Environ Biol Fish (2022) 105:453–458
https://doi.org/10.1007/s10641-022-01239-3

Previously undocumented relationship between spiny dogfish *Squalus acanthias* and juvenile Atlantic horse mackerel *Trachurus trachurus* revealed by stereo-BRUV

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Received: 11 November 2021 / Accepted: 1 March 2022 / Published online: 15 March 2022

Abstract This study revealed a previously undocumented association between a teleost and a shark. Atlantic horse mackerel *Trachurus trachurus* were observed following spiny dogfish *Squalus acanthias* during 3 consecutive years (2018–2020) on off-shore banks in Kattegat (57°N; 11°E, Sweden). The observations were made by the use of stereo-BRUV (baited remote underwater stereo-video systems). Our findings provide additional information about relationships between sharks and teleosts and suggest that stereo-BRUV can add to the ecological knowledge gained from the commonly deployed trawl surveys in temperate waters such as the Kattegat. With the increasing use of BRUVs in areas where the method has rarely been used before, such as higher latitudes or deeper water, observations as the one described here will likely increase. We urge the growing community of BRUVvers to make use of the methods full potential and to share not only estimations of abundance of different species but also observations of species associations and behaviors. These observations are important for better understanding of the interaction between species and could be important knowledge for targeted management measures.

Keywords Atlantic horse mackerel · Spiny dogfish · stereo-BRUV · *Squalus acanthias* · *Trachurus trachurus*

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10641-022-01239-3.

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The use of baited remote underwater stereo-video systems (stereo-BRUVs) for sampling of demersal fish assemblages have increased rapidly in recent years (Whitmarsh et al. 2017). In addition to being a robust, cost-effective, and non-invasive method for data collection on relative abundance and size distributions of demersal fish (Langlois et al. 2020), it also has potential to reveal previously unknown behaviors and relationships between various fish species (Fuller and Parsons 2019). Although the stereo-BRUV method is commonly used globally, it is not a common sampling method in the North East Atlantic (Unsworth et al. 2014). Therefore a study was designed with the purpose to evaluate and apply stereo-BRUV as a method to monitor relative abundance and body size structure of predatory fish on off-shore bank habitats in the Kattegat, Sweden. However, during the video analysis, a previously unknown association between spiny dogfish *Squalus acanthias* L. and Atlantic horse mackerel *Trachurus trachurus* L. was observed and data could opportunistically be collected to describe this relationship.

Sharks associate with various fish species, such as sharksucker *Echeneis naucrates* L., cleaner wrasses *Labroides* spp., and pilotfish *Naucrates doctor* L., resulting in a range of relationships from mutualisms and commensalisms to parasitism and predator–prey interactions. The association between cleaner fish and sharks, in which the cleaner feeds on ectoparasites (Sazima and Moura 2000), is an example of a mutualistic relationship, such that both organisms benefit from the interaction. The association of sharks with *E. nacrates* has been proposed as parasitic due to the potential for damage to the shark's skin and/or increased drag that the shark may experience (Brunnschweiler 2005). A commensalistic relationship is described between some small teleosts, such as *N. doctor*, and sharks because the sharks are assumed unaffected by the interaction, while the *N. doctor* may gain access to a food source and/or protection from predators. There is a wealth of information on the associations between sharks and the fish species exemplified above, but descriptions of relationships with other fish taxa are practically non-existent in published scientific literature (Fuller and Parsons 2019).

Squalus acanthias has a cosmopolitan distribution and was once considered to be the most abundant shark species in the world (Compagno 1984). Today *S. acanthias* is listed as "vulnerable" by the IUCN Red List of Threatened Species due to population decrease (Finucci et al. 2020). The species is divided into several stocks, and the Northeast Atlantic stock is found from the Bay of Biscay to the Barents Sea. It is a demersal and mid-water predator, but little is known about specific habitat requirements (McMillan and Morse 1999). Studies in the North-West Atlantic indicate that males tend to occupy deeper, more saline waters than females and that the species tends to prefer waters of 7–15º C (Compagno 1984).

Trachurus trachurus is a widely distributed pelagic species in the eastern Atlantic and the Mediterranean Sea, and the only resident carangid species in north-western Europe (ICES 2006). Habitat preferences are poorly understood; however, a variety of hydrographical features may be expected to affect their distribution, temperature being an important one (Iversen et al. 2002). *Trachurus trachurus* may grow to about 60 cm in length, maturity normally occur at a size of 16–25 cm, and they reach approximately 12 cm in length by the end of their first year (ICES 2006). The juveniles have been determined to be pelagic feeders that predate on planktonic organisms such as euphausiids and copepods (Macer 1977), adult individuals feed increasingly demersally, and small fish become more important in their diet as they grow (Dahl and Kirkegaard 1986). *Trachurus trachurus* have previously been documented to associate with a basking shark *Cetorhinus maximus* (Gunnerus 1765). More than 20 individuals where observed to follow *C. maximus* during observations with an autonomous underwater vehicle (Hawks et al. 2020). *Trachurus trachurus* followed the shark at the base of its tail fin as it was swimming near to the seabed and could be seen contacting the shark caudal fin on multiple occasions, suggesting they may be using the shark as a cleaning surface (Hawks et al. 2020). Juveniles of the fish species in the carangidae family have also been documented to associate with other larger organisms and floating objects, such as jellyfishes (Masuda et al. 2008) and floating patches of seaweed (Vandendriessche et al. 2007). The general hypothesis is that the juveniles associate with these larger objects for protection against predators.

For the purposes of evaluating the method to establish a baseline on relative abundance and body size structure of predatory fish, stereo-BRUVs have been used on the off-shore banks in Kattegat during 4 surveys (Table 1). Due to the evaluating properties of the first deployments, the design of the survey was initially not fully determined. In survey no. 4 (Oct 2020), sampling design and method was set according to a standardized protocol defined in Langlois et al. (2020). Video analysis was conducted in the software EventMeasure from SeaGis®, and abundance and body size measurement were collected at MaxN (the maximum number of individuals observed together in one frame over the sampling period; Whitmarsh et al. 2017). For the purpose of analyzing differences in spatial distribution, the off-shore banks were divided into three major areas: (1) Fladen, (2) Lilla Middelgrund, and (3) Glommaryggen (Fig. 1).

Table 1 Date (month–year), number of valid deployments (N), and mean depth (mD) of deployments per area for each survey. Apart from showing that relative abundance (RA) of Squalus acanthias was higher on the northern bank (Fladen) compared to the southern banks (L. Middelgrund and Glommaryggen), the table also shows that the abundance in each area was relatively consistent between the two surveys conducted in October (survey 3 and 4)

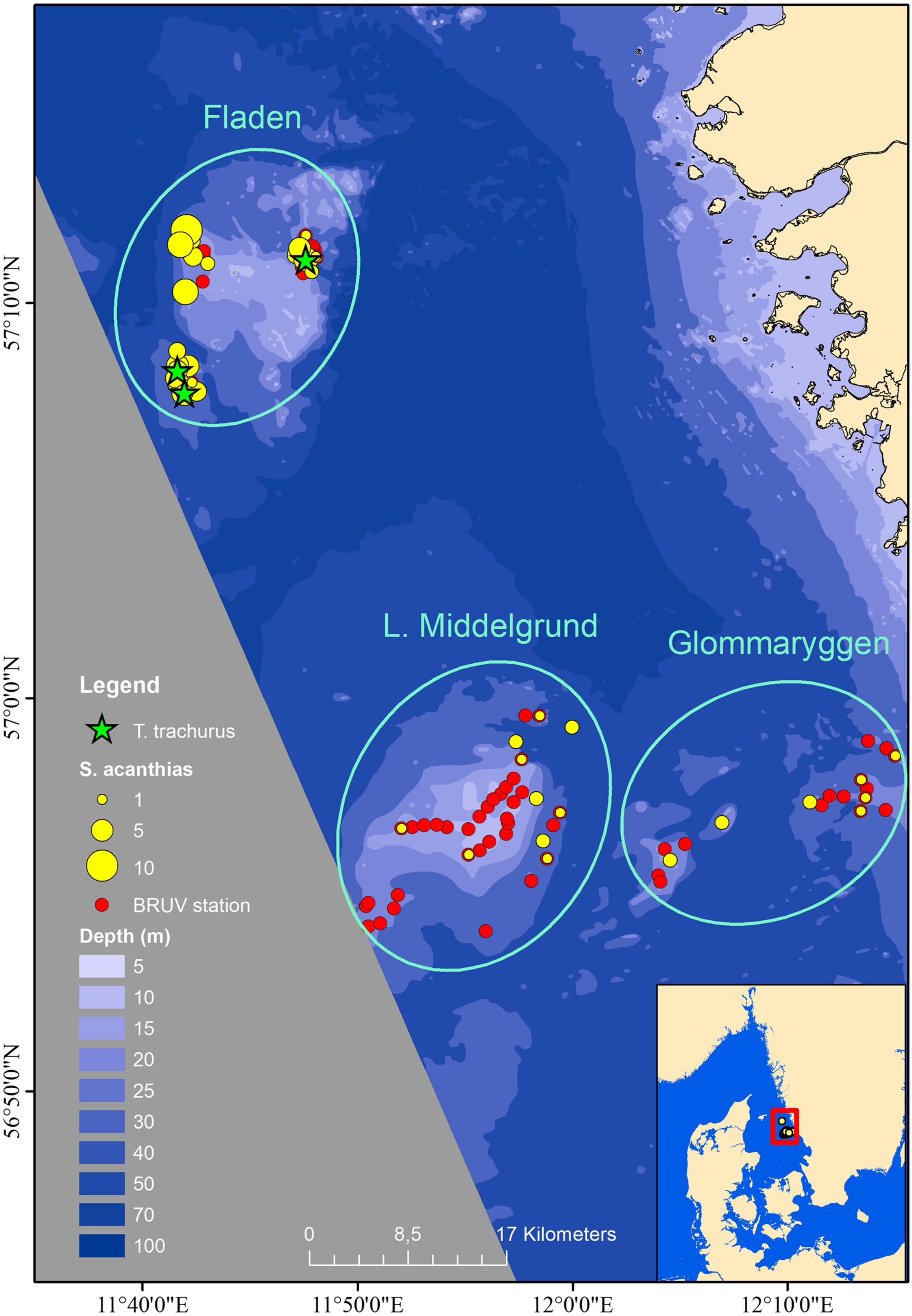
	Survey 1 (Dec – 18)			Survey 2 (Feb – 19)			Survey 3 (Oct – 19)			Survey 4 (Oct – 20)		
Area	N	mD	RA	N	mD	RA	N	mD	RA	N	mD	RA
Fladen	11	19	1.09	24	18	0	23	18	3.52	22	18	3.05
L. Middelgrund	11	22	0.09	23	16	0	36	19	0.31	38	16	0.37
Glommaryggen	4	30	0	14	23	0	12	25	0.50	18	18	0.55

Relative abundance of *S. acanthias* was calculated as sum of MaxN/by total number of deployments in each area. Frequency of occurrence of the relationship between *S. acanthias* and *T. trachurus* was calculated as observed number of pairs/by sum MaxN in each area. Deployments where the BRUV tipped over on landing, or landed on a rock, such that the cameras pointed vertically towards the surface were considered invalid and excluded from the analysis.

The result from the analysis revealed that relative abundance of *S. acanthias* was higher on the northern bank (Fladen) compared to the southern banks (L. Middelgrund and Glommaryggen) during surveys 1, 3, and 4 (Table 1; Fig. 1). No observations of *S. acanthias* were made during survey 2. All observations of *T. trachurus* following *S. acanthias* were made on the northern bank (Fig. 1). Frequency of occurrence of the relationship in this area was determined to be 8% during survey 1, 1% during survey 3, and 6% during survey 4. On one deployment during survey 4, two *T. trachurus* were observed at the same time, each individual following its own *S. acanthias*. *Trachurus trachurus* not accompanied by *S. acanthias* were only observed during survey 1. Shoals (> 10 individuals) of juvenile fish (10–12 cm) were seen after sunset at two different stations at L. Middelgrund, and one single juvenile fish was recorded during daylight hours at one station at Fladen. Length of *S. acanthias* that were accompanied by *T. trachurus* ranged from 65 to 100 cm and length of the *T. trachurus* ranged from 9 to 12 cm. Observations of the interactions between the two species showed that *T. trachurus* tried to stay close to the dorsal fin of *S. acanthias* at all time (Fig. 2). On one occasion *T. trachurus* was observed to switch between two individuals of *S. acanthias* in the turmoil around the bait bag of the stereo-BRUV. *Trachurus trachurus* was not observed to show interest in the bait bag or feeding on the small pieces of bait released in the water when *S. acanthias* attacked the bait. A video sequence showing the relationship can be found here: [submitted as Supplementary Information]

This study has revealed a previously undocumented association between a teleost and a shark and showed that stereo-BRUV can add to the ecological knowledge gained from the commonly deployed trawl surveys in temperate waters such as the Kattegat. Species identification can however be a challenge with the non-destructive BRUV technique, especially in the carangidae family where several species are similar in appearance at the juvenile stage. We are however confident that the carangid observed following *S. acanthias* during the stereo-BRUV survey in Kattegat is *T. trachurus* as the geographical area, the shape and colour of the fish, and the keeled scales on the arched lateral line running up to the posterior end of the dorsal fin exclude other possible species. Length measurements of the fish suggest that the observed *T. trachurus* were juveniles (9 to 12 cm) and that the *S. acanthias* they followed were adult individuals (65 to 100 cm). All observations of the relationship between the species were made in the same area. It could consequently be a local phenomenon, but it is more likely to be correlated with the number of observations of *S. acanthias*, which was about ten times higher in the Fladen area compared to the other two off-shore banks included in the survey.

Even though the video observations clearly show *T. trachurus* following the sharks, it was not possible to fully determine the nature of the relationship between the two species from the recordings. Interactions observed in other shark-teleost associations, such as parasite cleaning or scavenging, were not observed in the studied species pair. Based on the limited observations, a commensalistic relationship between the species, where *T. trachurus* uses *S.*


Fladen
L. Middelgrund
Glommaryggen
Legend
T. trachurus
S. acanthias
1
5
10
BRUV station
Depth (m)
5
10
15
20
25
30
40
50
70
100
0
8,5
17 Kilometers
57°10'0"N
57°0'0"N
56°50'0"N
11°40'0"E
11°50'0"E
12°0'0"E
12°10'0"E

◂**Fig. 1** Map of Swedish territorial waters in Kattegat with the three major areas of off-shore banks included in the study encircled. Red dots represent stereo-BRUV stations, size of the yellow dots represent MaxN of *Squalus acanthias*, green star show where *Trachurus trachurus* was observed following *S. acanthias* during survey number 4

acanthias for protection against other predators and/or as a way to obtain food (debris produced when feeding or feces (Sazima et al. 2003)), as well as an optomotor response (the compulsion of schooling fish to move along with a moving object (Kroger et al. 2003)) are both plausible explanations.

Regardless of the mechanisms behind the relationship between *S. acanthias* and the juvenile *T. trachurus*, this study highlights one important benefit of using stereo-BRUV that often is missed in papers discussing the pros and cons of the method (e.g., Harvy et al. 2001, 2002; Langlois et al. 2020; Whitmarsh et al. 2017). Underwater recordings provide observations of nekton species in their natural environment. Survey methods relying on catching the organisms and bring them out of the water for counting and measuring do not have this benefit. For ecosystem based management and the establishment of MPAs for the protection of species, species associations (behavioural interactions, dependences at different life stages) is essential knowledge (Crowder and Norse 2008).

With the increasing use of BRUVs in areas where the method has rarely been used before, such as higher latitudes or deeper water (which generally also is less explored by divers) observations such as the one described here will likely increase. We urge the growing community of BRUVvers to make use of the method's full potential and to share not only estimations of abundance of different species but also observations of species associations and behaviors. These observations are important for a better understanding of the interaction between species and could be important knowledge for targeted management measures.

Fig. 2 Screenshot from the left camera of a stereo-BRUV deployed at Fladen during survey 4. The main picture show *Trachurus trachurus* following the dorsal fin of *Squalus acanthias*. The inserted picture in the top right corner show *T. trachurus* in close proximity to the camera when it temporarily separated from *S. acanthias* in the turmoil around the bait. The keeled scales and the arched lateral line, which is one of the main characteristics of *T. trachurus*, is clearly visible

Acknowledgements We thank Karl Lundström, Diana Hammar Perry, and the crew on the fishing vessels and Cindy Wester, Wanndee, and R/V Skagerrak for their assistance with deployment of the stereo-BRUVs during the surveys. We thank the reviewers for their time and effort and for improving the quality of this publication.

Author contributions Data was collected by MO and JH and analysed by MO. The first draft of the manuscript was written by MO and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding Open access funding provided by Swedish University of Agricultural Sciences. This study was financed by the Swedish Agency for Marine and Water management (SwAM) (HaV Dnr. 1826–2021).

Data availability No further data than that presented in this manuscript are available.

Declarations

Ethics approval No animal testing was performed during this study.

Conflict of interest The authors declare no competing interests.

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