Marine Environmental Research 112 (2015) 152–159

Contents lists available at ScienceDirect

Marine Environmental Research

journal homepage: www.elsevier.com/locate/marenvrev

Influence of fish aggregating devices (FADs) on anti-predator behaviour within experimental mesocosms

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ARTICLE INFO

Article history:
Received 4 June 2015
Received in revised form
19 October 2015
Accepted 21 October 2015
Available online 24 October 2015

Keywords:
FAD
Carangidae
Predator-prey interactions
Schooling
Aggregation
Behaviour
Predation
Refuge

ABSTRACT

Commercial fishers have used fish aggregating devices throughout the Mediterranean Sea for over 40 years. These devices attract numerous predatory and forage species in both coastal and offshore environments. This study examined the influence of fish aggregating devices on schooling and aggregating behaviour by small forage fish in quasi-natural mesocosms. Anti-predator behaviour was evaluated for juvenile *Caranx crysos* under a variety of treatment conditions. Results suggest that, in the absence of physical structure, *C. crysos* first respond to a predatory threat by forming a school. When a physical structure is present, however, *C. crysos* show an occasional tendency to aggregate near the structure. These results suggest that a threatened prey species can change their defensive strategy against predatory behaviour. Further examination is required to explain if fish aggregating devices can increase survival rates of post-larval and juvenile prey species in the southern Mediterranean Sea. Management agencies should consider the relationship between the use of fish aggregating devices by commercial fisheries and the potential influence such devices possess on population dynamics of aggregating fish species.

1. Introduction

In open ocean environments, many pelagic species are attracted to physical structures such as drifting algal mats (Ida et al., 1967; Casazza and Ross, 2008), animal carcasses (Castro et al., 2002), jellyfish (Masuda et al., 2008; Masuda, 2009), pillars (Hunter and Mitchell, 1967; Kingsford, 1993; Fréon and Dagorn, 2000), petroleum platforms (Hastings et al., 1976; Franks, 2000), discarded fishing gear (Carr, 1987), rafts (Shomura and Matsumoto, 1982), and trash (Riera et al., 1999). These structures, commonly referred to as fish aggregating devices (FADs), facilitate spatially heterogenetic aggregations of marine species in otherwise oligotrophic waters. Such aggregations have been well documented for hundreds of fish species throughout the world's oceans (Castro et al., 2002).

It is commonly believed that aggregative behaviour in fish, either obligatory or facultative, likely evolved to reduce individual predation risk (Hamilton, 1971), enhance food detection (Stephens and Krebs, 1987), or increase mating success (Pitcher and Parrish, 1993). Schooling behaviour is defined by further organization of the aggregate into synchronized groups whereby swimming speed and direction uniformly change to increase hydrodynamic efficiency (Weihs, 1973) or reduce predation risk (Brock and Riffenburgh, 1960). For small aggregative fish, FADs provide either direct protection from predation (Hunter and Mitchell, 1967; Rountree, 1989; Castro et al.,2002) or they facilitate the implementation of mimicry or camouflage techniques that reduce a predator's ability to detect and capture its prey (Hunter and Mitchell, 1967; Kingsford, 1993; Fréon and Dagorn, 2000).

In the southern Mediterranean Sea, the number of permanently moored offshore FADs has consistently increased in recent decades (Morales-Nin et al., 2000). Moored FADs are often placed at great depths (800–1000 m) by commercial fishers, and, despite their

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http://dx.doi.org/10.1016/j.marenvres.2015.10.008
0141-1136/

obvious differences, possess a similar function and attractive capacity compared to man-made drifting FADs employed by purse seine fisheries in tropical waters (Dempster and Taquet, 2004; Dagorn et al., 2013). In general, FADs exploit aggregative behaviour of both demersal juvenile and adult pelagic species (Andaloro et al., 2007; Sinopoli et al., 2011). Of these, greater amberjack *Seriola dumerili* (Risso, 1810) and blue runner *Caranx crysos* (Mitchill, 1815) are two of the most common FAD-aggregated species in the Mediterranean Sea during their juvenile and semi-adult stages (Andaloro et al., 2007; Sinopoli et al., 2011). In these early life stages, both species are considered opportunistic predators that consume a variety of crustacean and teleost prey (Badalamenti et al., 1995; Sley et al., 2009), including the consumption of *C. crysos* by *S. dumerili* (Stergiou and Karpouzi, 2002; Auster et al., 2009). As adults, however, both species establish themselves as demersal reef-associated piscivores (Cervigón et al., 1992; Riede, 2004) with little direct predatory interaction (Andaloro and Pipitone, 1997).

Often, large-scale quasi-natural experimentation is hindered because of physical constraints such as the inaccessibility (i.e. depth) to offshore FADs (Andaloro et al., 2007). As a result, predator-prey experiments that observed the defensive strategies of prey in relation to physical structure have largely been carried out in laboratory reconstruction systems that try to mirror the environment of natural habitats (Masuda and Tsukamoto, 2000; Shoji et al., 2007; Masuda, 2009). Similar to large-scale experiments, predator-prey interactions observed under laboratory settings are also subject to limitations such as the size of the prey, the size of the predator, and physical structure implemented in the mesocosm (Masuda, 2009). Consequently, the functional basis of aggregative behaviour in fish is currently based upon empirical observations and unsubstantiated hypotheses (Capello et al., 2012; Dagorn et al., 2013; Robert et al., 2013). Among these, the “shelter from predator (SfP)” hypothesis (Hunter and Mitchell, 1967; Castro et al., 2002) attempts to disentangle the function of these behaviours in small aggregative fish.

The SfP hypothesis describes anti-predator behaviour of small fish when they are aggregated near FADs in open ocean environments (Fréon and Dagorn, 2000). Castro et al. (2002) proposed that post-larval and juvenile fish might aggregate with FADs in order to increase their dispersal capabilities and likelihood of survival during phases when they are most vulnerable to predation. Despite the importance of understanding the behavioural aspects implicated in SfP, studies that examined predator-prey interactions in relation to physical structure *in situ* are limited. Furthermore, if one considers the escapement potential by smaller fish from the gear commonly used in the commercial FAD purse seine fishery (Sinopoli et al., 2012), the SfP hypothesis could play an important role affecting the mechanisms that underlie fish population structure and dynamics. Therefore, additional predator-prey experiments using large-scale mesocosms under quasi-natural conditions are required to examine the role of SfP on aggregative behaviour in fish.

This study examined the two primary traits implicated in SfP behaviour (i.e. schooling vs. aggregative) during predator-prey interactions between *S. dumerili* (predator) and *C. crysos* (prey) held within offshore mesocosms. Three hypotheses related to SfP behaviour were examined using a variety of treatments (e.g., the presence of physical structure and/or predators). First, *C. crysos* would display a greater tendency to form schools as a main defensive strategy in the absence of FADs when predators were present. Second, *C. crysos* would show a significant tendency to aggregate if provided with available structure when predators were present. Finally, *C. crysos* would display randomized swimming behaviour similar to fish associated with FADs under natural conditions when predators were not present. The results of this study are necessary for implementing proper management strategies under conditions of increasing FAD use in the southern Mediterranean Sea.

2. Material and methods

2.1. Study area

This study was conducted from August–October, 2010 in the Gulf of Castellammare, on the northern coast of Sicily (LAT 38°02′31″ N; LONG 12°55′28″ E). Experimental treatments were performed in both quasi-natural mesocosms (i.e. large aquaculture cages; 3000 m^3, diameter 12 m, depth 6 m, mesh size of 12 mm) and open-sea environments. Mesocosms were positioned approximately 1.2 km off the coastline in the eastern Gulf of Castellammare, moored to the bottom at a depth of 32 m. Open-sea treatments were performed in an area approximately 4 km off the coastline at depths between 40 and 100 m.

2.2. Sample collection

Juvenile *C. crysos* ($n = 389$; mean TL ± S.D. $= 8.0 \pm 0.9$ cm) and semi-adult *S. dumerili* ($n = 247$; mean TL ± S.D. $= 37.0 \pm 2.8$ cm) were collected during August 2010 in the Gulf of Castellammare using a purse seine beneath commercially implemented FADs. Within 1 h of collection, specimens were transported to separate (*C. crysos* versus *S. dumerili*) offshore aquaculture holding cages. Fish were allowed to acclimate to the holding cages for two weeks prior to selection for experimental treatments; only non-debilitated individuals were selected for use in the study.

2.3. Experimental design

Experimental FADs were constructed by tying three *Phoenix canariensis* palm leaves together with six 2.5 L plastic bottles anchored to either the centre (base) of the mesocosm (i.e. mesocosm treatments) or to the substrate by a 30–40 kg boulder (i.e. open-sea treatments) (Fig. 1A). Polypropylene anchor lines (0.5 mm diameter) were long enough to allow the FADs to float at the surface of the water. With the exception of the mooring point (i.e. the anchor was connected to the centre of the mesocosm instead of the sea floor), all FADs were similarly constructed to those used by the commercial purse seine fishery.

Experimental treatments at both mesocosms and open-sea sites were sequentially conducted for 10 consecutive days between 0900 and 1400 h. Treatments were classified into one of the following three categories:

1) Prey + FAD − Predators (hereinafter FNP; Fig. 2A);
2) Prey + FAD + Predators (hereinafter FP; Fig. 2B); or
3) Prey − FAD + Predators (hereinafter NFP; Fig. 2C).

To assess the effect of captivity (i.e. presence of the mesocosm) on *C. crysos* behavioural responses, additional experiments were performed at FADs in open-sea environments (i.e. Prey + FAD − Predators − Mesocosm, hereinafter WFNP treatment; Fig. 2D). Open-sea experimentation allowed for the observation of aggregative behaviour by *C. crysos* near FADs in the absence of predators.

All treatments included 21 individuals of *C. crysos*; three specimens of *S. dumerili* were used in treatments that incorporated predators (e.g., FP and NFP). The number of individuals of *C. crysos* and *S. dumerili* used per treatment was based on the average number of fish present under FADs within the same season and geographic area as the experimental treatments (Sinopoli et al.,