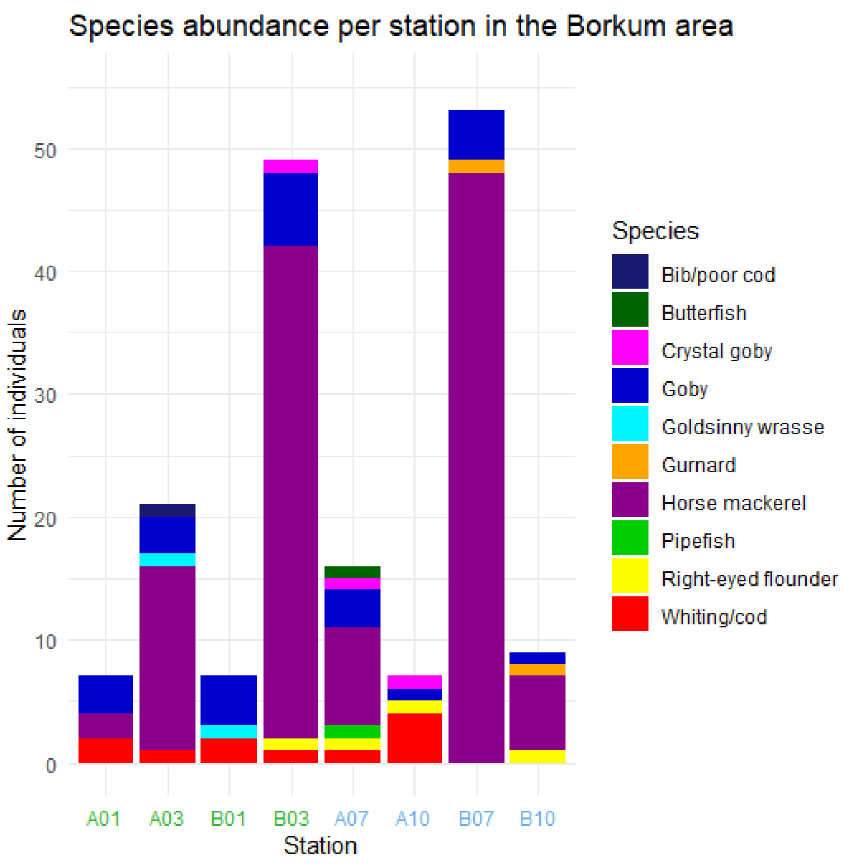


Figure 16: Number of individuals per species and per station in the Borkum area. Axis labels in green are stations inside of the reef and labels in blue are stations outside of the reef.

The T1st per species and per station is displayed in figure 17 and the richness per station in figure 18. The species richness ranged from 3 to 5 species inside the reef and 3 to 7 species outside of the reef. The T1st of gobies inside of the reef was between 00:00 and 13:54, and outside of the reef between 02:41 and 26:50. For horse mackerel it ranged from 10:14 to 47:58 inside and 00:48 to 50:10 outside of the reef. T1st of whiting/cod ranged from 00:11 to 48:07 inside of the reef and is 11:11 and 20:29 in the two stations outside of the reef. The T1st of flatfish was 20:06 inside of the reef and between 21:15 and 27:33 outside of the reef. Crystal goby's T1st was 8:14 inside of the reef and 25:00 and 30:06 outside of the reef. The T1st of goldsinny wrasse was 05:07 and 26:07 and that of gurnard was 16:26 and 58:49. Butterfish, pipefish and bib/poor cod were present in only one station, and their T1st were 26:00, 49:06 and 37:22 respectively. There was no significant difference between the T1st of the species ($p = 0.42$) and median richness ($p = 0.881$) inside and outside the Borkum reef. The species richness was slightly higher outside of the reef than inside of the reef, but not significantly.

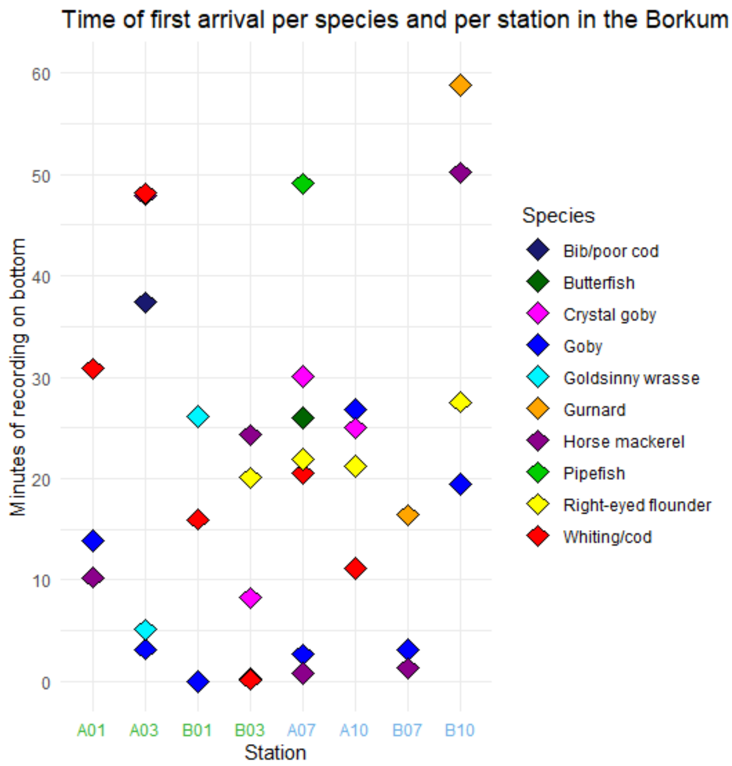


Figure 17: Time of first arrival in minutes per species and per station in the Borkum area. Axis labels in green are stations inside of the reef and labels in blue are stations outside of the reef.

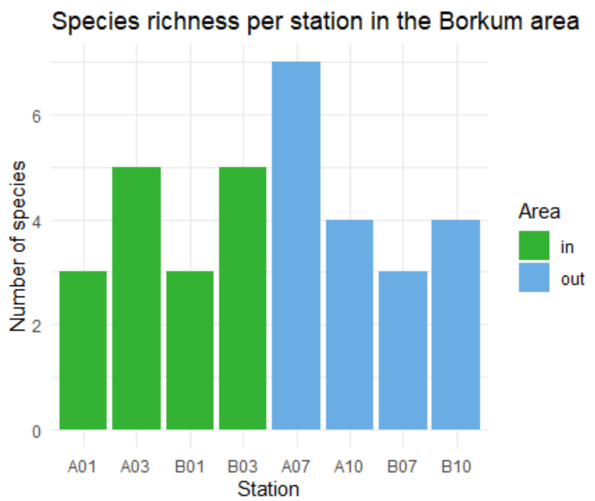


Figure 18: Number of species per station in the Borkum area.

3.3 PERMANOVA and correlation analysis

The results of the PERMANOVA are displayed in figure 19. Station F10 is left out of the Voordelta PERMANOVA, because there were no fish present in that station, thus no observations. In the Voordelta plot, stations B03 and C03 are so similar that they overlap, and so are stations F01, B10 and C10. There is no obvious clustering of stations that are all either in- or outside of the reef, except for B01, B03 and C03 inside and F01, B10 and C10 outside of the Voordelta reef. However. there is still a notable distinction between stations located inside and outside of the reef, except for station C01 which appears to be more similar to the outside stations than the inside stations. The same applies to the Borkum plot. A notable distinction between the inside and outside stations is visible, except for station B03 which appears to be more like the outside stations.

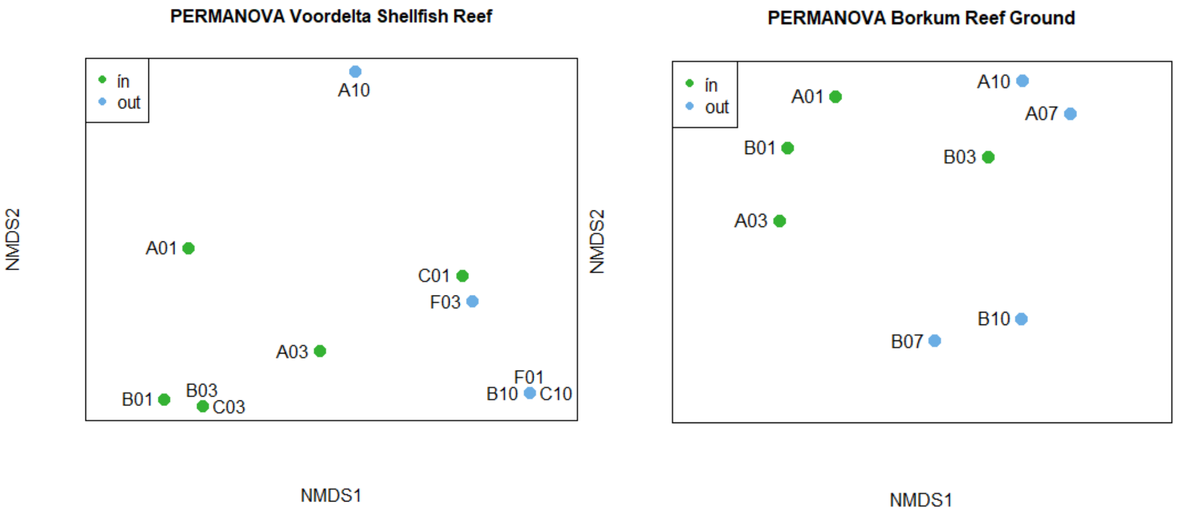


Figure 19: Results of PERMANOVA in non-metric multidimensional scaling plots.

For both study areas, the abundance of species was plotted against T1st to display a possible correlation between the variables (figure 20). In the Voordelta there was no significant correlation between the two (p = 0.11), and in the Borkum area there was a slight negative correlation with a correlation factor of -0.32 (p = 0.02).

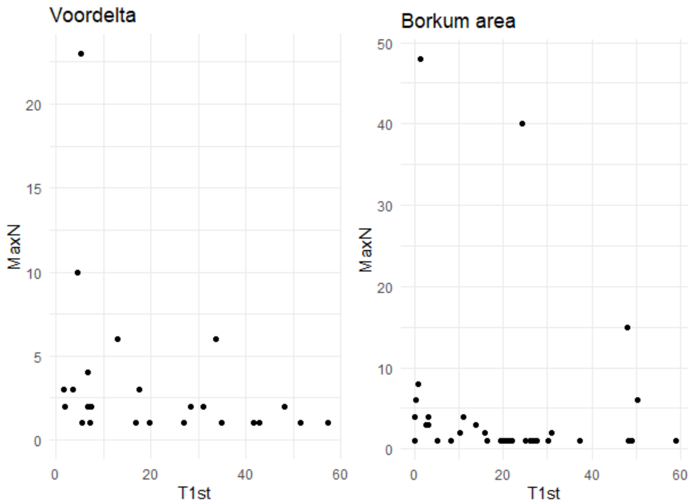


Figure 20: MaxN against T1st in study areas.

4. Discussion

4.1 Summary

The aim of this research was to investigate the effects of reefs on fish communities in the southern North Sea, to assess to what extent these effects radiate towards the surrounding environment, and whether there is spillover of species of commercial interest. To reach these objectives, video footage was analysed from cameras on baited remote underwater video systems placed inside and outside two reef areas in the southern North Sea. The research areas were the Voordelta shellfish reef and Borkum stones area. In these areas an equal amount of sampling stations inside the reef and outside of reef were designed, and for each station the maximum number of individuals per species and the number of different species present on the footage was noted. The stations inside the reef were then compared to the ones outside of the reef. The expectation was that the species diversity and abundance would be higher in the stations inside of the reef compared to the stations outside of the reef, because of the attraction of the reef on fish by providing food and shelter.

The results from the Voordelta indicate that species richness and abundance is significantly greater inside of the reef than outside of the reef. This is not the case in the Borkum reef area, where the abundance and richness are slightly higher outside of the reef than inside of the reef, but not significantly. However, the results of the PERMANOVA of both areas demonstrate that there is a clear distinction between the stations located inside of the reef and outside of the reef, except for 1 station inside of both the reefs that is closer to the outside stations. There is no correlation between T1st and MaxN in the Voordelta, and only a weak correlation in the Borkum area. MaxN is the more robust indicator for abundance, so the focus lies on MaxN.

4.2 Interpretations

4.2.1 Voordelta

The results of the PERMANOVA of the Voordelta showed that there is a distinction between the inside and outside stations (figure 19). This can be explained by the significant difference in species richness and abundance between the inside and outside stations. Station C01 is the only station inside of the reef where seabass is not present and the species richness is 2, and this might explain why this station is closer to the outside stations than the other inside stations in the plot. It is especially close to station F03, which is likely because the abundance is slightly less in station F03, but the species composition is the same. The distance in the PERMANOVA between the stations in the same area, meaning the area inside the reef or outside of the reef, can be explained by the differences in abundance of species, see figure 12. Station B01 has the same species composition as stations B03 and C03, but the abundance of horse mackerel and gobies is different, which explains why it is not located in the same spot as B03 and C03 in the PERMANOVA.

The results from the Voordelta are in line with the hypothesis that fish species richness and abundance are higher inside the shellfish reef than on the sandy bottom, as expected and described by previous studies (Arve, 1960; Peterson et al., 2003; Gilby et al., 2021). Especially seabass and juvenile horse mackerel seem to prefer the reef habitat over the sandy habitat, because seabass was exclusively present in stations inside of the reef and horse mackerel was present in all stations inside the reef, and 2 out of 6 stations outside of the reef.

Both species are not known for specifically inhabiting reefs (Heesen et al, 2015). However, seabass feed on small fish and crabs, which makes the shellfish reef a good place for foraging (Kousoulaki et al, 2015). For horse mackerel the Voordelta shellfish reef seems to act as a nursery, even though specific nursery areas do not seem to exist, according to Ellis et al. (Cited in Heesen et al, 2015). On the other hand, recent studies indicate that nearshore reef environments might be important nursery areas for juvenile horse mackerel in Portugal (Klein et al., 2018).

Other environmental factors could be of influence on the distribution of seabass and horse mackerel in the area, such as temperature, salinity, distance from shore, and water depth. However, temperature and salinity do not vary significantly on such a small scale, and both species do not seem to be influenced by these factors in their spatial distribution (figure 4.A, 4.B, and 6). The distance from shore at the stations is displayed in table 2. Seabass was present in stations with distance from shore ranging from 180 metres to 390 metres and absent in stations with distance from shore ranging between 130 and 740 metres. Horse mackerel was only present in station 3 in transect F, while it was present in stations 1 and 3 in the other transects, and even in station 10, the furthest station, of transect A. Thus, distance from shore does not appear to be of influence on the distribution of seabass and horse mackerel in this study. The water depth at all stations is displayed in table 2. The depth where both species were present ranged from 4.8 to 5.6 metres, and the depth where both species were absent ranged from 4.3 to 5.5, so depth is also likely not affecting the distribution of the species in this study.

Table 2: Distance from shore and water depth at time of deployment of camera systems at Voordelta stations in metres.

Station	A01	A03	A10	B01	B03	B10	C01	C03	C10	F01	F03	F10
Depth	5.5	4.8	5.5	5.6	5.2	4.5	5.6	5.2	4.3	5.2	5.5	5.1
Distance from shore	180	390	740	210	320	630	200	320	620	130	200	480

4.2.2 Borkum stones area

In the Borkum area there is also a distinction between the inside and outside stations visible in the PERMANOVA, but this cannot be explained by the species richness or total abundance, because there are no significant differences between these variables in the different areas. An explanation for the results of the PERMANOVA could be the species composition in the different areas. There were 3 species exclusive to the stations outside of the reef, namely butterfish, pipefish, and gurnard, and 2 species exclusive to the stations inside the reef, namely goldsinny wrasse and *Trisopterus sp.* There were also certain species that were more abundant either in the inside or outside area, compared to other species. For example, flatfish and crystal goby were overall more abundant in the outside stations, and whiting/cod were more abundant in the inside stations. These scattered species occurring in both areas, could explain why there is still a distinction between the areas in the PERMANOVA (figure 19), even though number of species and total abundance in the stations inside of the reef is similar to the stations outside of the reef.

Goldsinny wrasse is known to inhabit areas with rocks, mainly along the Western coast of the British Isles (Reeds, 2004). Their diet consists of benthic crustacea and molluscs, which they prey in rocky environments. The individual belonging to the genera *Trisopterus* is likely of the species bib or poor cod. Bib is known to inhabit rocky grounds and feed on species that are found in those areas, such as shrimps and crabs. Poor cod is less associated with rocky areas and is a more opportunistic feeder than bib (Heessen et al., 2015). Whiting and cod are both widespread in the southern North Sea and not necessarily known for inhabiting reef areas. However, their diet is comparable and consists of mainly fish and crustaceans that they feed on near the seabed (Heessen et al., 2015). These prey, especially crustaceans, tend to be attracted to the rocky reef (Coolen, 2017). It is likely that feeding opportunities attracts these species to the rocky reef area.

Butterfish are often found in coastal waters with a depth of less than 50 metres, and typically occur in rocky habitats. However, they are also found in completely different environments, such as the Waddensea (Heessen et al., 2015). Thus, it could be that the sighting of butterfish outside of the reef was coincidental, and without explanation. *Syngnathus acus* is a species of pipefish that generally occurs on barren sandy and muddy grounds in areas with a depth of maximally 20 metres (Heessen et al., 2015). This habitat preference makes it most likely that *S. acus* is the pipefish species present on the video footage and explains why the one sighting was outside of the rocky area. The gurnard species that generally occur in and around the Borkum area are tub gurnard (*Chelidonichtys lucerna*) and grey gurnard (*Eutrigla gurnardus*). Both these species are generally found on sandy bottoms, which explains their absence in the stations inside of the reef. Many flatfish species of the Pleuronectidae family are known for inhabiting sandy bottoms, thus it is no surprise that they favoured the areas outside of the reef. Only lemon sole (*Microstomus kitt*) is most often found on coarser substrates, and was found inside the Borkum reef area before (Coolen., 2017; Heessen et al., 2015). This could explain the one sighting within the reef area. Crystal goby is a pelagic species that is not very abundant in the southern North Sea. They have a short lifespan and die after spawning, which happens from May to September. The eggs are laid in the tubes of polychaete worms and guarded by males (Heessen et al., 2015). This explains their presence on the video footage, because polychaete worms are abundant in the Borkum rocky reef (Coolen, 2017). However, this does not explain their presence outside of the reef.

The results from the Borkum stones area indicate that species richness and abundance are not higher inside of the reef than outside of the reef, thus are not in line with the hypothesis. These results are comparable to the results of the study by Coolen (2017), who studied benthic biodiversity in the Borkum area and found 12 species of fish, of which 3 were exclusively found inside of the reef, and 6 were found exclusively on sandy areas. One of the species that was found exclusively outside the reef by Coolen (2017) was horse mackerel, which is different from this study where horse mackerel was present equally inside and outside of the reef. Like in this study, Coolen (2017) found goldsinny wrasse to be present exclusively inside of the reef. Both these results and the results of Coolen (2017) indicate that total richness in the area is greater due to the presence of the reef, but the species richness is not greater inside of the reef than in the surrounding sandy habitat.

These results differentiate from other studies that indicate that there is generally a positive correlation between habitat complexity, or relief, and species richness and abundance (Charton & Ruzafa, 1998; Carminatto et al., 2020). Of course, these studies were executed in different environments compared to the Borkum area. The study area of Charton and Ruzafa (1998) was located within a kilometre of the shore, which is a lot closer to the shore than the Borkum area is, and the study area of Carminatto et al. (2020) was in an estuary.

Other environmental factors that could be of influence on species distribution do not vary enough between the inside and outside stations to influence the results. Both temperature and salinity do not vary in the area where the Borkum reef is located, as is described in chapter 1.3, and displayed in figure 4, and the distribution of the commercial species, which are flatfish, whiting/cod, and horse mackerel, seems not to be influenced by these factors (figures 5, 6 and 7). The depth in the research area is between 20 and 25 metres, as is described in chapter 1.3, and the species that are present on the footage are not influenced by this variation (Heessen et al., 2015). Solely the pipefish could perhaps be influenced by water depth because it usually prefers shallower waters (Heessen et al., 2015). The transects are approximately parallel to the shore of the island Schiermonnikoog, so there is no difference in distance from shore between the inside and outside stations. The difference in distance from shore between the two transects is approximately 100 metres, and they are both approximately 20 kilometres from the shore of Schiermonnikoog, so the difference of 100 metres is likely not of influence on the species distribution.

4.3 Implications

The results of the Voordelta build on existing evidence that shellfish reef have a positive effect on fish species diversity and provide a picture of these effects in the southern North Sea (Arve, 1960; Peterson et al., 2003; Gilby et al., 2021). The results also provide new insights into how species such as seabass and horse mackerel use these areas for foraging or as nurseries. This implies that it could have a positive effect on the fish populations as a whole because of spillover, and this could benefit fisheries targeting these species as well. However, further research is necessary to establish whether the shellfish reef in this area only attracts fish from the surrounding area, or whether it increases the productivity and carrying capacity of the area for fish.

The results of the Borkum area prove that the theory of reefs alone having positive effects on species diversity and abundance is not as simple and imply that habitat variance in an area is most important. This is in compliance with existing evidence that rocky reefs have a positive effect on biodiversity in the entire area (Coolen, 2017).

These findings contribute to the existing knowledge of effects of natural reefs on fish communities. This knowledge is relevant to provide background information for projects on oyster reef restoration and can be used in the design of offshore wind farms, and especially important with various of such projects being executed (Sas et al., 2016; Van Oord, 2022). The results of the Borkum rocky reef show that the differences in biodiversity between the reef area and surrounding area were not significant, while Stenberg et al. (2015) found that the biodiversity inside an offshore wind farm is significantly higher compared to outside the wind farm. The effects of a rocky reef on fish communities are not similar to the effects of offshore wind farms, as was also concluded by Coolen (2017), even though the species that are attracted to the wind farms are species that normally inhabit rocky reefs (Zintzen, 2007; Stenberg et al., 2015; Krone et al., 2017). If oyster reef restoration in wind farms is successful, avenues for future research would be to study the differences in fish communities and how fish use the habitats, compared to the natural oyster reef and considering the different environmental factors.

4.4 Limitations

There are some limitations to this study which need to be considered. Firstly, with 20 samples, of which all 12 in the Voordelta were taken on the same day, the generalizability is limited. Because this study is the pioneer of video analysis in the ReViFES project, there was some trial and error with establishing the most efficient method of analysis. This lead to the analysis of a small number of stations in the Voordelta due to time constraints. Consequently, the results cannot provide an answer to the question regarding the extent of reef influence. More video footage of the stations from different days is available and should be added to the data of this study to be able to find out to what extent the influence of the reef radiates outwards and to create better reliability. Secondly, there was some variation in the camera systems in the stations in the Voordelta. There were 2 types of GoPro´s that were used, and the angle with which the cameras were pointed towards the bait stick varied due to deployment by different people. As a result, the ratio of bottom and water column and the bottom area that was visible varied between the stations. It is unlikely that this influenced the results much, but it is a point of improvement.

5. Conclusions

This research aimed to identify the effects of reefs on fish communities in the southern North Sea, to what extent these effects radiate outwards to the surrounding environment, and whether there is spillover of species of commercial interest. Through analysis of abundance and richness of fish species inside and outside of 2 reefs in the southern North Sea, this research has provided a picture of the effects of these reefs on fish communities. In a shellfish reef like in the Voordelta, species richness and abundance are generally higher inside of the reef than outside of the reef. Such conclusions cannot be drawn for a rocky reef like the Borkum stones area, but the results show that the presence of the rocky reef might enhance species richness in the entire area. This study cannot provide an answer to the questions regarding the relationship between the reef effects and the distance from the reef, but future research should be done with the available footage to focus on this. In addition, the results imply that there is the possibility of spillover of commercial species such as horse mackerel, seabass, and whiting or cod, but cannot confirm this without a control area far away from the reef. To better understand the effect of spillover, an idea for future research would be to create a baseline of species richness and abundance in an area before shellfish reef restoration projects and monitoring of these variables after establishment of the shellfish reef.

The presence of the reef is most likely the cause of the differences in species composition, richness, and abundance, since other environmental variables such as temperature, salinity, and water depth do not vary significantly on the studied scale, and neither does distance from shore in the Borkum area. The distance from shore could have been an influence in the Voordelta, but analysis of a control transect some distance from the reef excluded this as an influence on the results.

The findings that shellfish reefs such as the one in the Voordelta enhance species richness and abundance, and provide nursery or foraging areas for juvenile horse mackerel and seabass, are new insights in the field. These conclusions are an addition to arguments for shellfish reef restoration.

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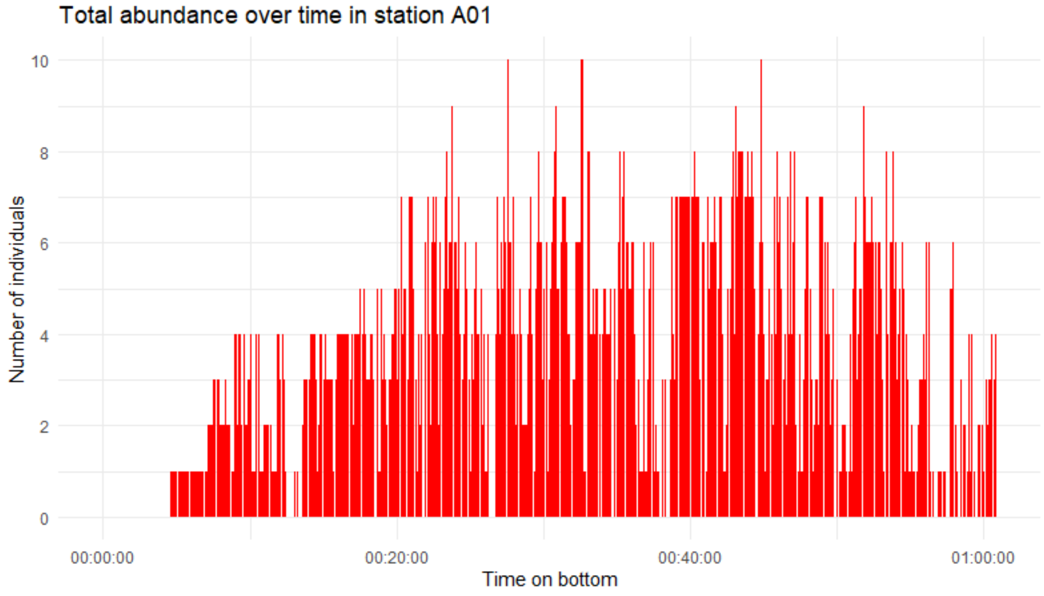
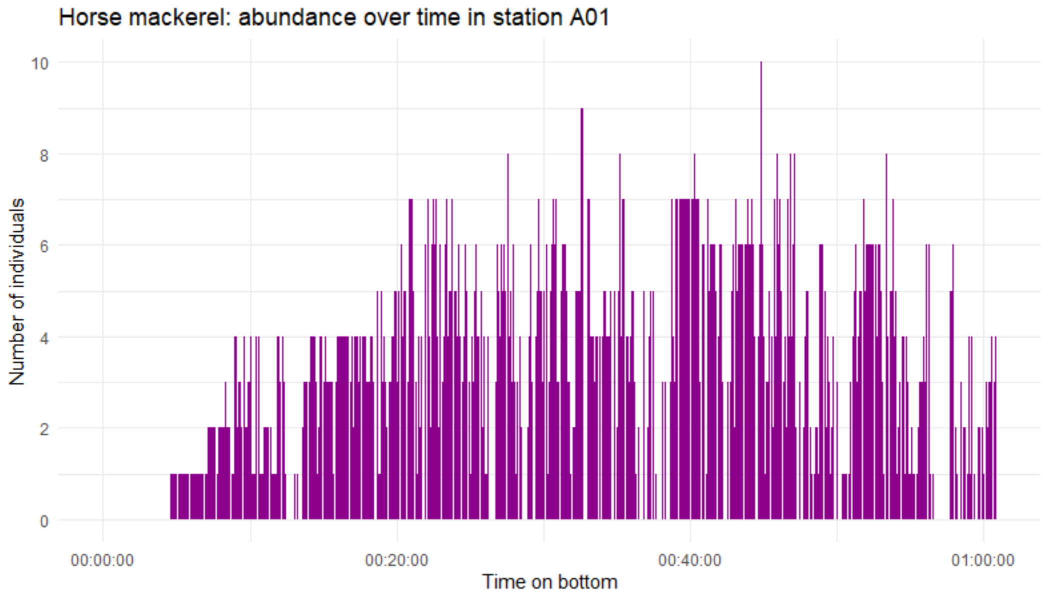
Appendix A: Abundance of species over time of the videos

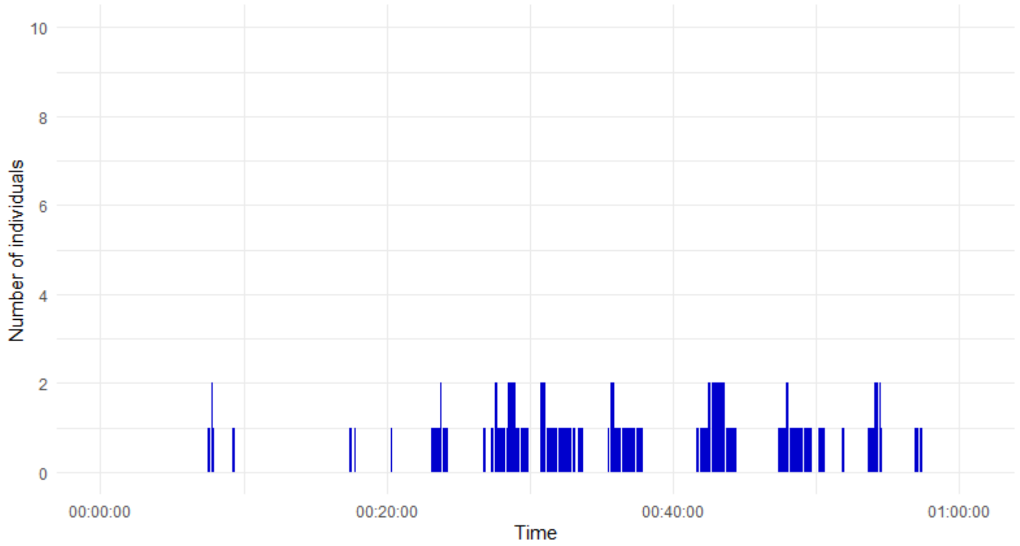
Voordelta

Station A01

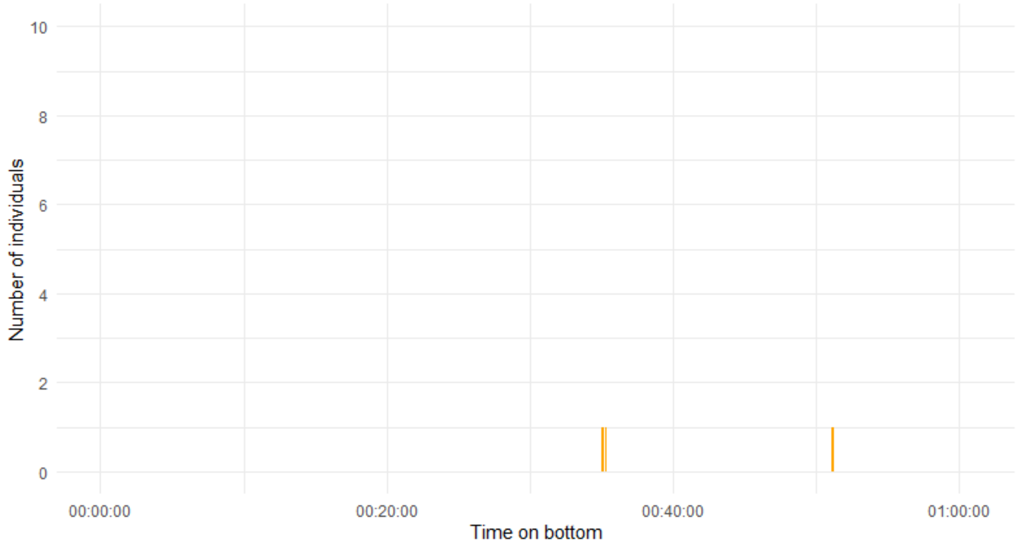




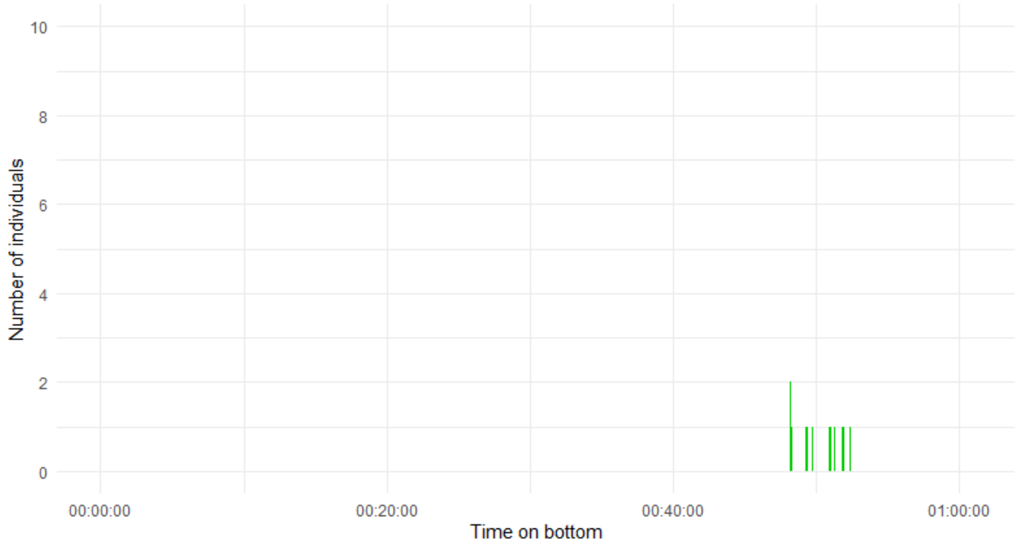
Gobies: abundance over time in station A01



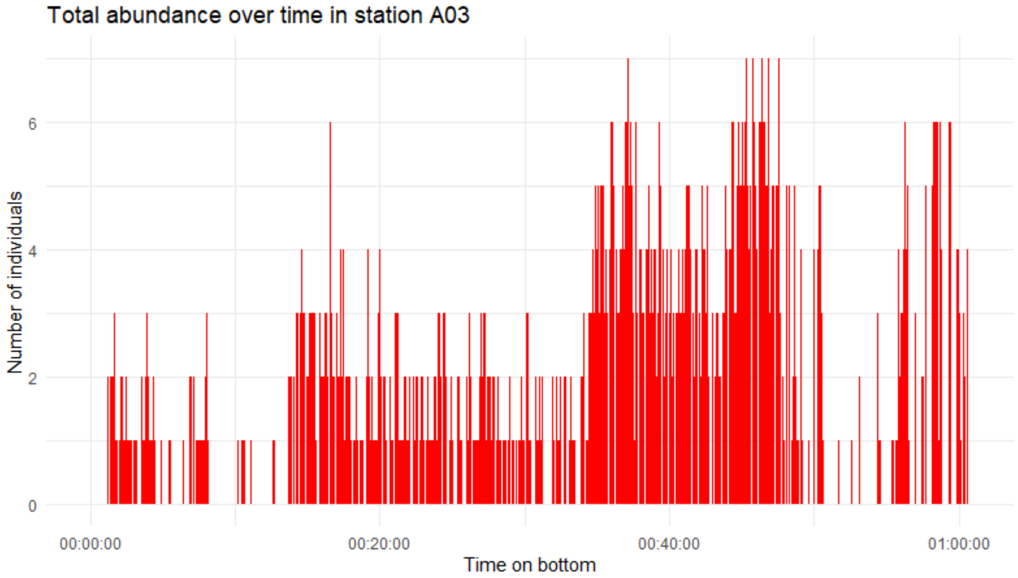
Seabass: abundance over time in A01



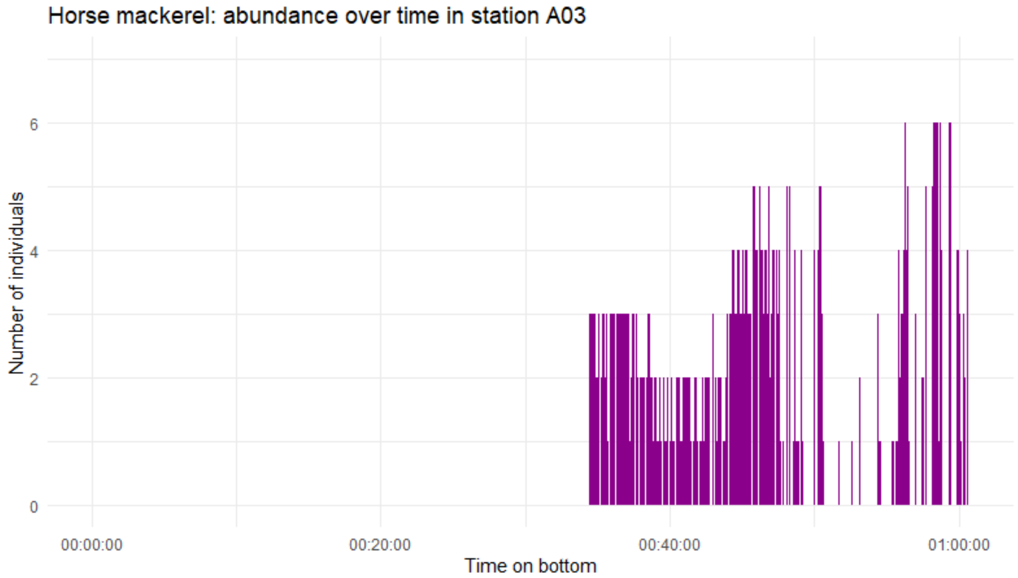
Sand smelt: abundance over time in A01

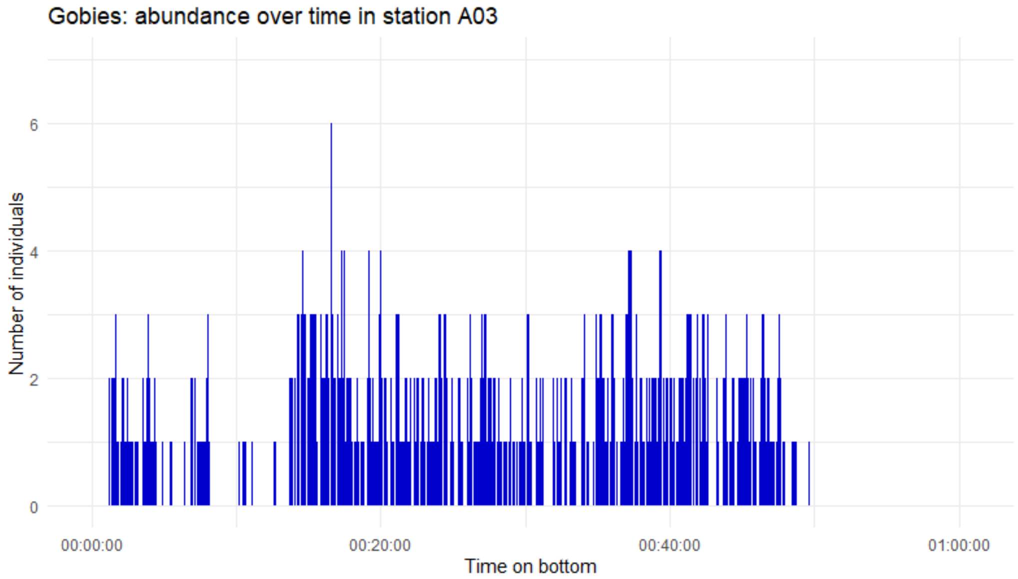


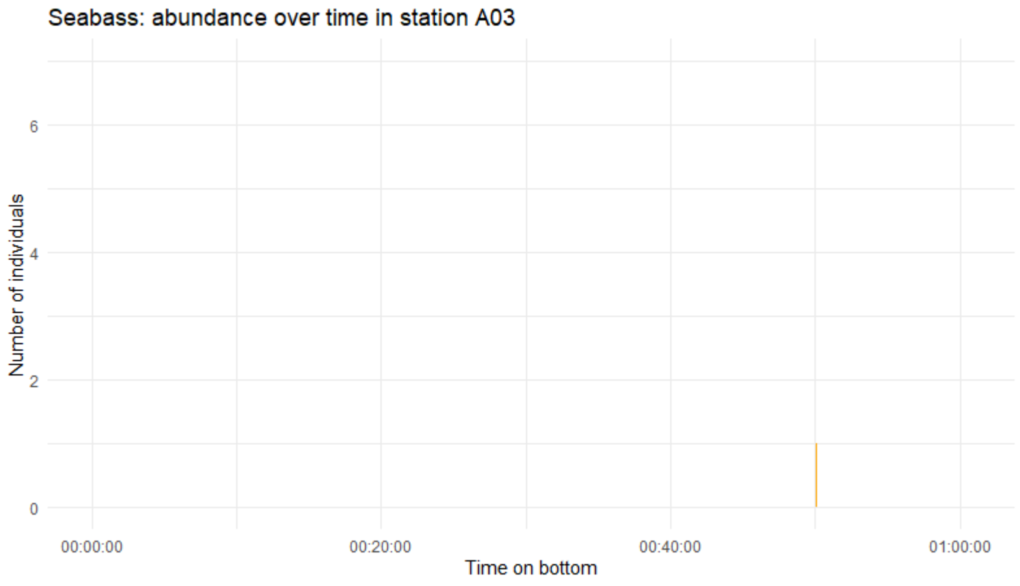
Station A03



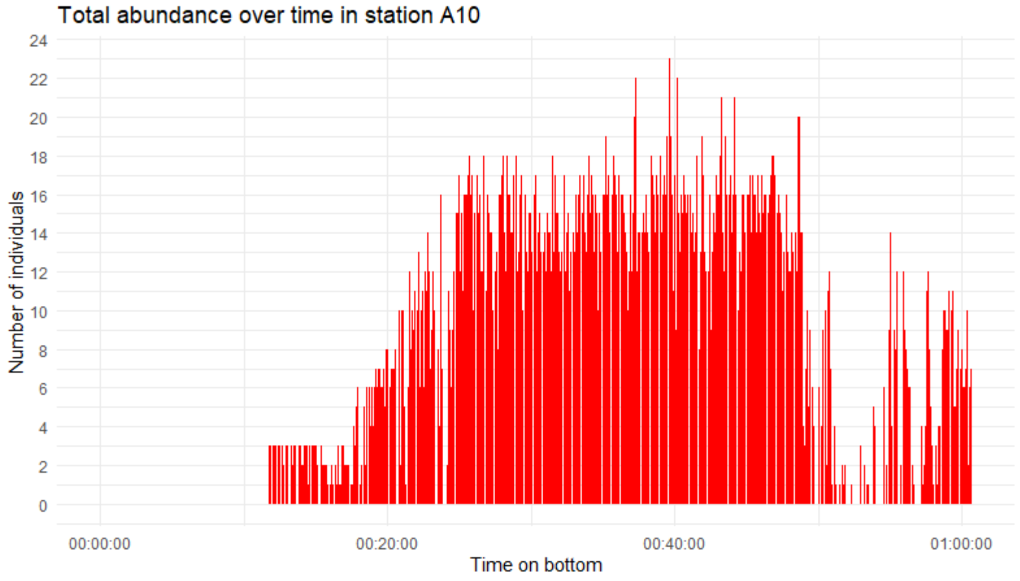
8

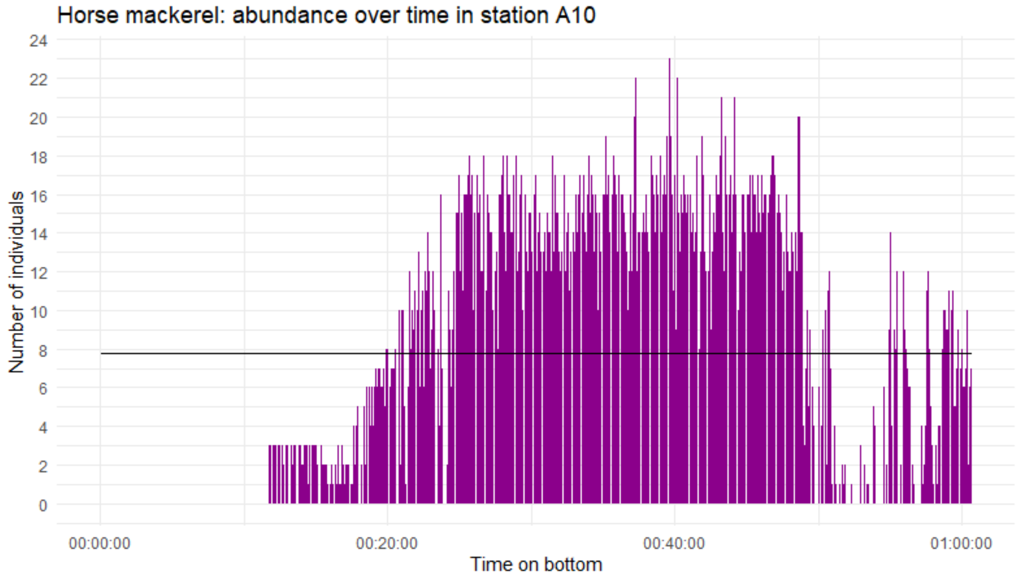


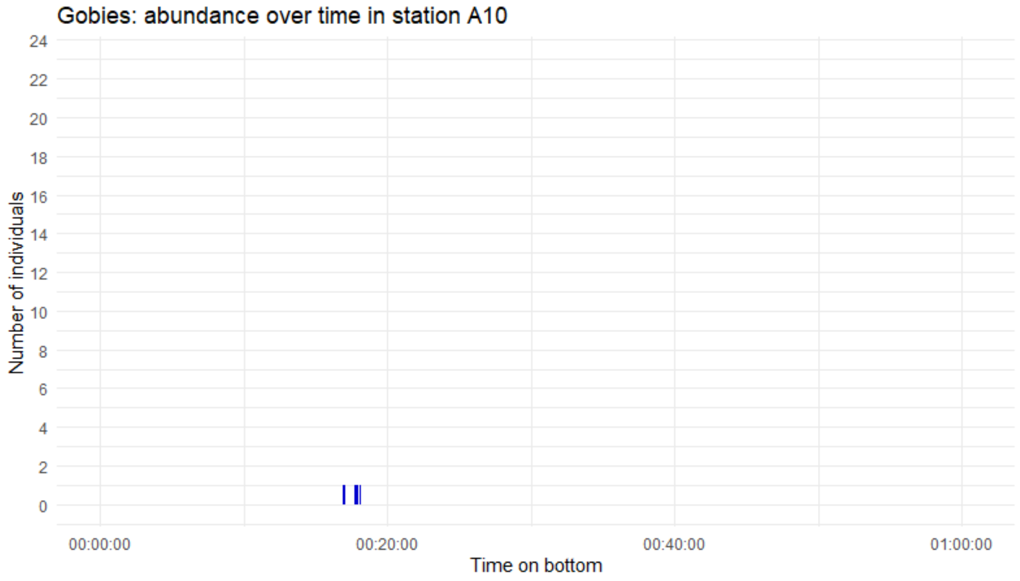



Seabass: abundance over time in station A03
Number of individuals
0
2
4
6
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

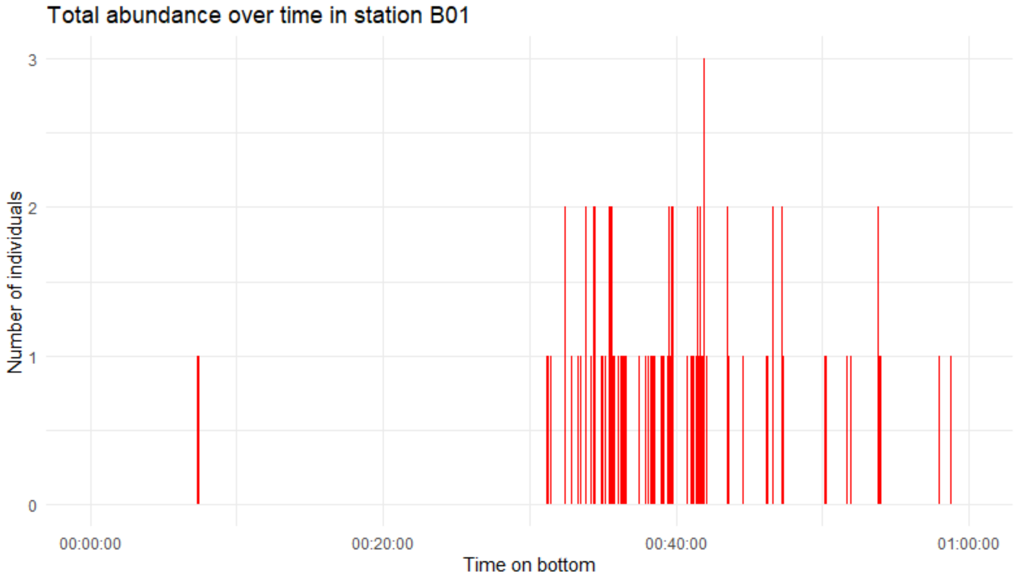
Station A10


Total abundance over time in station A10
24
22
20
18
16
14
12
10
8
6
4
2
0
Number of individuals
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

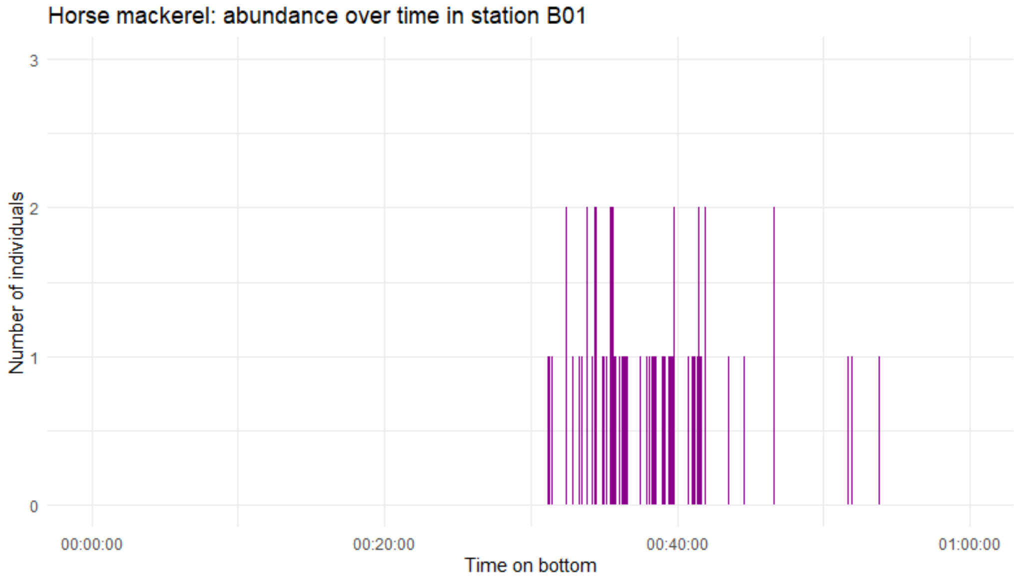

Horse mackerel: abundance over time in station A10
24
22
20
18
16
14
12
10
8
6
4
2
0
Number of individuals
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

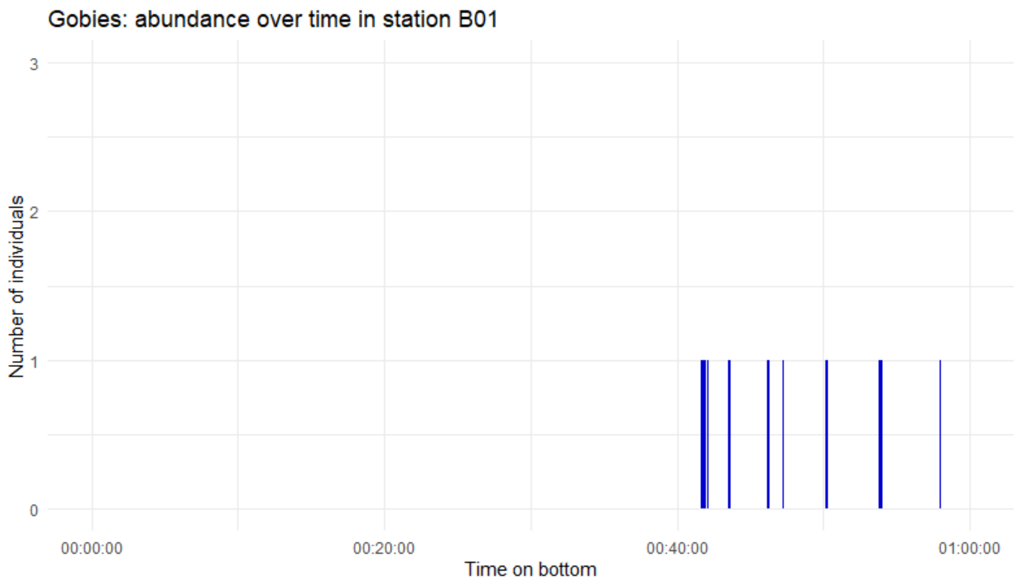

Gobies: abundance over time in station A10
24
22
20
18
16
14
12
10
8
6
4
2
0
Number of individuals
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

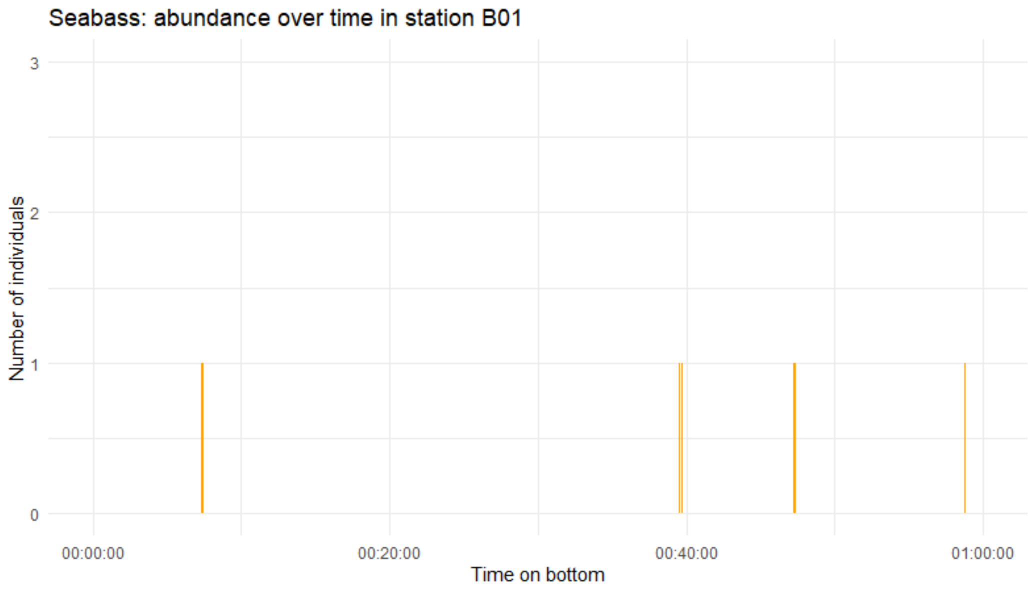
Station B01



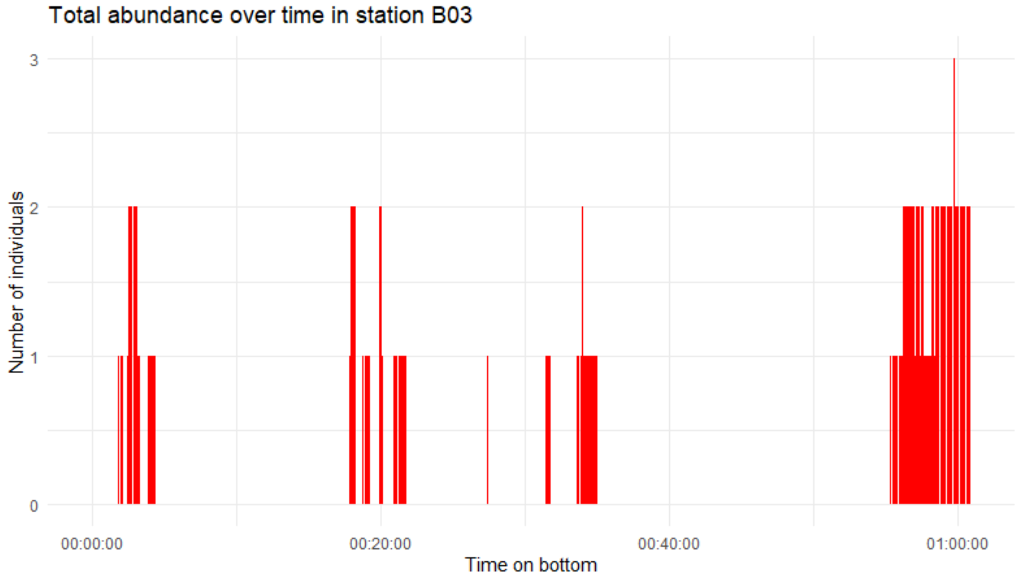
8

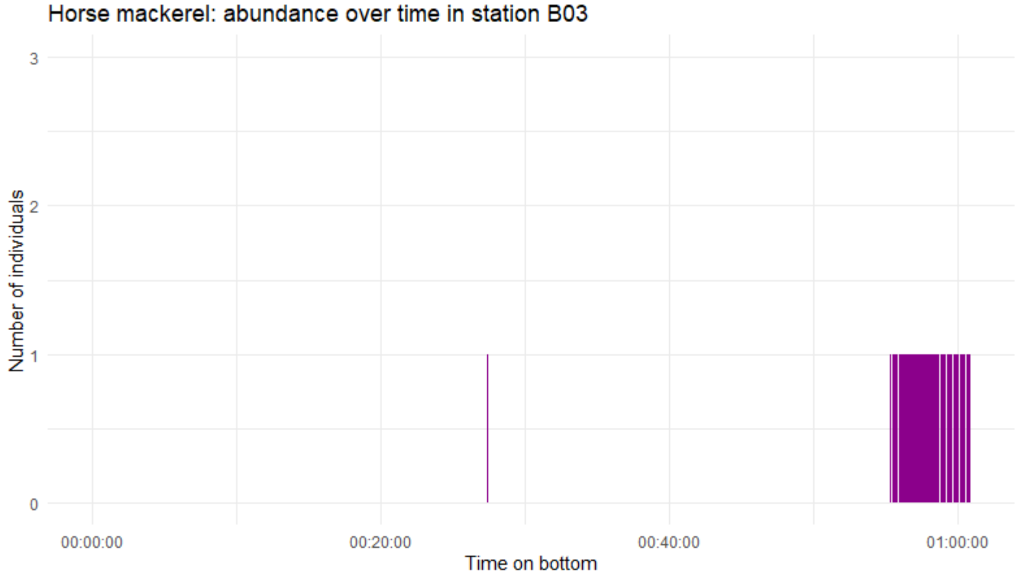


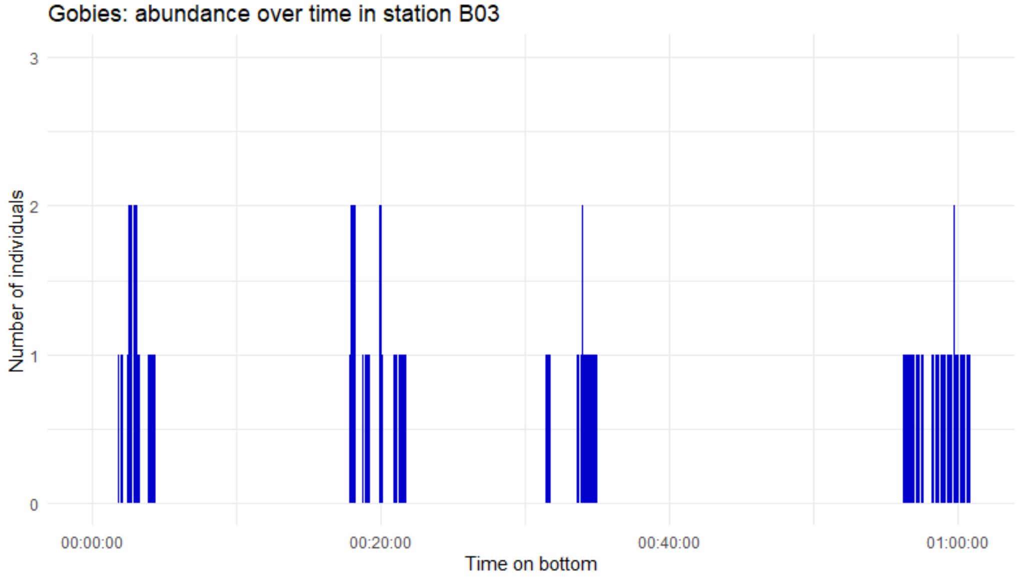


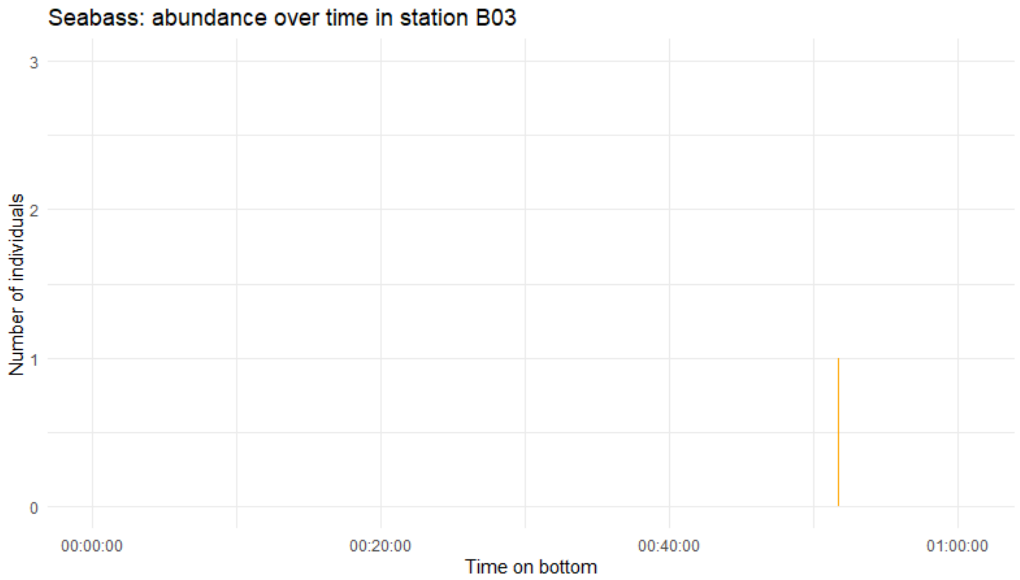

Seabass: abundance over time in station B01
Number of individuals
0
1
2
3
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

Station B03

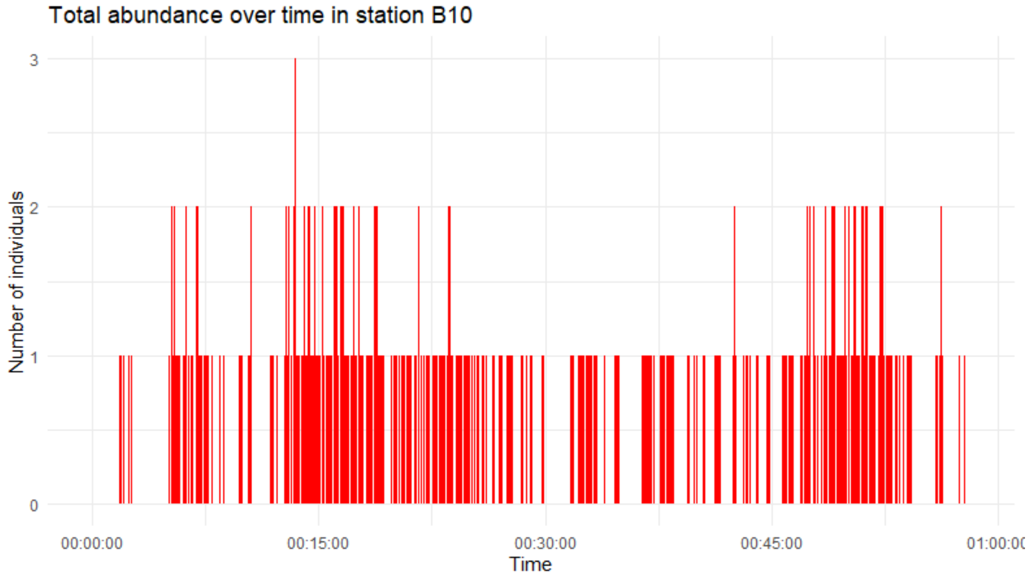

Total abundance over time in station B03
Number of individuals
0
1
2
3
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

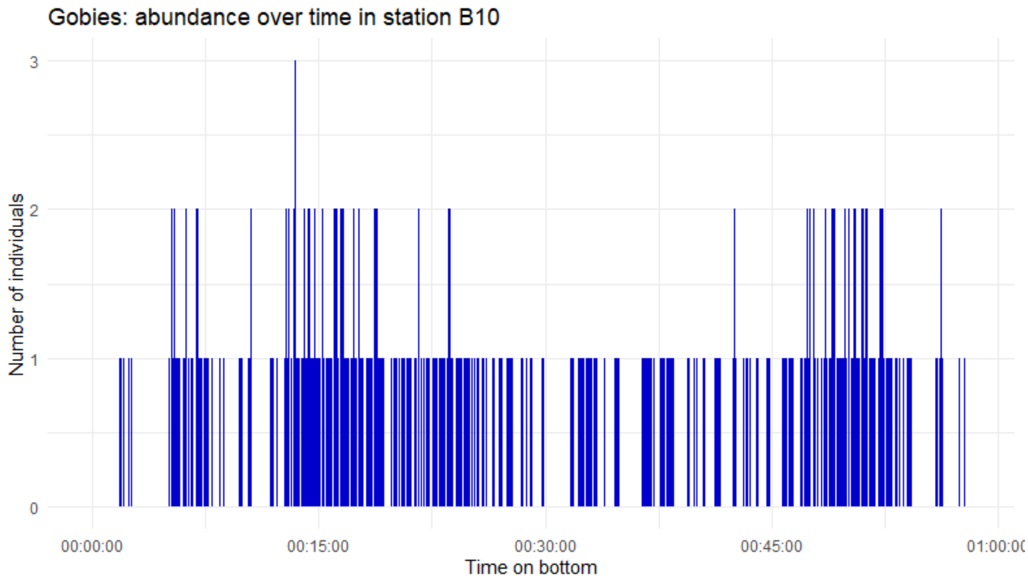

Horse mackerel: abundance over time in station B03
Number of individuals
0
1
2
3
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom


Gobies: abundance over time in station B03
Number of individuals
0
1
2
3
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

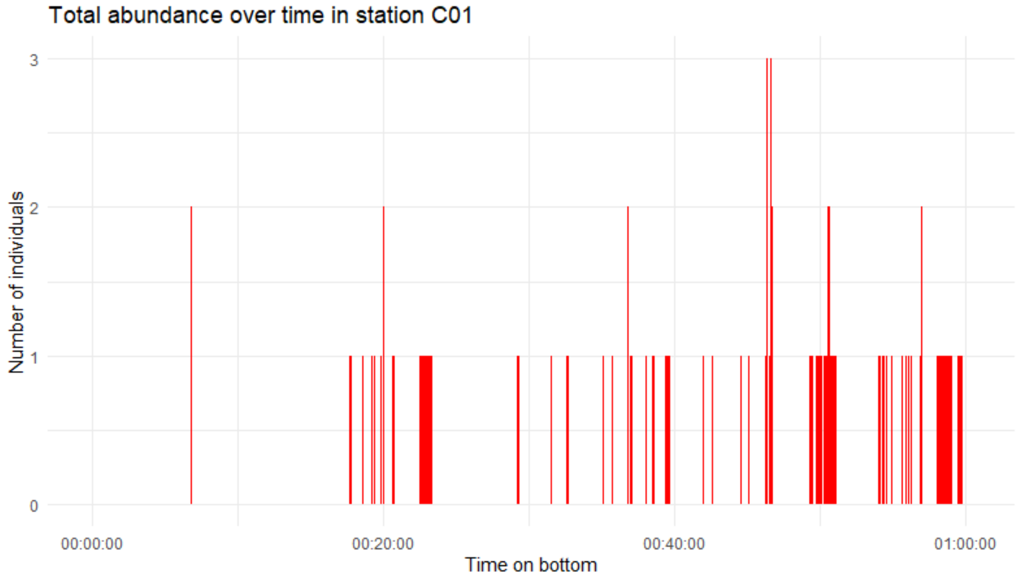

Seabass: abundance over time in station B03
Number of individuals
3
2
1
0
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

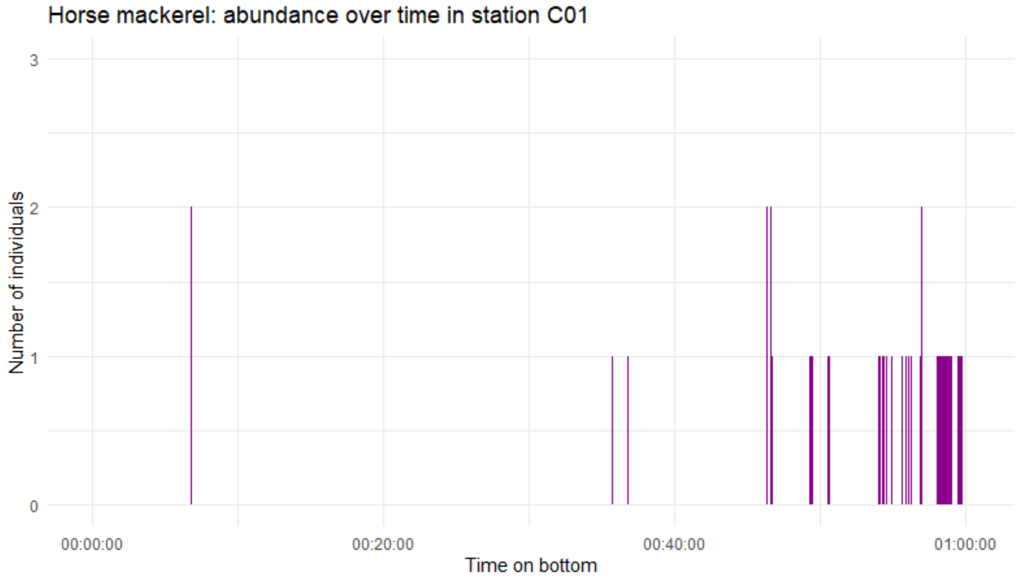
Station B10

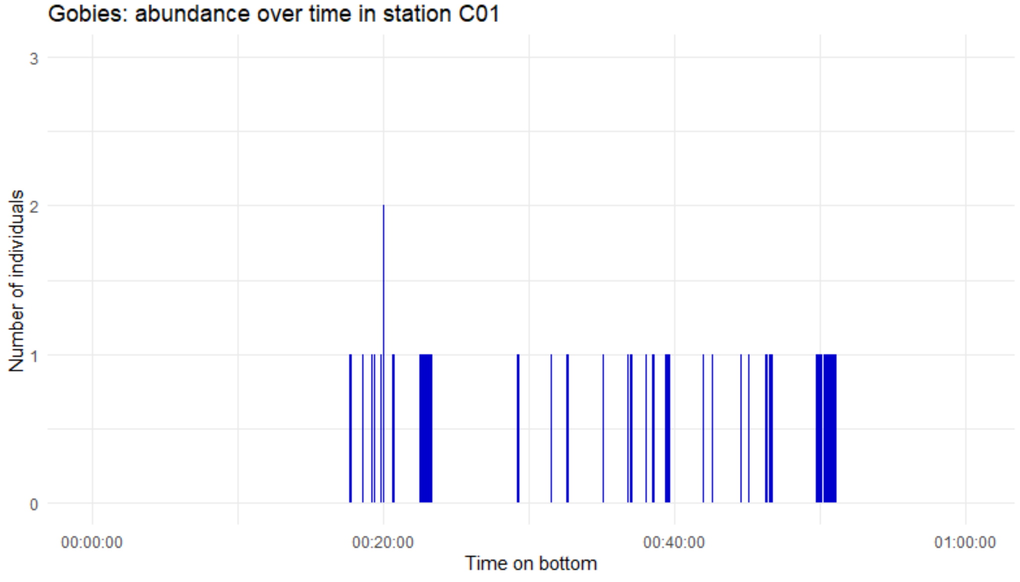

Total abundance over time in station B10
Number of individuals
3
2
1
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time


Gobies: abundance over time in station B10
Number of individuals
3
2
1
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

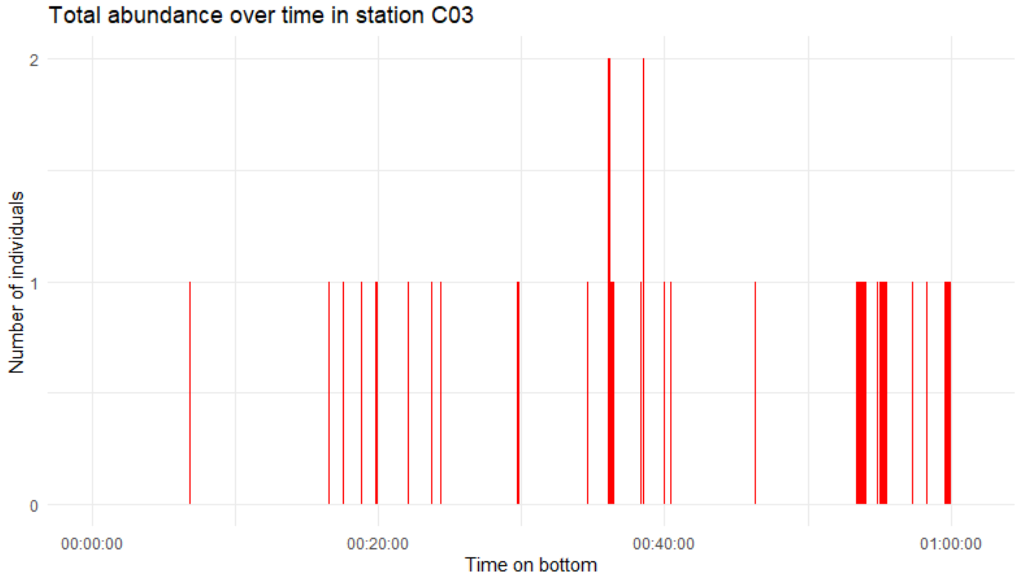
Station C01

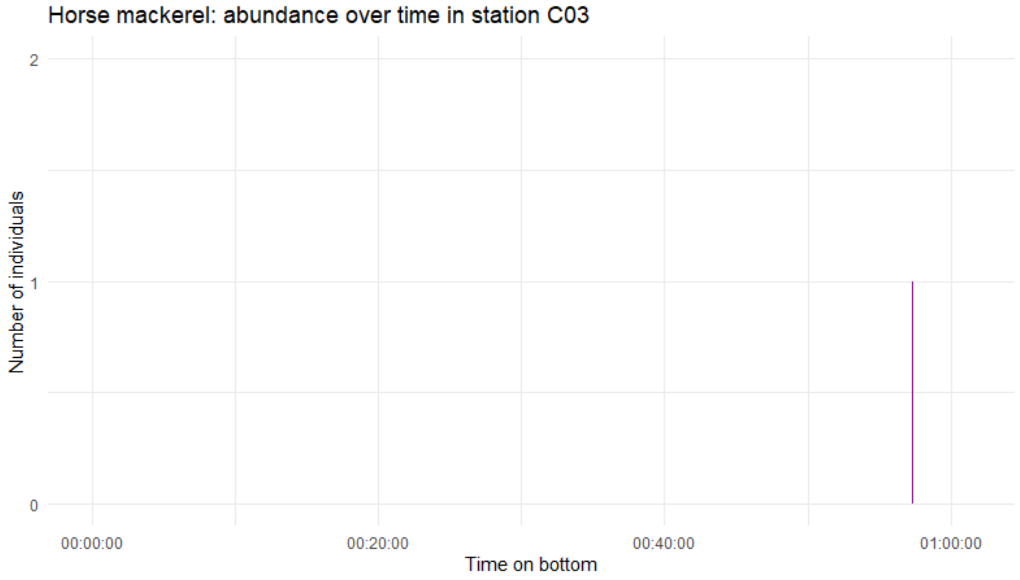

Total abundance over time in station C01
Number of individuals
0
1
2
3
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

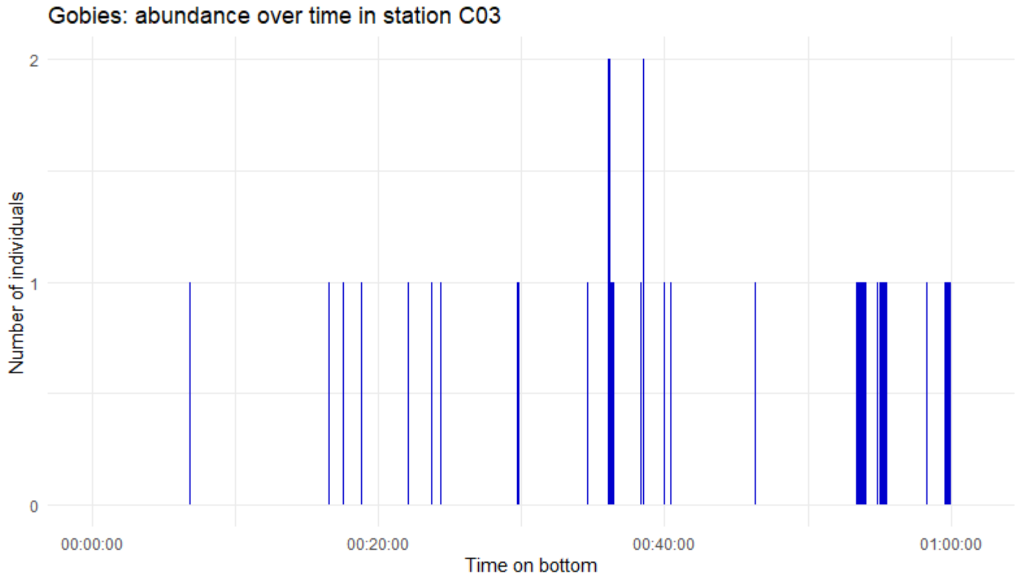

Horse mackerel: abundance over time in station C01
Number of individuals
0
1
2
3
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

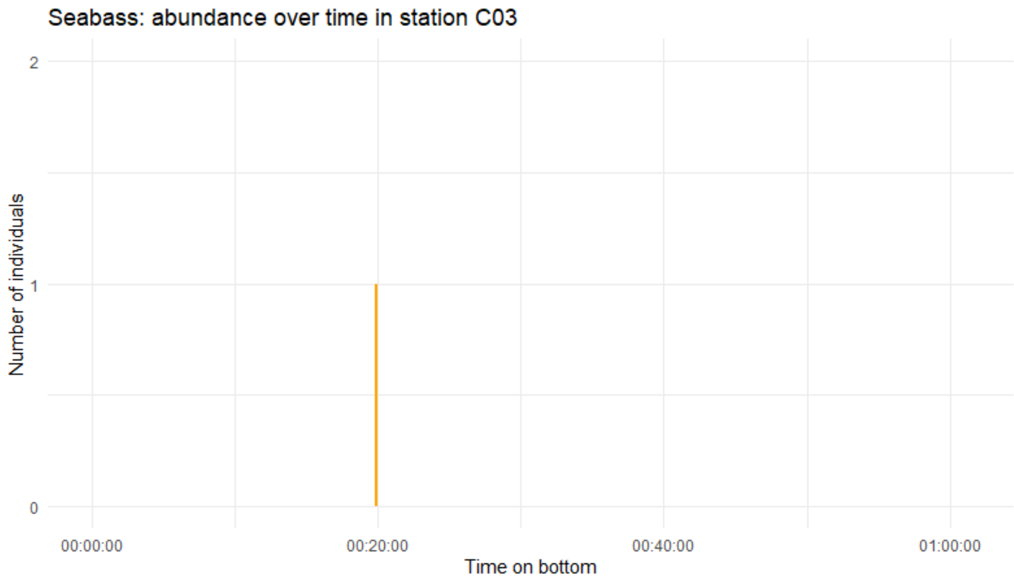

Gobies: abundance over time in station C01
Number of individuals
0
1
2
3
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

Station C03


Total abundance over time in station C03
2
1
0
Number of individuals
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

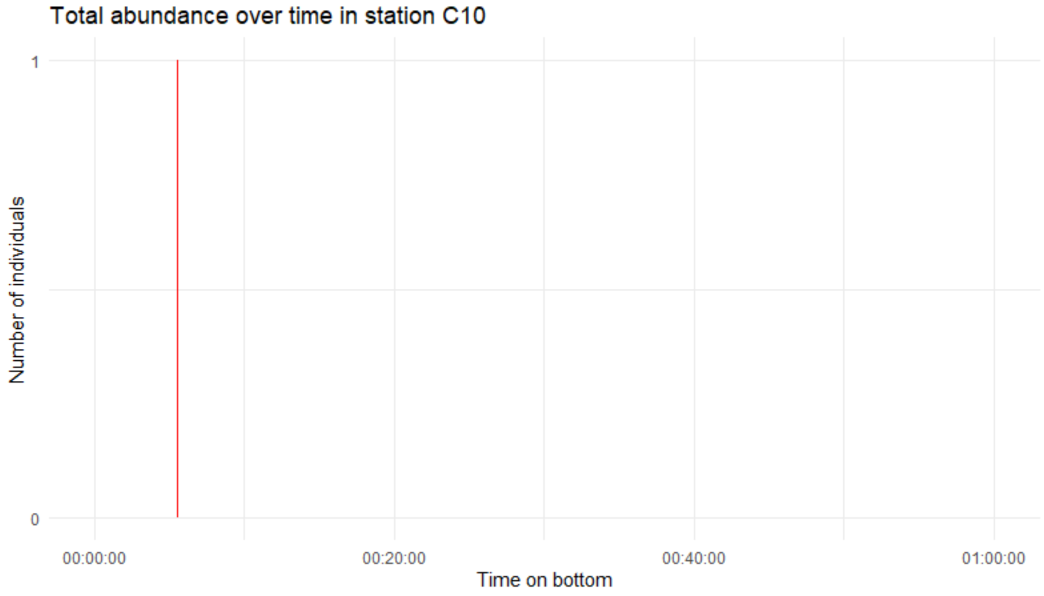

Horse mackerel: abundance over time in station C03
2
1
0
Number of individuals
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

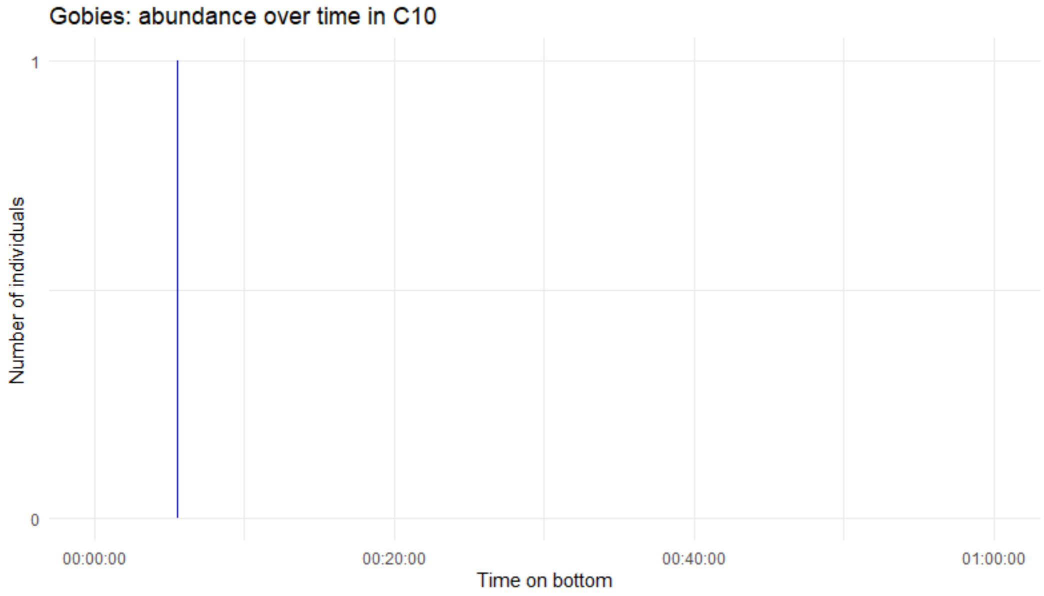

Gobies: abundance over time in station C03
2
1
0
Number of individuals
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom



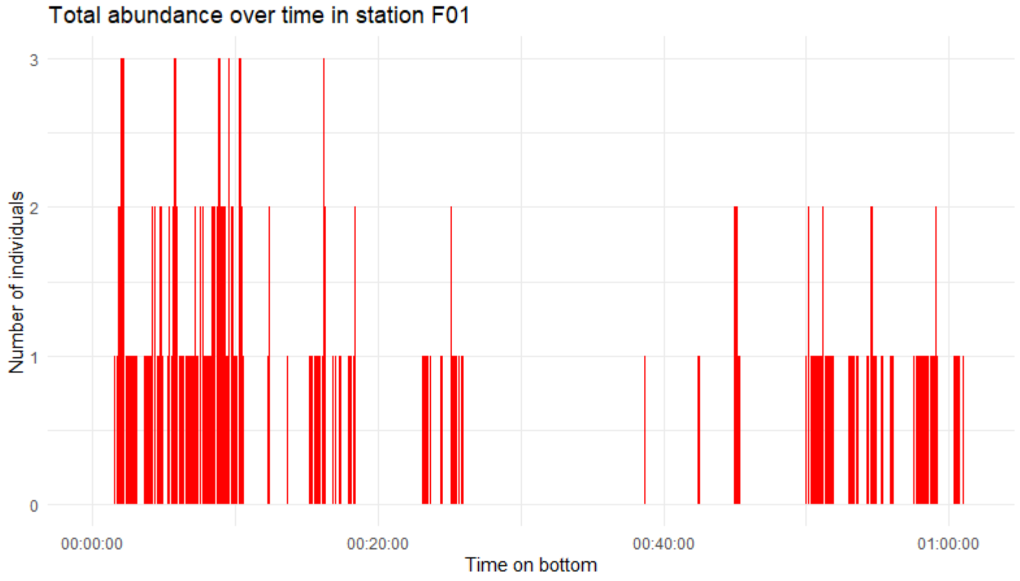
Seabass: abundance over time in station C03
Number of individuals
2
1
0
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

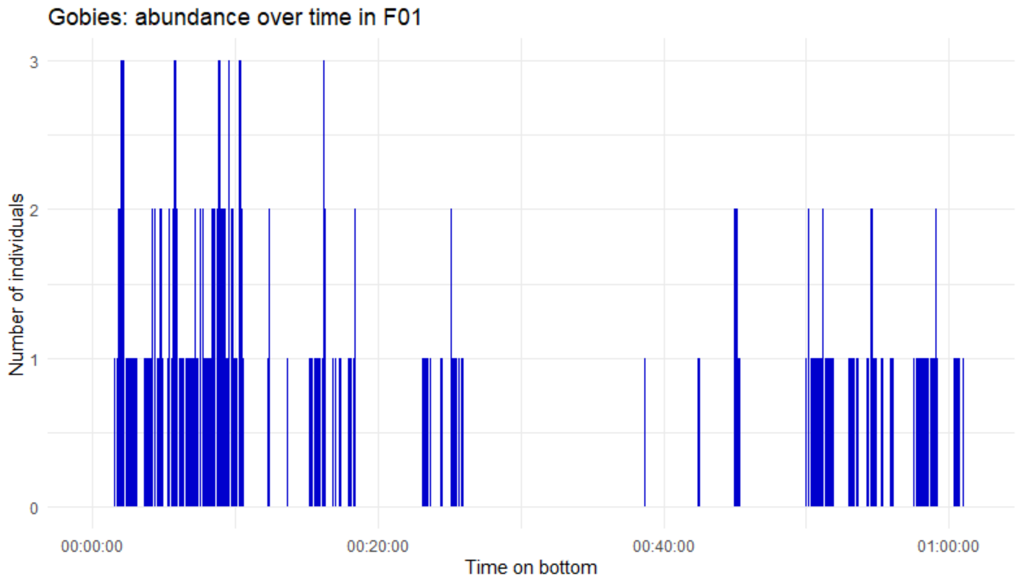
Station C10


Total abundance over time in station C10
1
0
Number of individuals
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

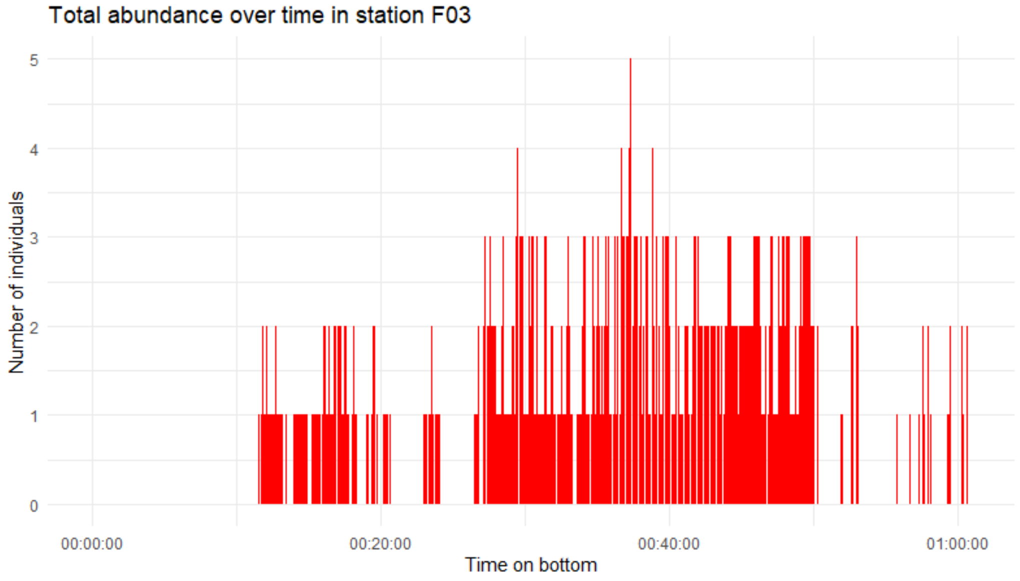

Gobies: abundance over time in C10
1
0
Number of individuals
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

Station F01

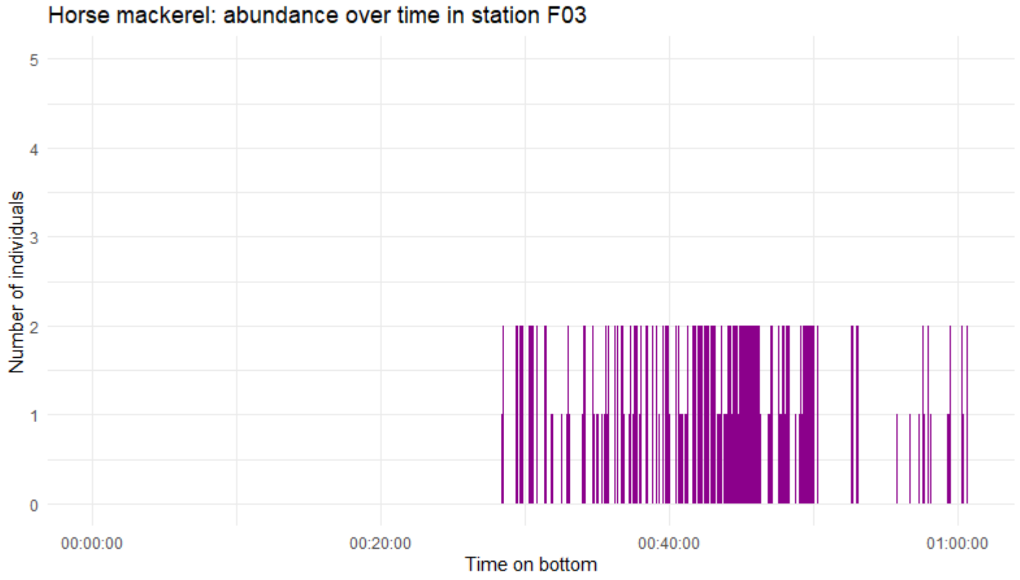

Total abundance over time in station F01
Number of individuals
0
1
2
3
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom


Gobies: abundance over time in F01
Number of individuals
0
1
2
3
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

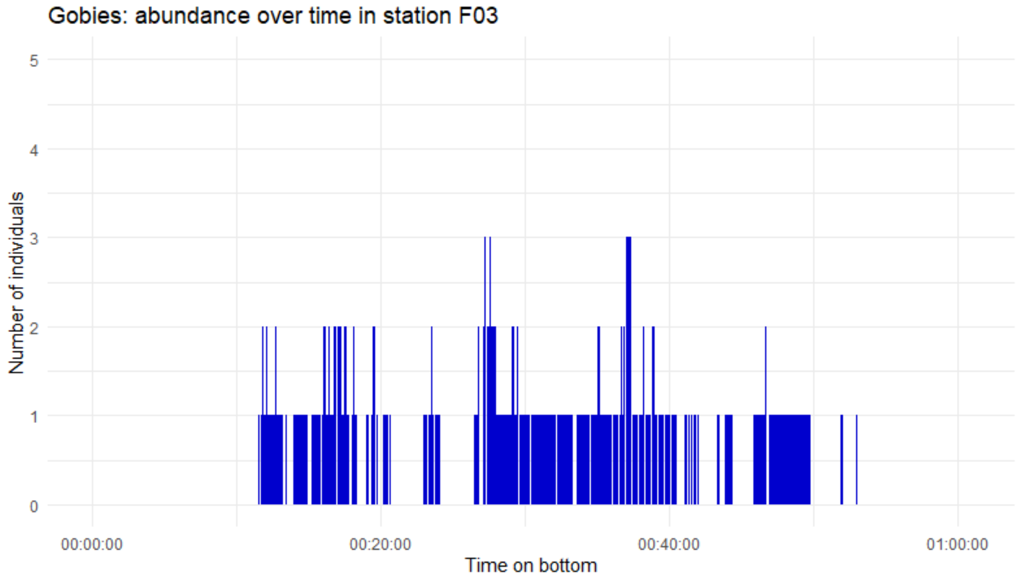
Station F03



Total abundance over time in station F03
Number of individuals
5
4
3
2
1
0
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom



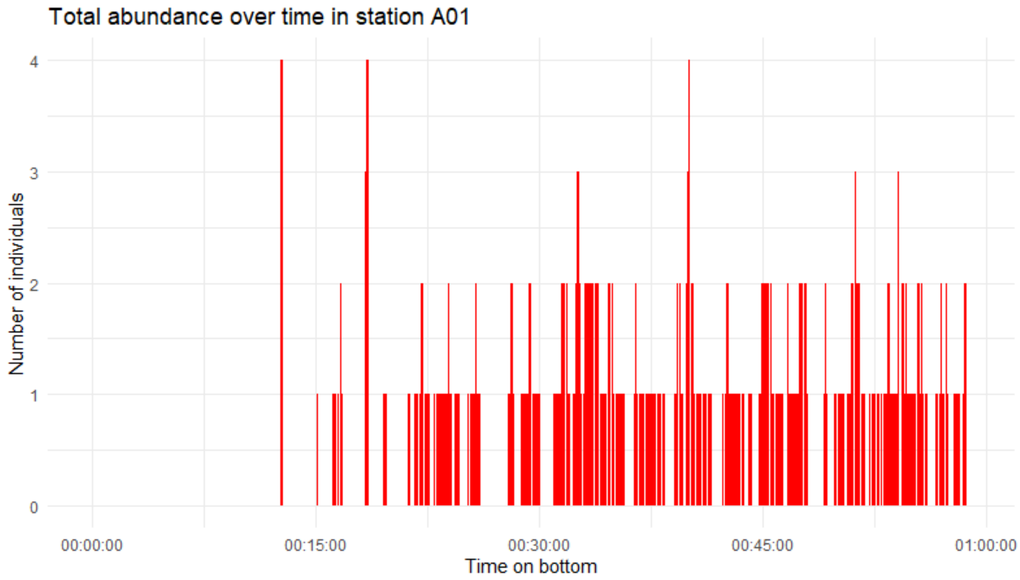
Horse mackerel: abundance over time in station F03
Number of individuals
5
4
3
2
1
0
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

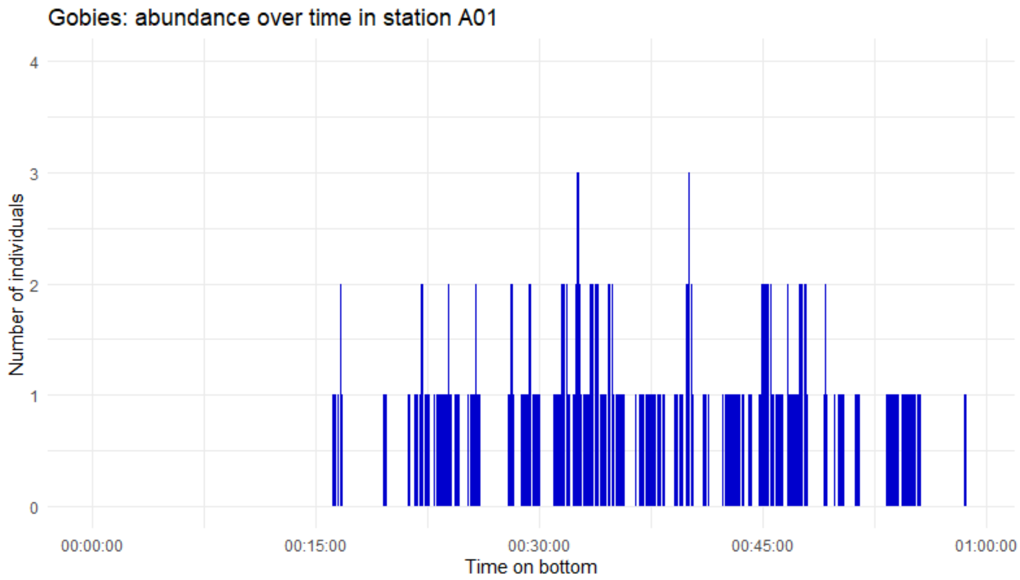


Gobies: abundance over time in station F03
Number of individuals
5
4
3
2
1
0
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

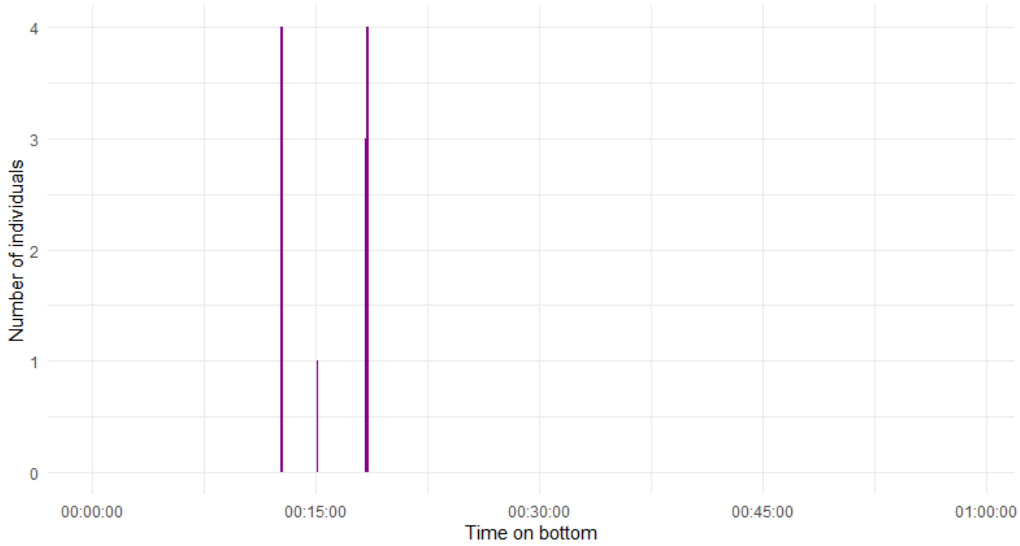
Borkum

Station A01

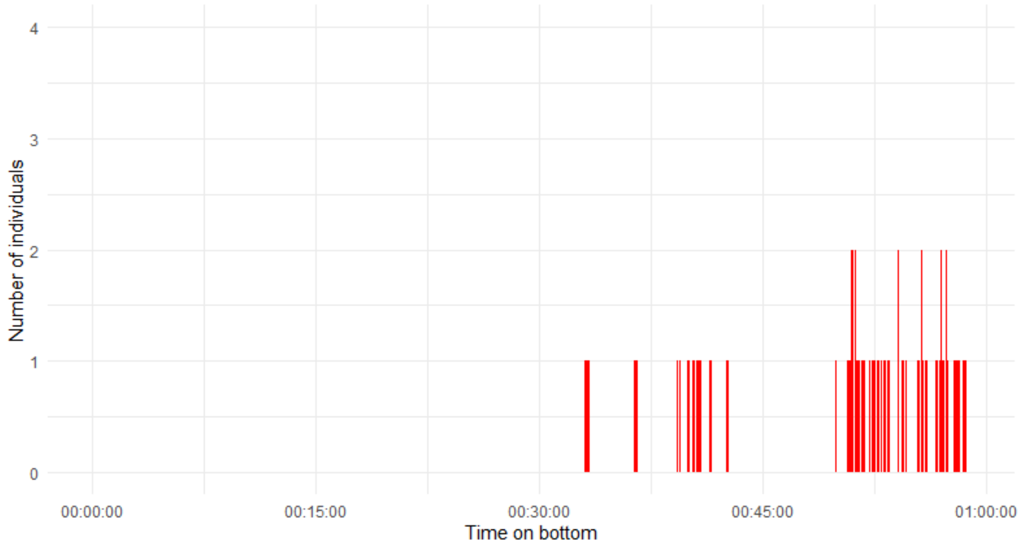




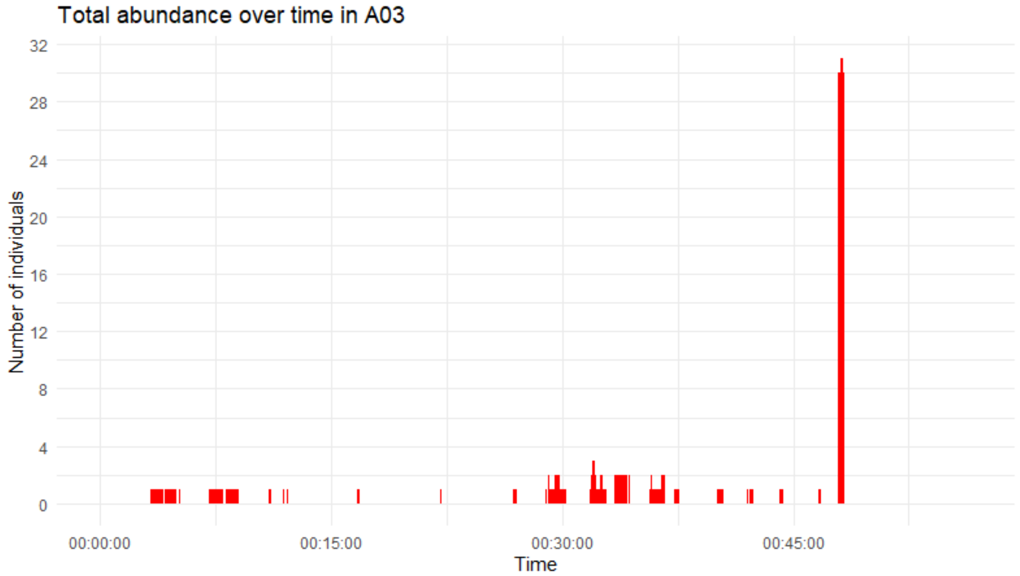
Horse mackerel: abundance over time in station A01

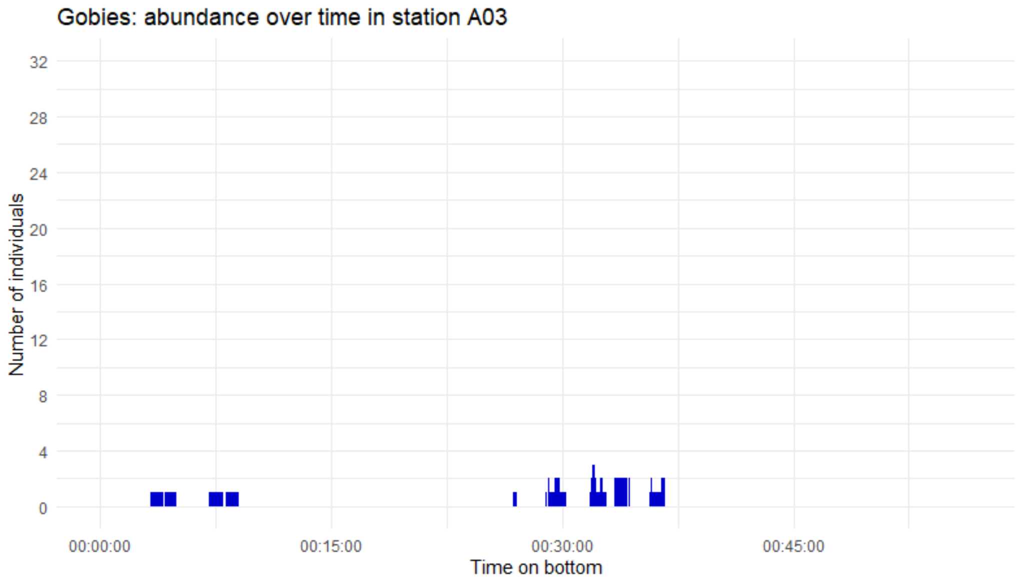


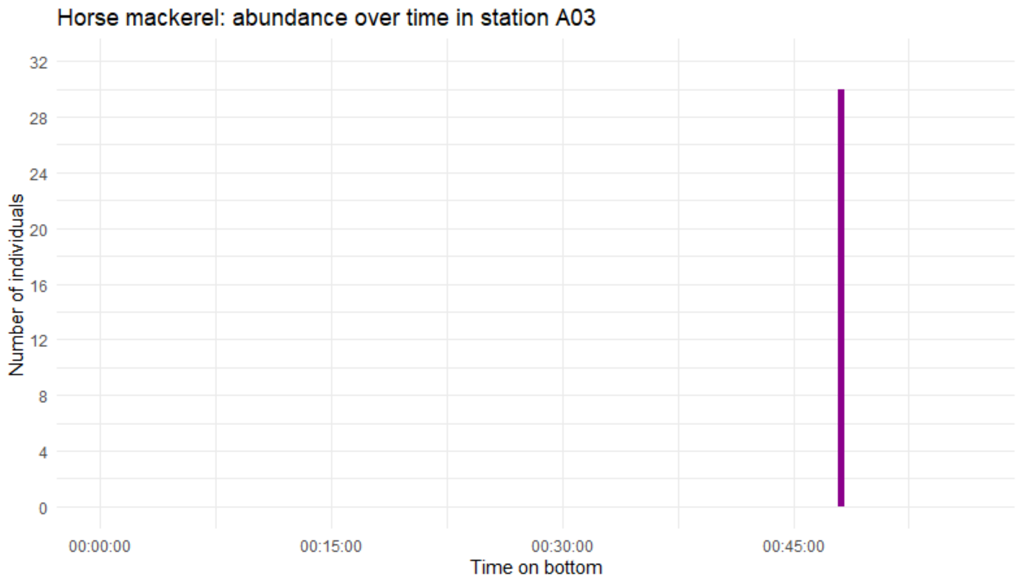
Whiting/cod: abundance over time in station A01

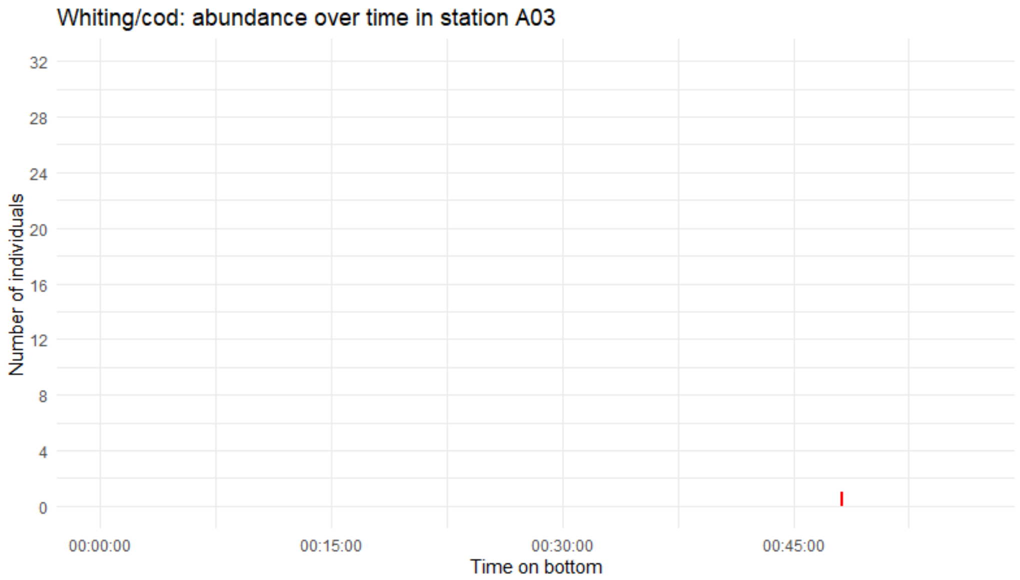


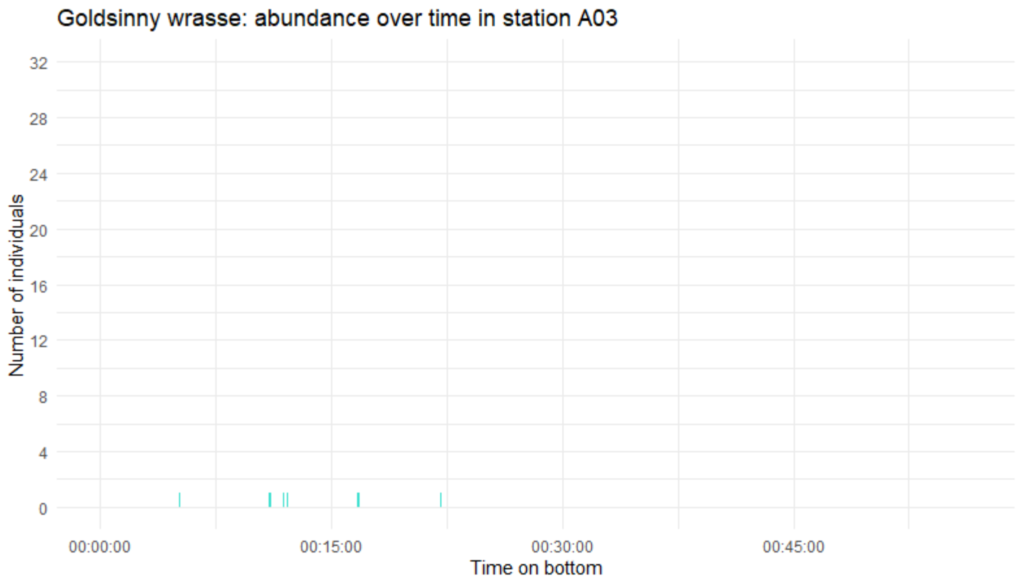
Station A03

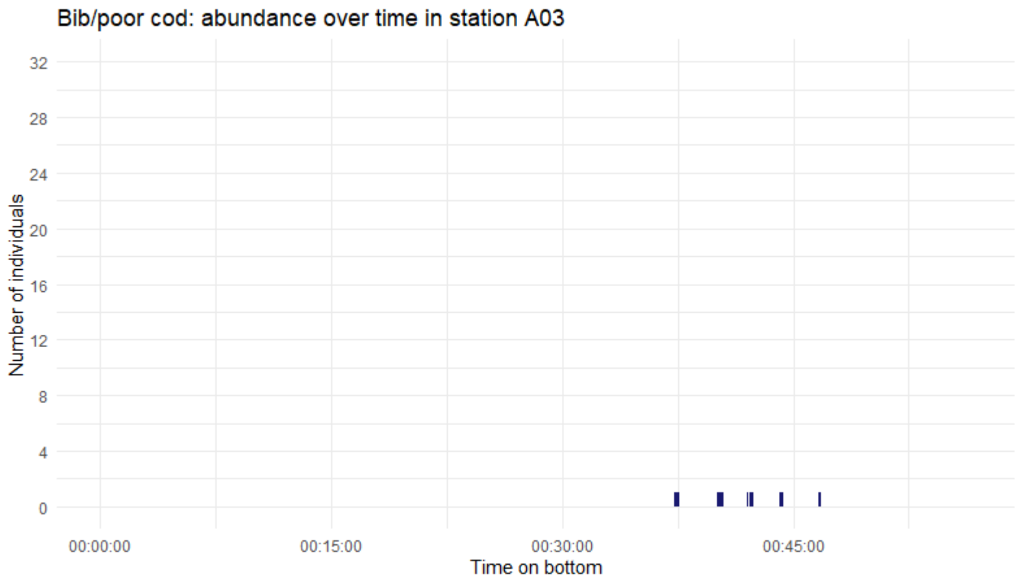

Total abundance over time in A03
Number of individuals
32
28
24
20
16
12
8
4
0
00:00:00
00:15:00
00:30:00
00:45:00
Time


Gobies: abundance over time in station A03
Number of individuals
32
28
24
20
16
12
8
4
0
00:00:00
00:15:00
00:30:00
00:45:00
Time on bottom

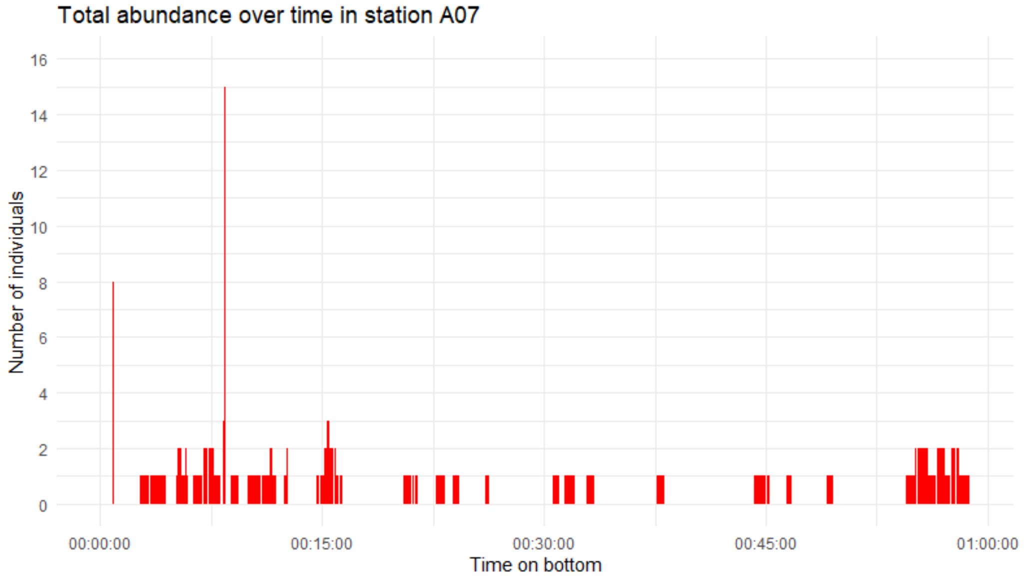

Horse mackerel: abundance over time in station A03
Number of individuals
32
28
24
20
16
12
8
4
0
00:00:00
00:15:00
00:30:00
00:45:00
Time on bottom

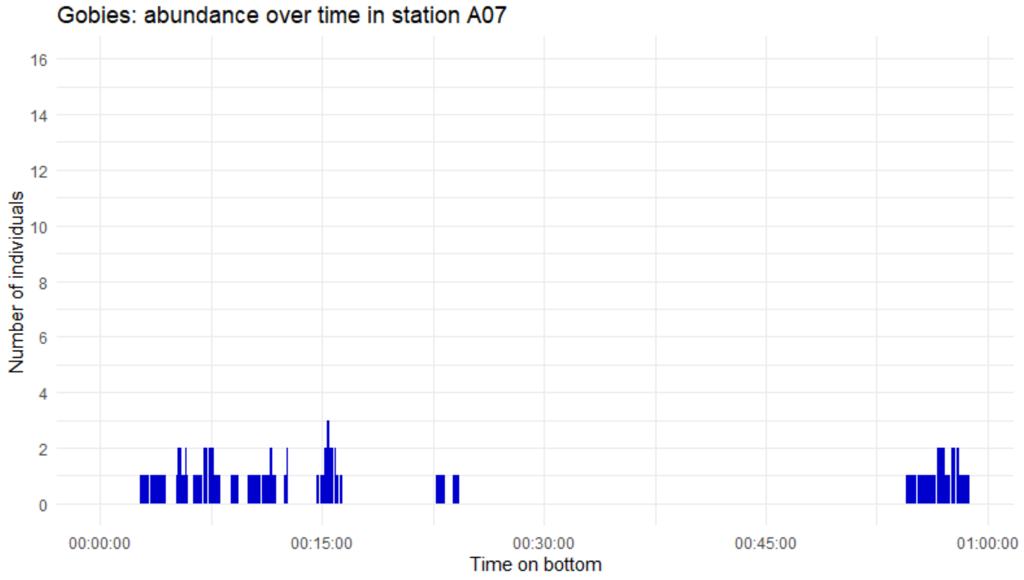

Whiting/cod: abundance over time in station A03
Number of individuals
32
28
24
20
16
12
8
4
0
00:00:00
00:15:00
00:30:00
00:45:00
Time on bottom

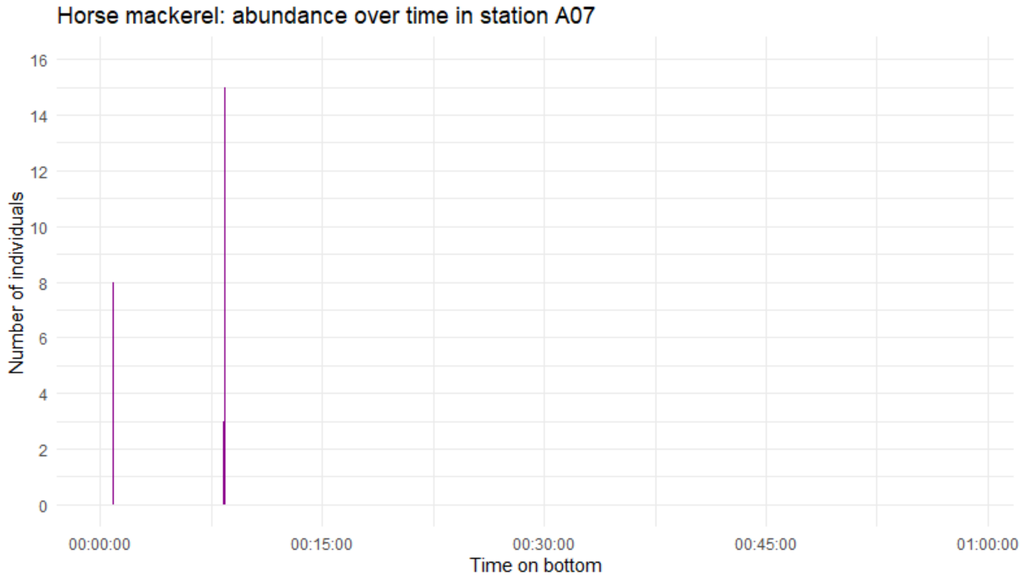

Goldsinny wrasse: abundance over time in station A03
Number of individuals
32
28
24
20
16
12
8
4
0
00:00:00
00:15:00
00:30:00
00:45:00
Time on bottom

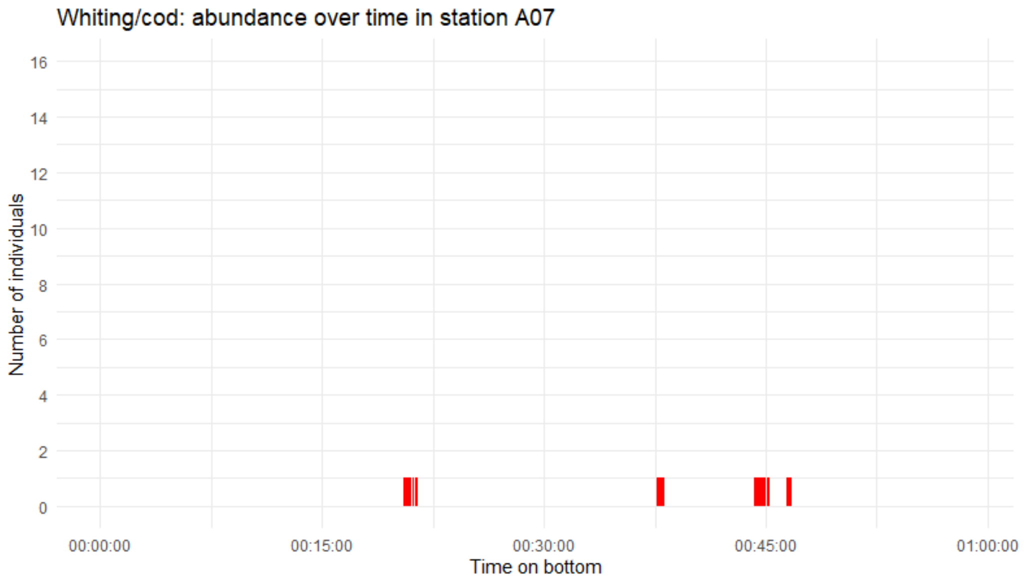

Bib/poor cod: abundance over time in station A03
Number of individuals
32
28
24
20
16
12
8
4
0
00:00:00
00:15:00
00:30:00
00:45:00
Time on bottom

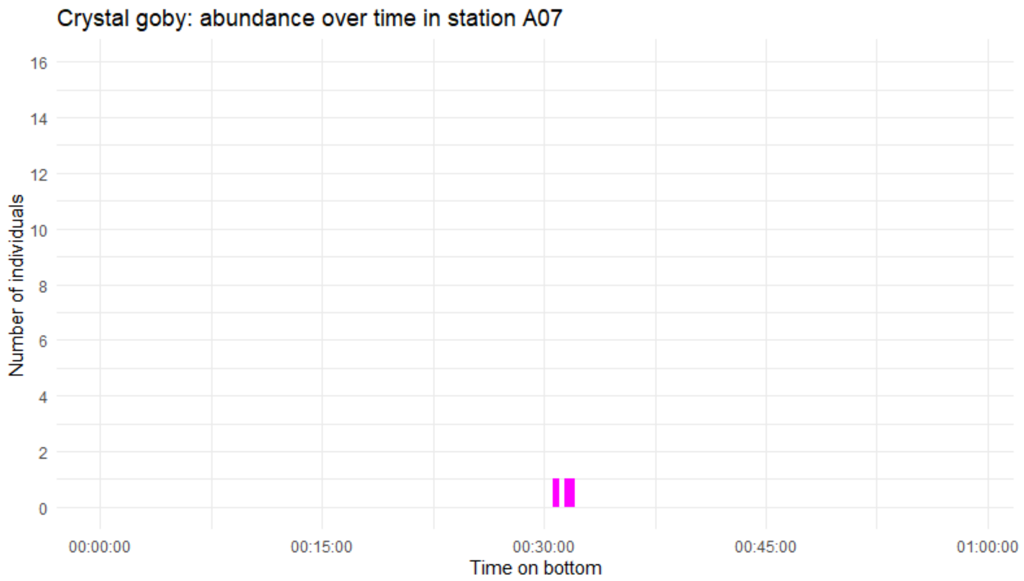
Station A07

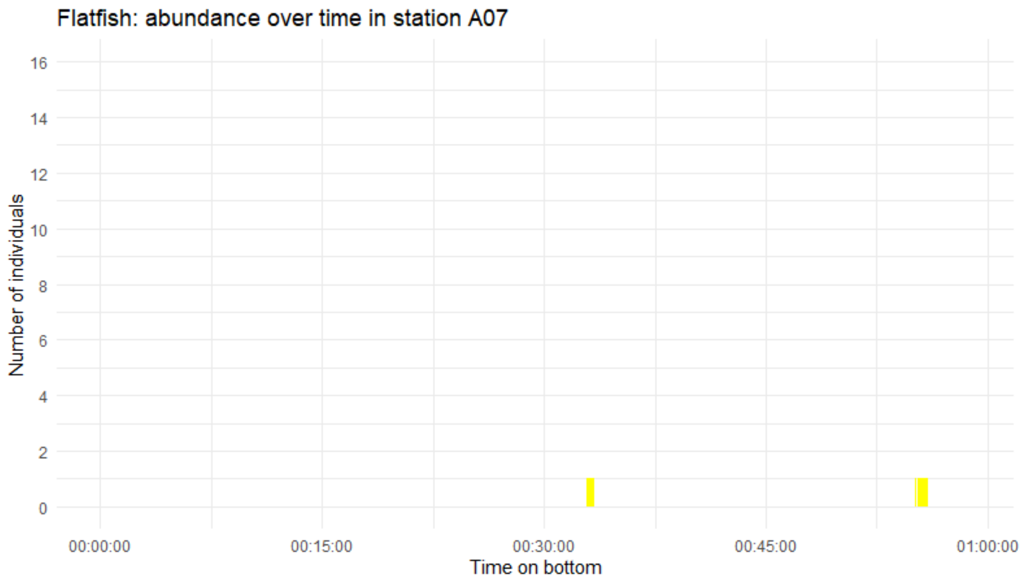

Total abundance over time in station A07
Number of individuals
16
14
12
10
8
6
4
2
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom


Gobies: abundance over time in station A07
Number of individuals
16
14
12
10
8
6
4
2
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

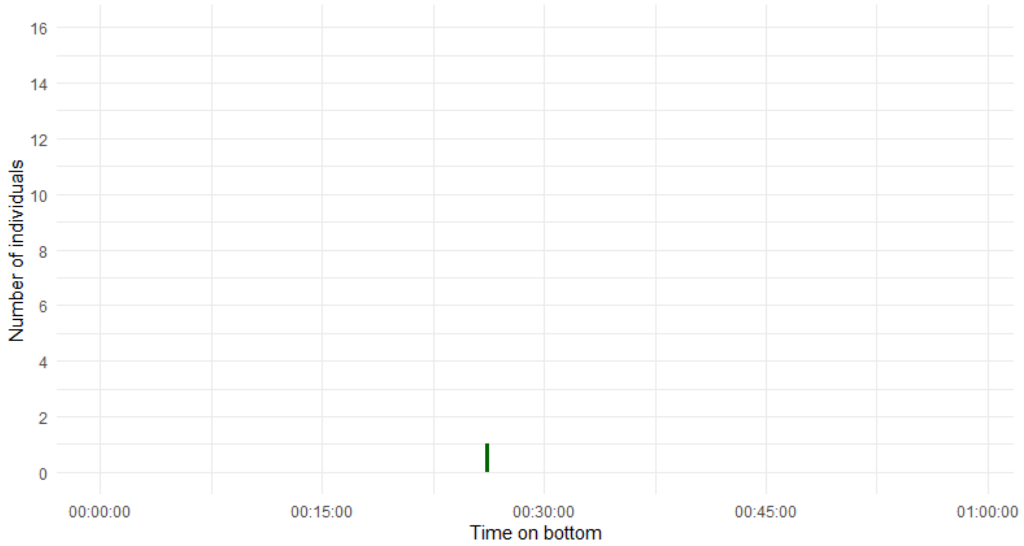

Horse mackerel: abundance over time in station A07
Number of individuals
16
14
12
10
8
6
4
2
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom


Whiting/cod: abundance over time in station A07
Number of individuals
16
14
12
10
8
6
4
2
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

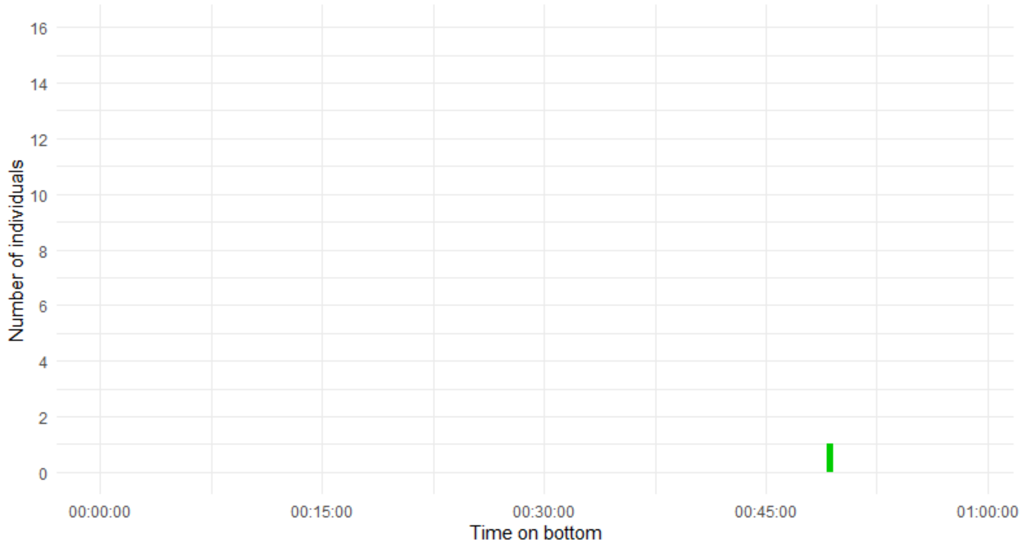

Crystal goby: abundance over time in station A07
Number of individuals
16
14
12
10
8
6
4
2
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom


Flatfish: abundance over time in station A07
Number of individuals
16
14
12
10
8
6
4
2
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

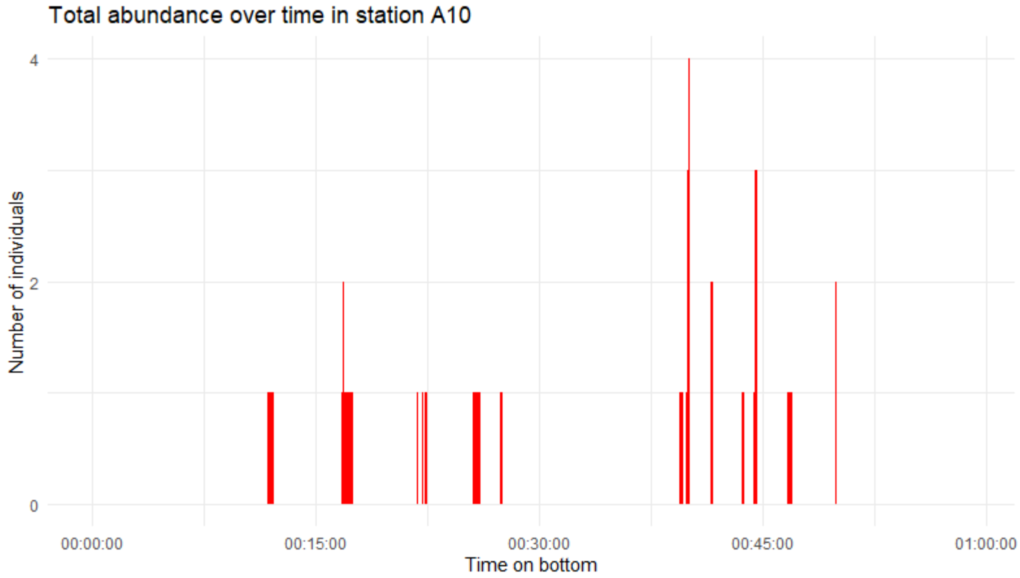
Butterfish: abundance over time in station A07

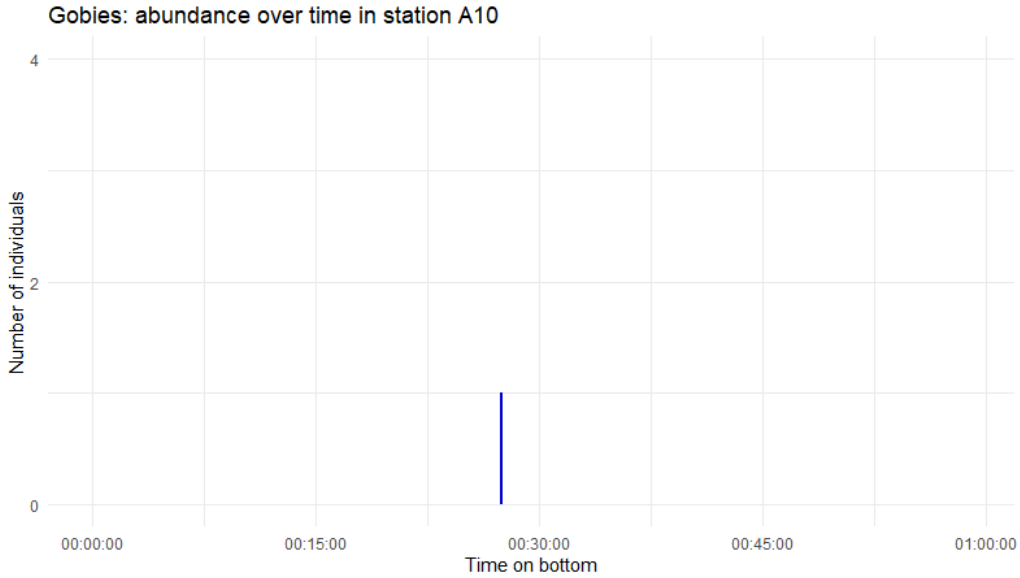


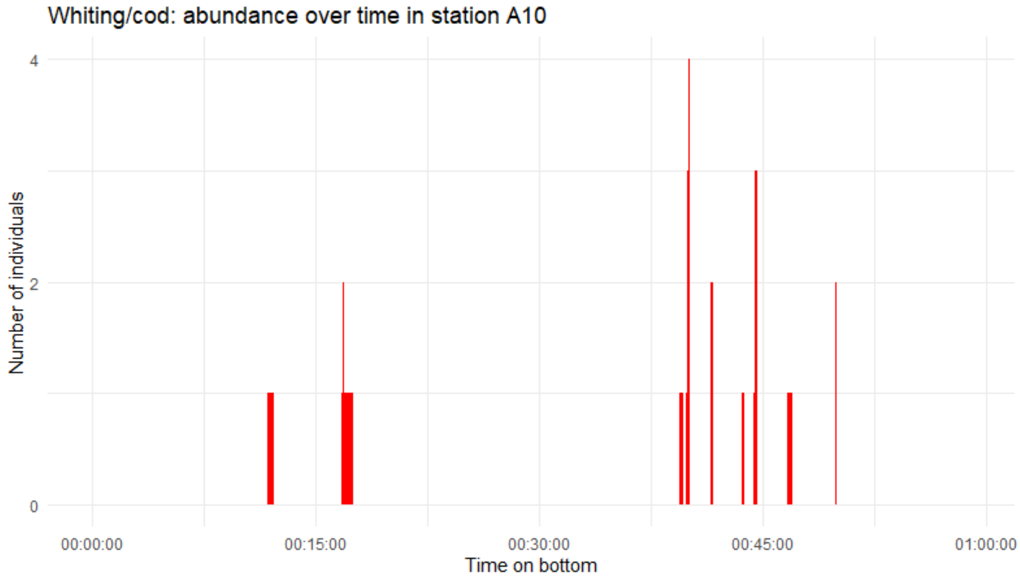
Pipefish: abundance over time in station A07



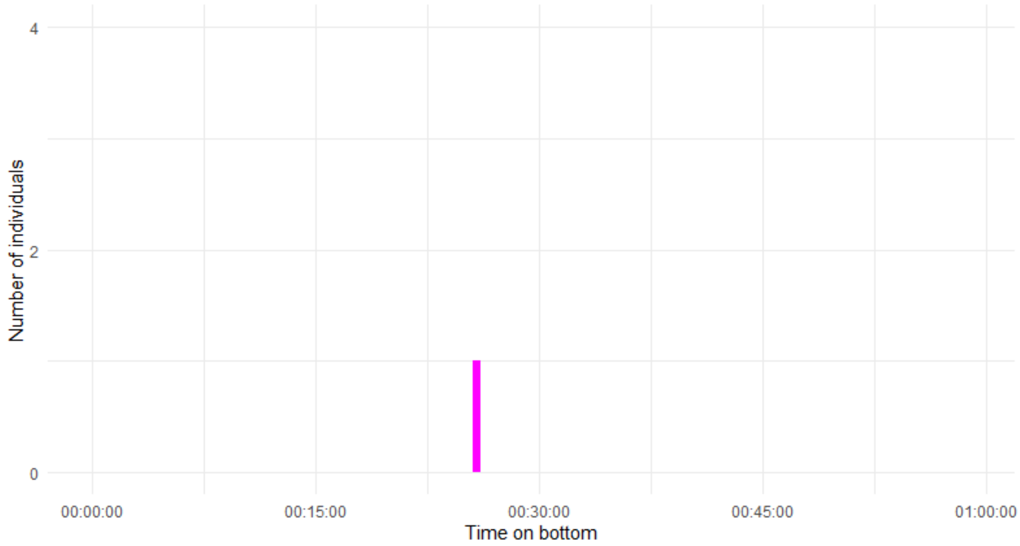
Station A10


Total abundance over time in station A10
Number of individuals
4
2
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

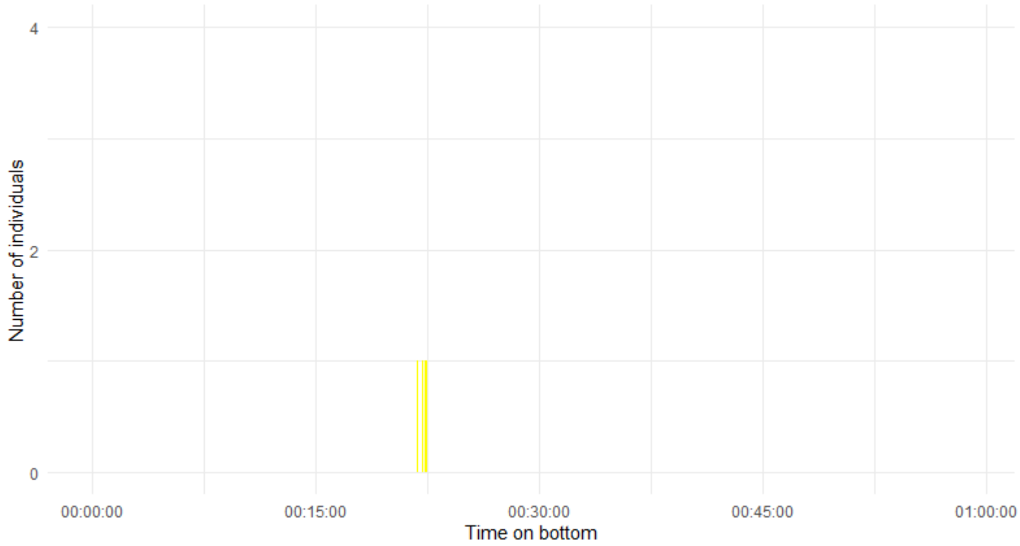

Gobies: abundance over time in station A10
Number of individuals
4
2
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom


Whiting/cod: abundance over time in station A10
Number of individuals
4
2
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

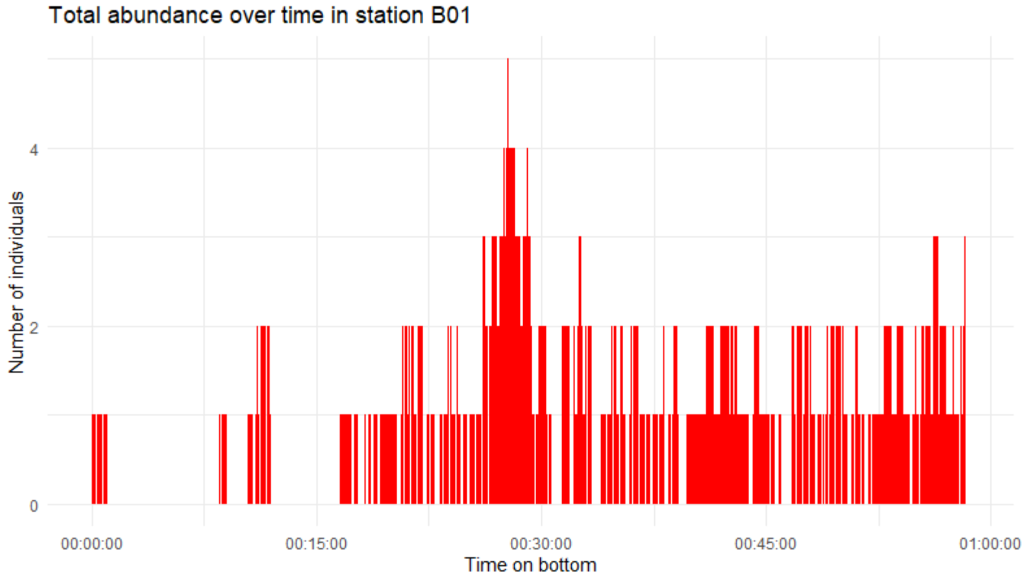
Crystal goby: abundance over time in station A10

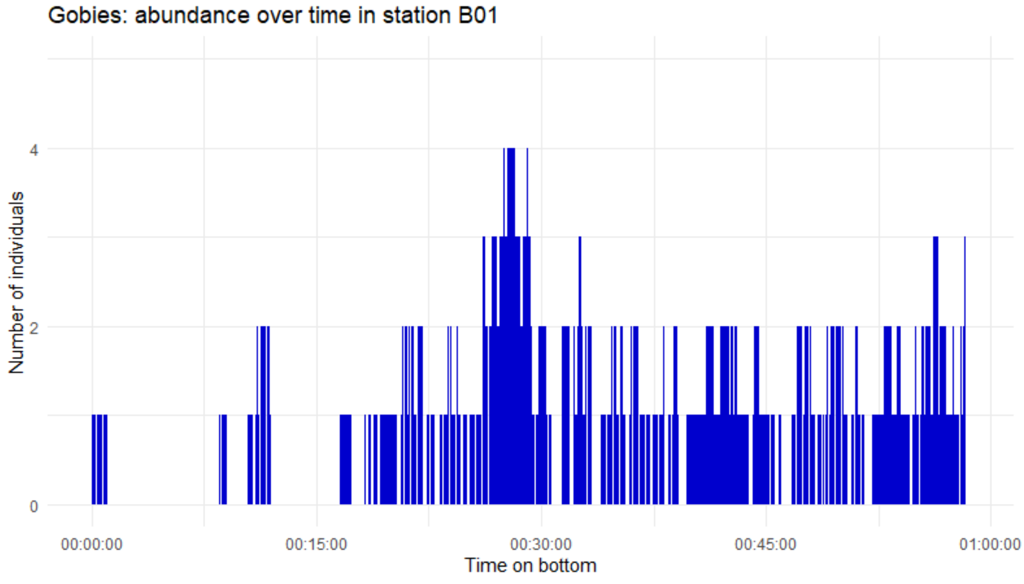


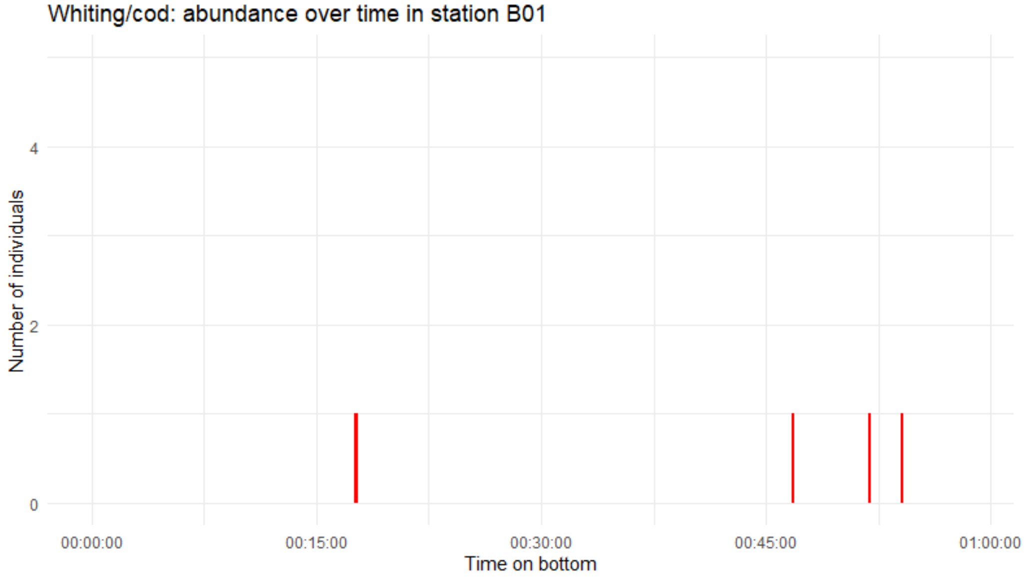
Flatfish: abundance over time in station A10



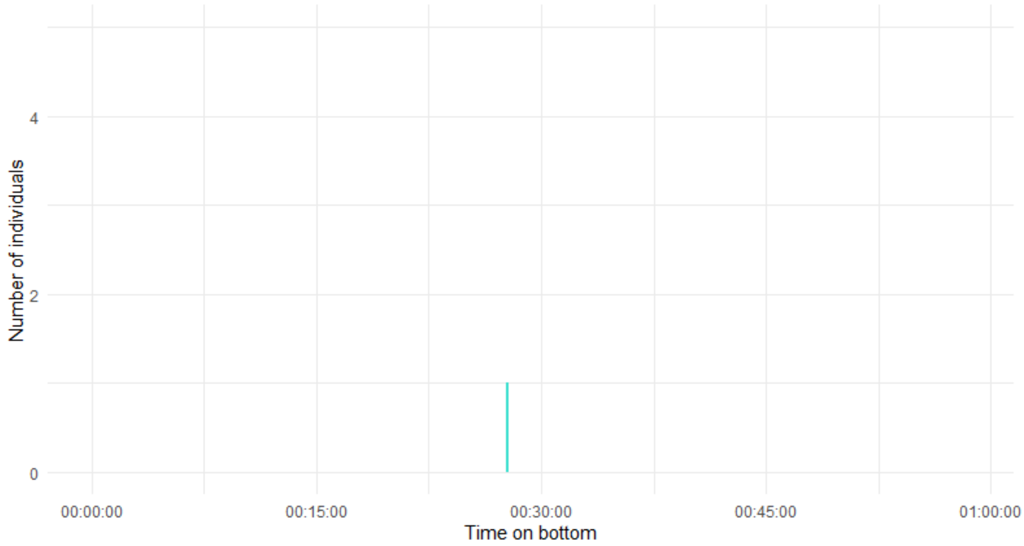
Station B01


Total abundance over time in station B01
Number of individuals
0
2
4
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

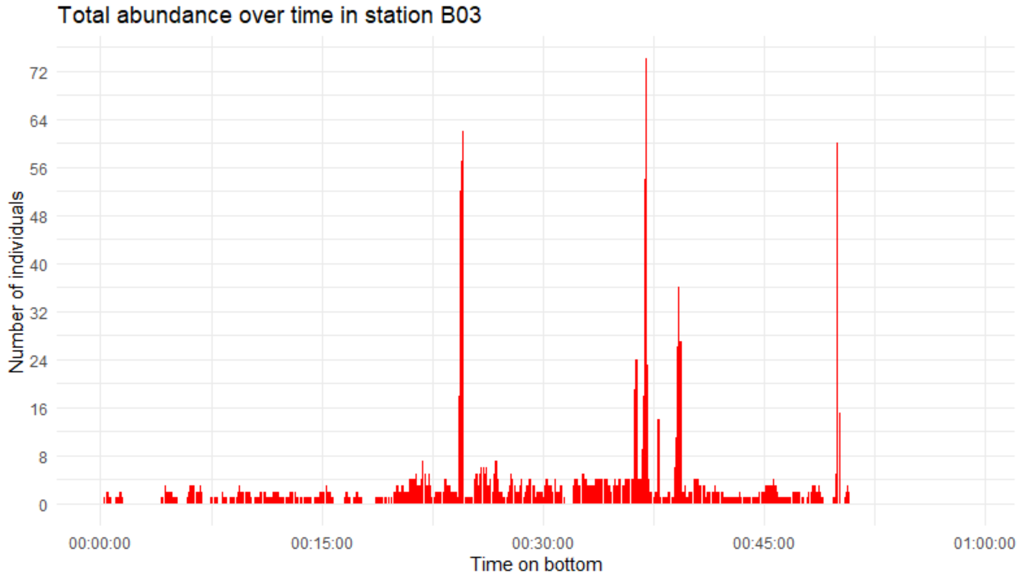

Gobies: abundance over time in station B01
Number of individuals
0
2
4
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom


Whiting/cod: abundance over time in station B01
Number of individuals
0
2
4
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

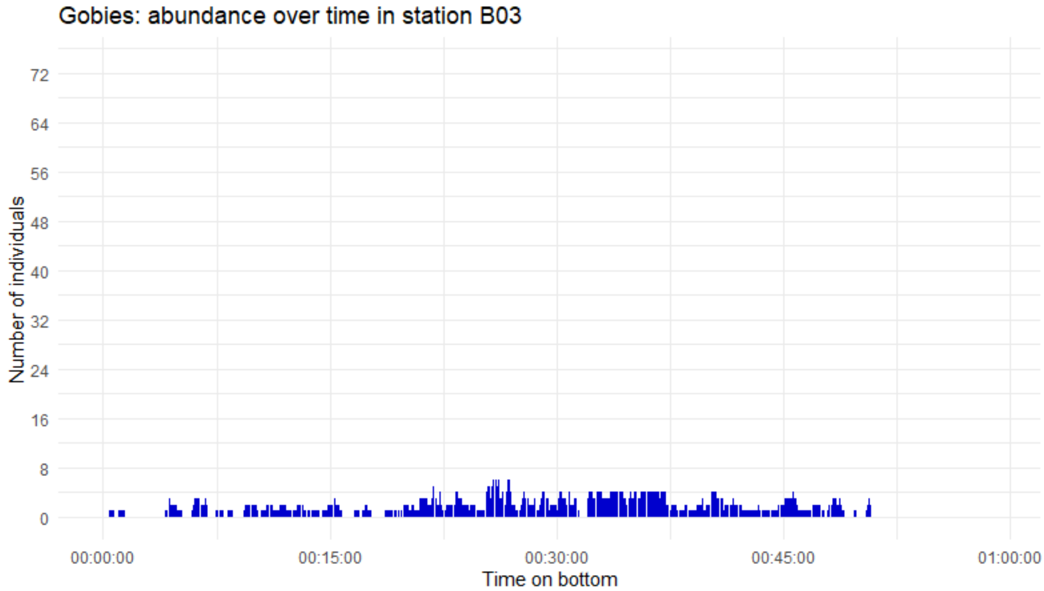
Goldsinny wrasse: abundance over time in station B01



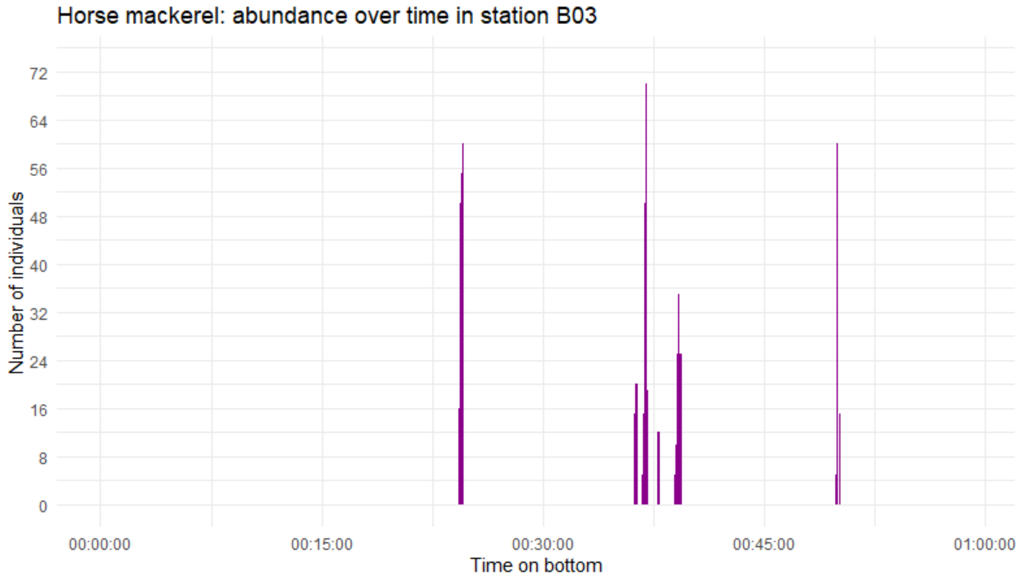
Station B03



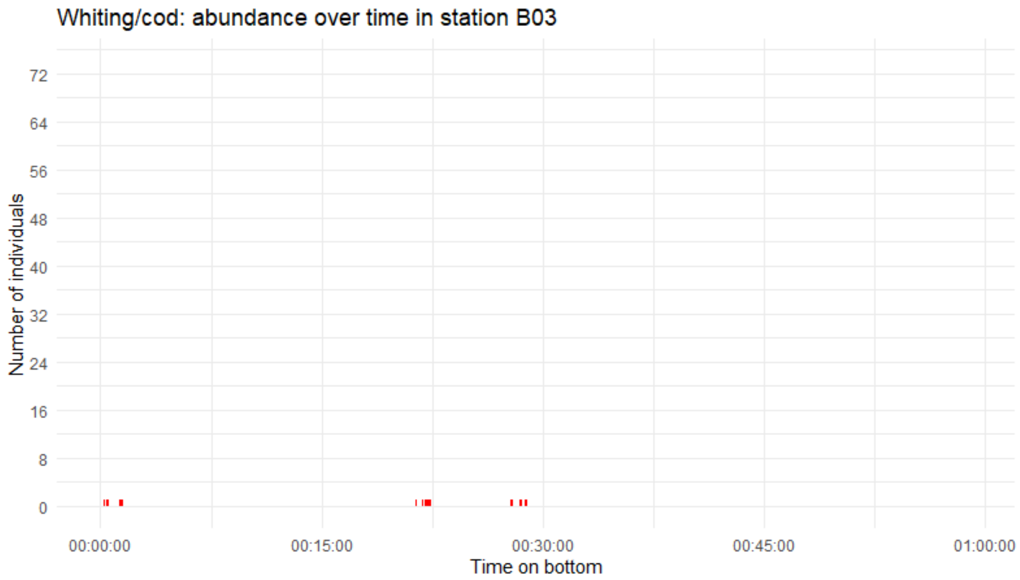
Total abundance over time in station B03
Number of individuals
72
64
56
48
40
32
24
16
8
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

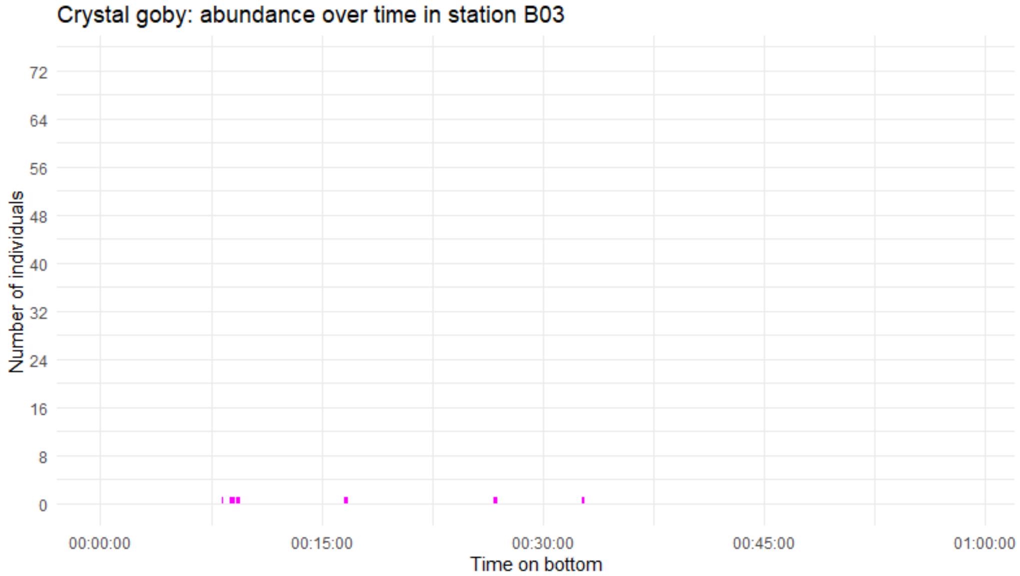


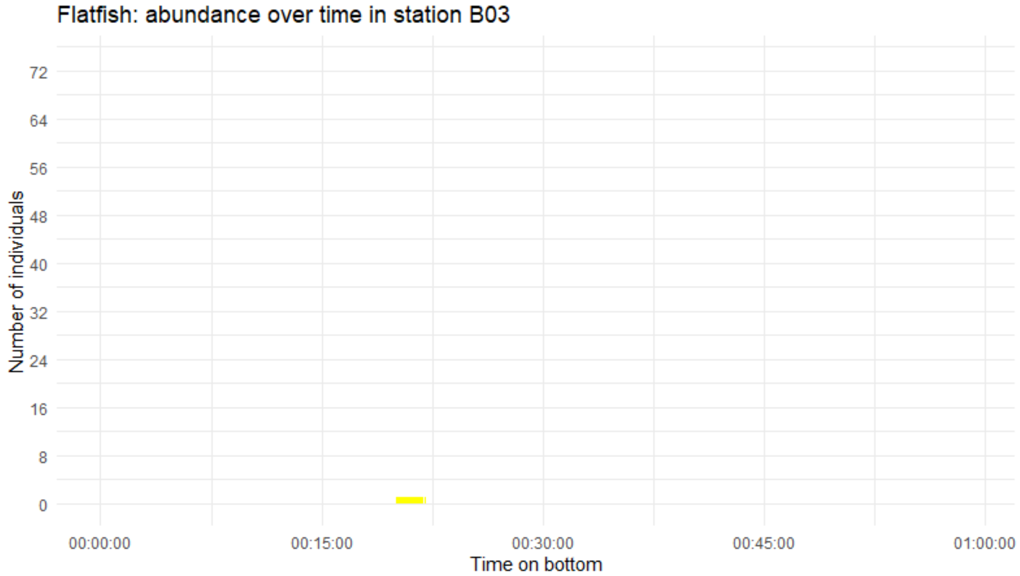
Gobies: abundance over time in station B03
Number of individuals
72
64
56
48
40
32
24
16
8
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom



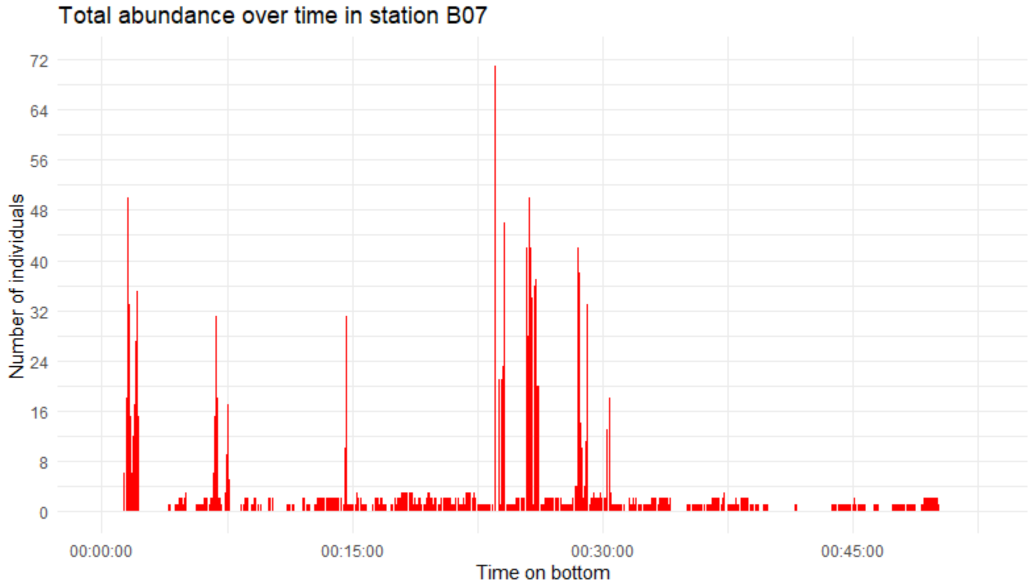
Horse mackerel: abundance over time in station B03
Number of individuals
72
64
56
48
40
32
24
16
8
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom


Whiting/cod: abundance over time in station B03
Number of individuals
72
64
56
48
40
32
24
16
8
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

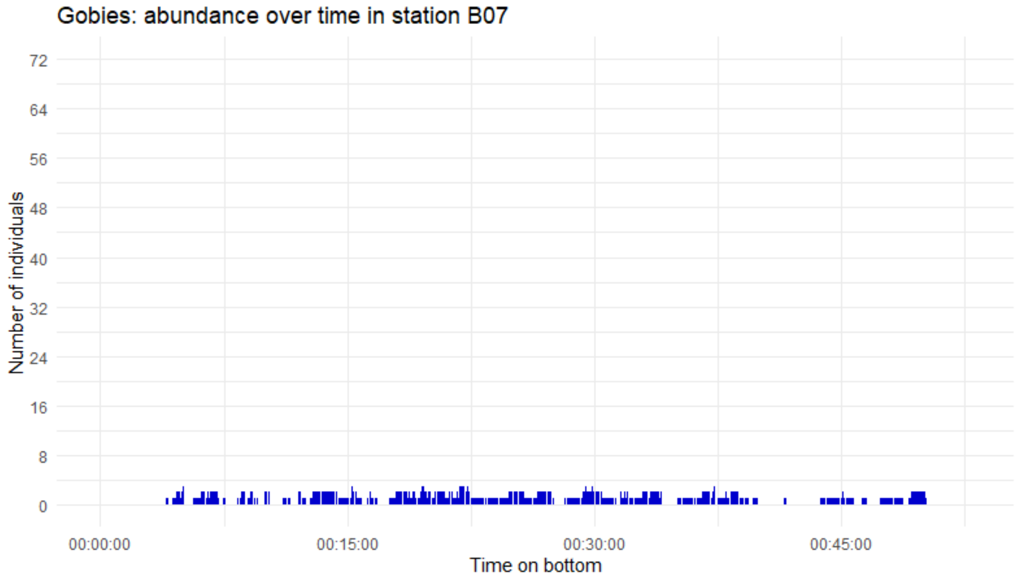

Crystal goby: abundance over time in station B03
Number of individuals
72
64
56
48
40
32
24
16
8
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

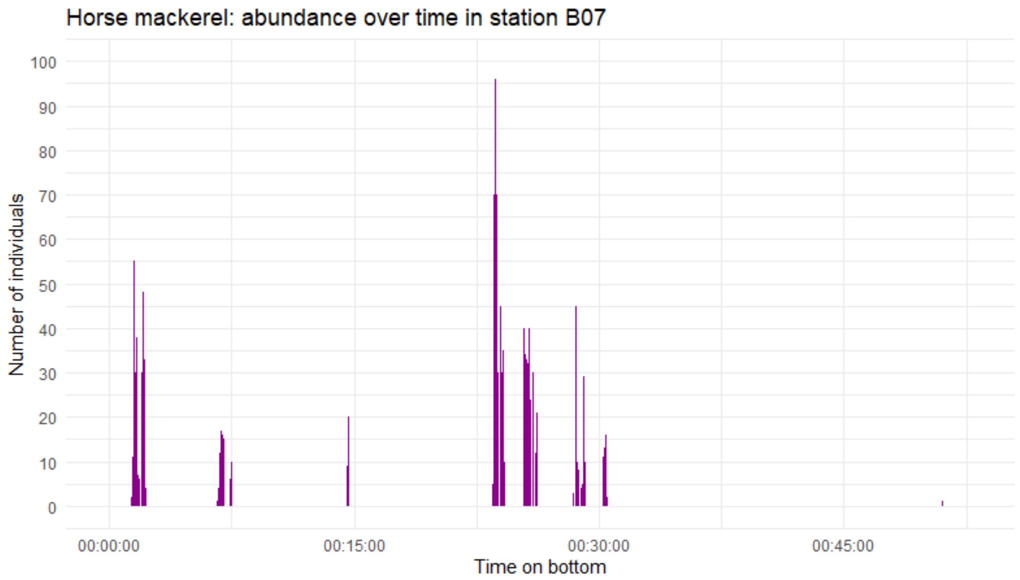

Flatfish: abundance over time in station B03
Number of individuals
72
64
56
48
40
32
24
16
8
0
00:00:00
00:15:00
00:30:00
00:45:00
01:00:00
Time on bottom

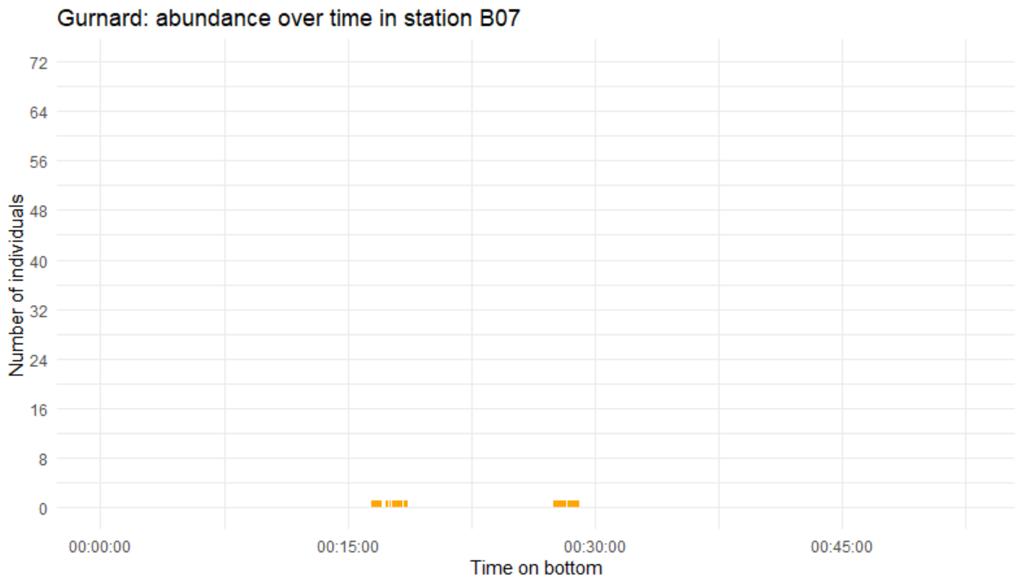
Station B07



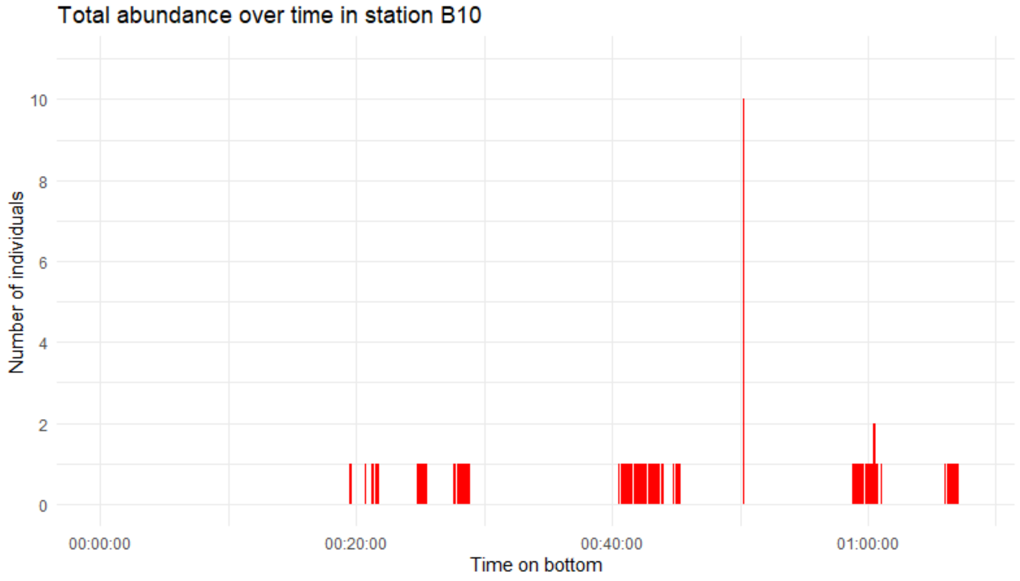
Note: There were 9 seconds where the abundance of horse mackerel went up to 97 individuals. These datapoints were left out of the total abundance graph to ensure readability.



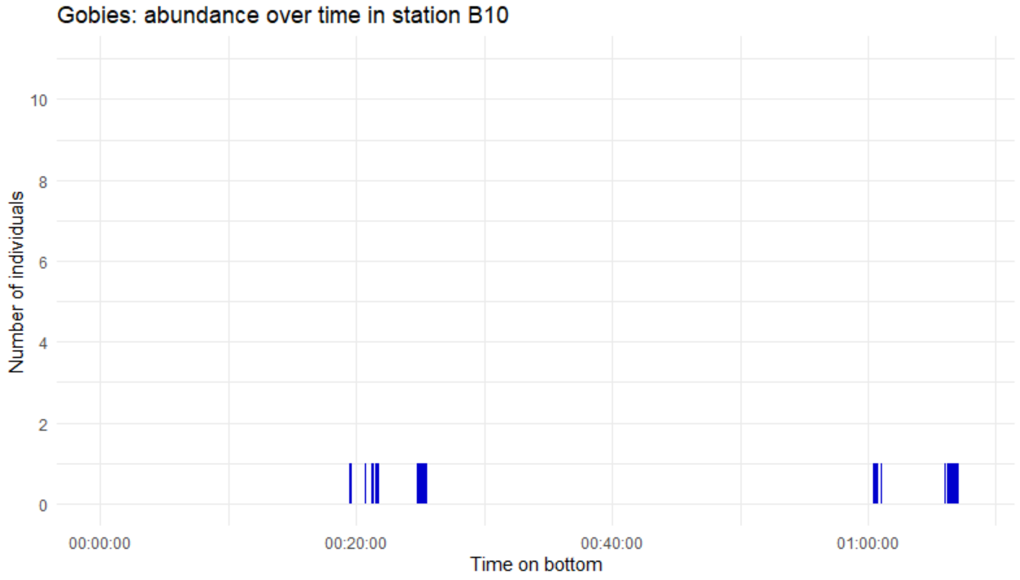

Horse mackerel: abundance over time in station B07
Number of individuals
100
90
80
70
60
50
40
30
20
10
0
00:00:00
00:15:00
00:30:00
00:45:00
Time on bottom


Gurnard: abundance over time in station B07
Number of individuals
72
64
56
48
40
32
24
16
8
0
00:00:00
00:15:00
00:30:00
00:45:00
Time on bottom

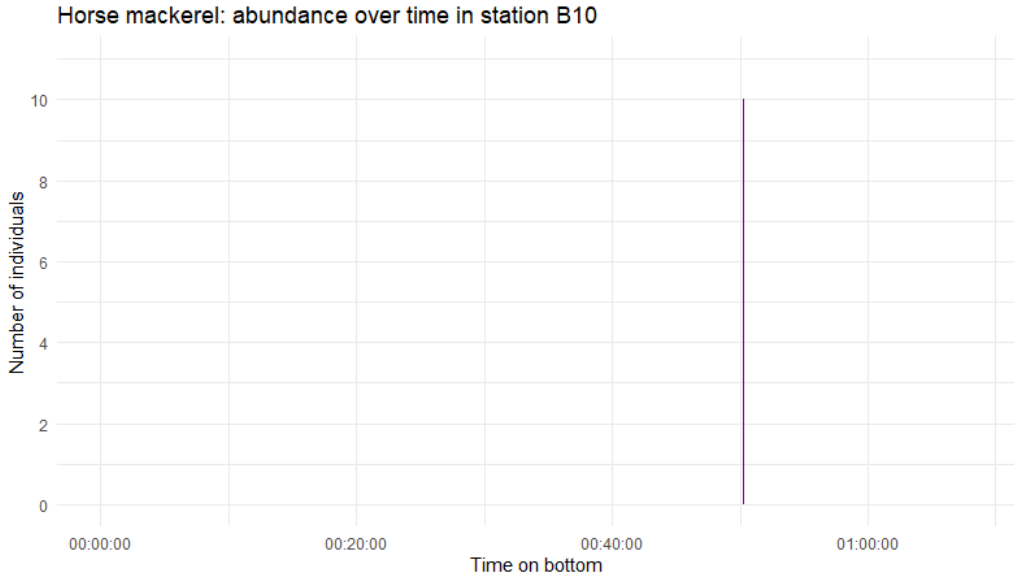
Station B10



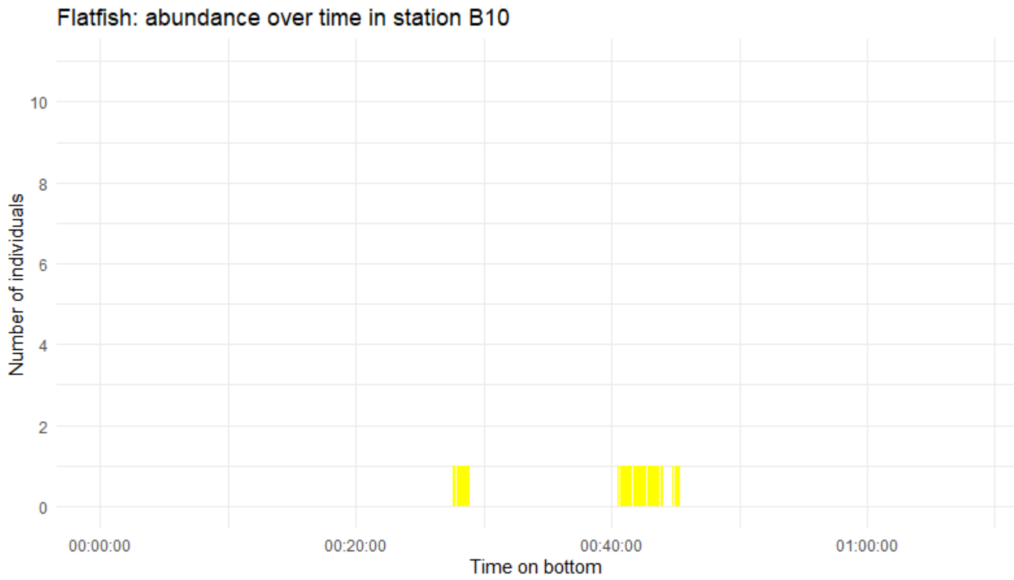
Total abundance over time in station B10
Number of individuals
10
8
6
4
2
0
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom

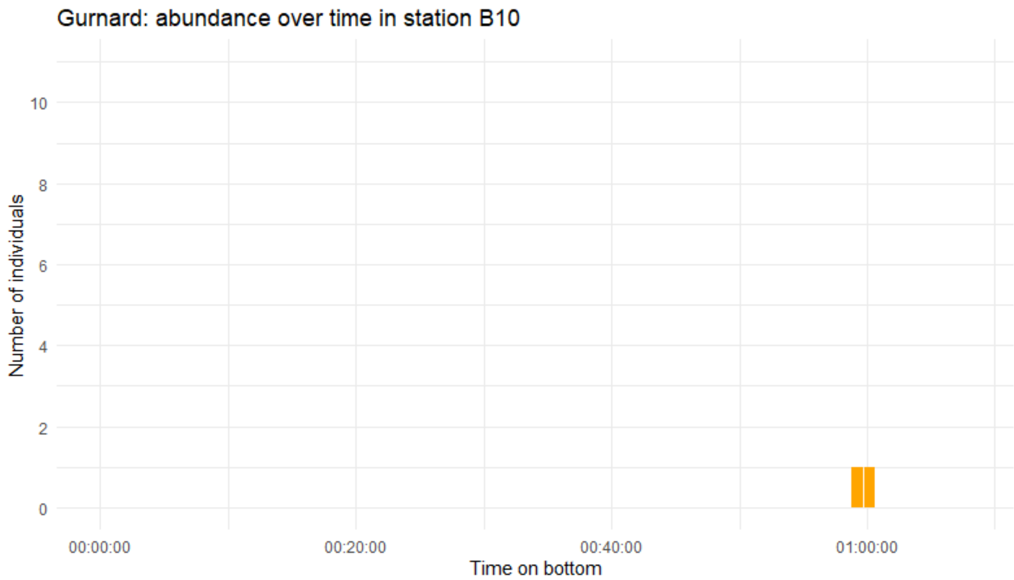


Gobies: abundance over time in station B10
Number of individuals
10
8
6
4
2
0
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom



Horse mackerel: abundance over time in station B10
Number of individuals
10
8
6
4
2
0
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom


Flatfish: abundance over time in station B10
Number of individuals
0
2
4
6
8
10
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom


Gurnard: abundance over time in station B10
Number of individuals
0
2
4
6
8
10
00:00:00
00:20:00
00:40:00
01:00:00
Time on bottom