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Predation of hatchery-reared scallop spat (*Pecten maximus* L.) by the Ballan wrasse (*Labrus bergylta*)—consequences for sea ranching

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Abstract

Fish predation on scallops has received relatively little attention compared to the primary predators sea stars and crabs. Available knowledge of fish predation is mainly based on observations from scallop beds and fish stomach analysis. These are the first controlled experiments conducted to test if fish (Ballan wrasse, *Labrus bergylta*) prey upon on hatchery-reared scallop spat. Under laboratory conditions Ballan wrasse from 22 to 40.5 cm in length were offered spat from 15 to 34 mm in shell height at a density of 50–103 individuals m^{-2}. Predation was recorded in 15 out of 35 tanks. The mean predation frequency for all tanks was 0.10. The mean predation frequency for the 15 predation tanks was 0.17 and the mean size class predation frequency was 0.53 (15–19 mm), 0.16 (20–24 mm), 0.03 (25–29 mm) and 0 (30–34 mm) ($n=15$). The mean predation frequency was significantly different between spat of 15–19 and 20–24 mm in shell height. No significant difference in predation frequency was found between larger spat. There was also indication of size-dependent predation from a field experiment, although this experiment was not conclusive. Results from this study indicate that farmers may seed spat larger than 30 mm in shell height for sea ranching with a minor risk of predation from Ballan wrasse.

Keywords: Ballan wrasse (*Labrus bergylta*); Great scallop (*Pecten maximus*); Sea ranching; Size dependent predation

1. Introduction

Fish predation on scallops has received relatively little attention compared to the primary predators sea stars and crabs. Knowledge of fish predation is mainly based on observations from scallop beds and fish stomach analysis (Spencer, 1991; Stokesbury and Himmelman, 1995; Irlandi and Mehlich, 1996; Vacchi et al., 2000; Naidu, 2003; Strand, in press). We describe the first controlled experiments conducted to test if fish (Ballan wrasse, *Labrus bergylta*) prey upon hatchery-reared scallop spat.

Sea ranching of scallops (*Pecten maximus*) in Norway has been associated with great losses due to predation by the edible crab (*Cancer pagurus*) (Bergh and Strand, 2001). This predation is now limited by the development and utilization of fencing that prevents intrusions of crabs, which has resulted in high survival of scallops in sea ranching (Strand et al., 2002). Since crab predation is significantly reduced, the opportunity of seeding smaller scallops directly from hatchery to bottom culture has emerged. A direct release of scallops from the hatchery will greatly reduce the labour effort and cost associated with operation of intermediate culture.

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In 2002 the scallop company Helland Kamskjell ANS carried out preliminary experiments with early transfer of spat (30–40 mm shell height) from intermediate culture to bottom culture. To obtain more information about the interaction between Ballan wrasse and scallop spat a remote-operated underwater camera was mounted on the seabed to record a seeding of scallop spat. These recordings showed an aggregation of wrasses on the seeding location, and the Ballan wrasse were observed to pick up scallops with their mouth. It was not clear from the recordings whether Ballan wrasse ate spat or fouling on the shell. Therefore, a pilot trial was carried out, which indicated that Ballan wrasse preyed on spat smaller than 27 mm. On this basis we wanted to conduct a more extensive study of Ballan wrasse predation of hatchery-reared scallop spat.

The Ballan wrasse is reported as a carnivorous (Wheeler, 1969; Quignard and Pras, 1986) and omnivorous feeder (Deady and Fives, 1995). The extendable jaws, forward projecting teeth and pharyngeal plates are well suited for preying on hard-shelled organisms (Deady and Fives, 1995) and the pharyngeal plates are used to crush shells of prey items (Larsson, 1975). These features, together with the relatively short, straight and thick-walled gut (Jacobshagen, 1913) indicate the carnivorous nature of these fishes and their ability to specialize on hard-bodied crustacean and molluscan prey (Al-Hussaini, 1947). The Ballan wrasse feed predominantly during the mid-day period and some feeding activity may occur at dusk but no foraging is recorded at dawn (Turner and Warman, 1991). The diet of Ballan wrasse becomes less varied with increasing fish length and age, and bivalve consumption increases considerably in large (>19 cm) Ballan wrasses to 35% of the diet (Deady and Fives, 1995).

In this paper we present results from predation experiments with Ballan wrasse (*L. bergylta*) offered scallop spat (*P. maximus*) in a size range (10–34 mm in shell height) proposed to be released for fenced sea ranching. The objective was to determine size-dependent predation within this size range. The study was conducted using both tank experiments and in field experiments at a sea ranching location.

2. Materials and methods

2.1. Tank experiments

Experiments were carried out at the Parisvatn Field Station (Institute of Marine Research) outside Bergen, Norway (N 60°38′, E 4°48′). Scallop spat were obtained from a nearby hatchery (Scalpro A/S). Prior to the experiments the spat was kept in trays at a density of 200 individuals/m^2 in 2.1 m^3 outdoor tanks. All tanks were continuously supplied with seawater from 20 m depth. The scallops were held 19 days in the outdoor tanks prior to experiments to recover from any handling and transport stress (Maguire et al., 1999).

Ballan wrasses were provided by local fishermen on three occasions (September 25, October 14 and October 31, 2003). The Ballan wrasses were caught adjacent to the sea ranch location. Fish from the first delivery were caught by trap net. In the second delivery fish were caught by fish net and in the third delivery fish were caught both by trap net and fish net. The fishermen delivered 100–150 Ballan wrasses. Prior to experiments the Ballan wrasses were kept in 2.1 m^3 outdoor tanks. The tanks contained tubes for shelter and dark mesh covered the tanks to shield direct sunlight. The wrasses were fed twice a week with crushed blue mussels (*Mytilus edulis*).

The experiments were conducted indoors from October to December 2003, in eight flow-through tanks of 0.5 m^3 (1 × 1 × 0.5 m, length × width × height). The continuous indoor light sources (Phillips TLM 40 W/83 oRS) were dimmed and covered with dark plastic bags (110 µm, Baca). Two PVC pipes (diameter 100 mm) and one 10-l bucket in each tank provided shelter for the wrasses. Daily measurements of seawater temperature (tinytag® temperature logger, Intab Interface-Teknik AB, Sweden) and weekly measurements of salinity were taken during the experiments.

We used 35 tanks for predation experiments and we had 14 control tanks. Each predation tank contained 50–103 scallops (50–103 scallops/m^{-2}) and 2 Ballan wrasses. The first fish selected for a tank was captured at random from the holding tank. The second (and in one case the third) fish was selected to be of similar size. In 17 predation tanks the fish and scallops were added simultaneously and in 18 predation tanks fish or scallops were added 2 days before the other species. A 3–4 cm deep layer of shell sand covered the bottom in 10 of the 35 predation tanks. The control tank contained only scallop spat and was randomly allocated by drawing lots. The duration of each experiment was 7 to 9 days.

Scallop shell height was measured to the nearest millimetre, at the start and end of the experiment. Shell height was measured as the distance from the dorsal hinge to the furthest ventral shell edge. We used scallops of 15–34 mm in shell height in the experiments. Scallops were selected so that the whole size range (15–34 mm) was represented in each tank. The spat were subsequently divided into four size classes (15–19, 20–24, 25–29 and 30–34 mm). The number of spat in the four size classes was not equal due to the size distribution of the available spat. Individuals were used only once. At the end of each experiment the tanks were drained and shell fragments and surviving scallops were carefully removed to avoid any exchange with scallops between experiments. Scallops were recorded as preyed by subtracting surviving scallops from start number of scallops.

The total length of Ballan wrasse was measured to the nearest 1.0 mm, and the wet weight of the fish was measured to the nearest 0.01 kg (MSI 6000, Measurement Systems International). The mean length of Ballan wrasse used in the experiments was 32.1 cm (n=81, SD=4.49) and the length range was from 22 to 40.5 cm. The mean wet weight was 0.57 kg (n=81, SD=0.24) and the range was from 0.17 to 1.06 kg. The maximum jaw gape height of 34 wrasse was measured to the nearest 1.0 mm with a calliper gauge. The wrasse was anaesthetized with Benzocain (30 ml/100 l seawater) to suppress movement during measurements.

Several wrasses used in these experiments had visible wounds and a few were extensively injured from initial capture, although wrasses without wounds were preferred. The wounds, especially on the dorsal fin and on the operculi were believed to stem from the fishing net, and 3 of the 9 wrasses that died during the experiments had injuries. Mortality in outdoor acclimation tanks was also high, though total mortalities were not recorded.

Analyses of predation frequency were conducted on the four scallop size classes for the predation tanks and predation frequency was calculated for each size class as: number of spat preyed upon per size class/total number of spat per size class (Table 1). Potential growth in shell height during the experiment was not measured since Chauvaud et al. (1998) reported a very low daily growth rate (less than 50 μm d^{-1}) for juvenile *Pecten maximus* in October and cessation of daily growth in November. Mean predation frequency for the four size classes was compared using Tukey multiple comparison test (Zar, 1996). A comparison of predation frequencies in tanks with and without sediment, and a comparison of predation frequencies between groups with either fish or scallops added first was analysed by the Fisher exact test (two tailed, df=1) (Zar, 1996). The relationship between jaw gape height and fish length, predation frequency and temperature was examined by a regression analysis (Zar, 1996). Statistica version 7.0 (StatSoft inc., Tulsa, OK, USA) was used for all statistical analysis. Confidence intervals (95%) were calculated according to Zar (1996). Effects were considered to be statistical significant if $P<0.05$ in all analyses.

Table 1
Tank experiments: tank number, duration of experiments, number of Ballan wrasses (*Labrus bergylta*), start number of scallops spat (*Pecten maximus*) (all size classes), mean Ballan wrasse length, mean Ballan wrasse weight and predation frequency in treatment

Tank (no)	Duration (days)	No. of wrasse	Start no. scallops	Mean fish length (cm)	Mean fish weight (kg)	Predation frequency
1	7	2	103	28.3	0.33	0.12
2	7	2	50	34.3	0.35	0.36
3	7	2	78	34.7	0.55	0.22
4	7	2	77	37.8	0.91	0.39
5	7	3	77	31.5	0.5	0.12
6	7	2	50	32	0.6	0.10
7	7	2	51	35.3	0.77	0.16
8	7	2	50	37.5	0.87	0.14
9	9	2	50	31.8	0.51	0.24
10	9	2	50	30.3	0.43	0.26
11	9	2	50	33.3	0.63	0.16
12	9	2	50	31.3	0.48	0.30
13	9	2	50	37.8	0.87	0.24
14	9	2	50	37	0.84	0.16
15	9	2	50	32.8	0.62	0.10

2.2. Sea ranching experiment

The sea ranching location was situated in Toskasundet (N 60°39′, E 004°57′), which is a 2 km long and 0.2 km wide sound in western Norway. The depth at the sea ranch location ranged from 11 to 22 m and the sediment consisted of shell sand. The experiment was conducted at 14 m depth. The tidal amplitude for this area is 0.5 m. A 0.5 m high fence encircled the sea ranching area to exclude decapod predators.

The experiment constituted eight cages (0.71 × 0.71 × 0.2 m, length × width × height) covered with fine nylon mesh, each holding 20 scallops of 11–30 mm shell height. Six cages had open tops to allow access for wrasse. Two cages were used as controls, by turning the cage upside down to prevent fish access to the scallops. It was therefore no mesh under the substrate of the control spat. A remote-operated underwater camera was mounted approximately 1.5 m above the seabed to cover all eight cages. The camera filmed on time lapse for seven days after release (October 29–November 4, 2003). All fish, scallop movements and other potential predators were recorded. The number of spat and shell height were recorded at the start and at the end of the experiment.

3. Results

3.1. Tank experiments

The temperature within tanks decreased from 12.0 to 8.4 °C and the salinity ranged from 32.5‰ to 33.9‰ during the experimental period. In 6 out of 14 control tanks we recorded ±2 spat at the end of the experiment and therefore tanks with a loss of ≤3 scallops were regarded as having no predation. No mortality was observed in the control tanks.

Predation was recorded in 15 tanks (15/35) and the predation frequency in these tanks varied from 0.10 to 0.39 (Fig. 1) or from 0.28 to 2.14 scallops fish^{-1} day^{-1}. The predation frequency for all 35 experiments was 0.10. There was no significant relationship between predation and mean water temperature during the experimental period ($R^2=0.006$, $p=0.62$), in predation frequency in tanks with or without sediment ($p=0.716$), or in predation frequency between tanks where Ballan wrasse or scallops were added first ($p=0.715$).

The comparisons of predation according to size class were conducted on data from the fifteen predation tanks (Fig. 1). These tanks constituted 886 scallops of which 148 (17%) were preyed (Fig. 2). The initial number of spat offered per size class was: 207 (15–19 mm), 316 (20–24 mm), 282 (25–29 mm) and 81 (30–34 mm). The mean predation frequency for the size classes was 0.53 (15–19 mm), 0.16 (20–24 mm), 0.03 (25–29 mm) and 0 (30–34 mm). The mean predation frequency significantly decreased between spat of 15–19 and 20–24 mm shell height ($p<0.001$).

There was a significant linear correlation between jaw gape height and length of Ballan wrasse (Fig. 3) ($R^2=0.78$, $p<0.001$, $n=34$). The mean jaw gape height was 23 mm (SD=4.1). The range in jaw gape height was from 14 to 29 mm. The mean Ballan wrasse length in the fifteen predation tanks was 33.7 cm (SD=2.95, max length 40 cm, $n=30$) and mean weight was 0.62 kg ($n=30$, SD=0.19, max weight 1.05 kg). There was no significant relationship between predation in the tanks and mean length of the fish used in each tank ($R^2=0.1$, $p=0.49$). The mortality of Ballan wrasse during the experimental period was 11% ($n=9$), of which a total of 2 wrasses died while in the experimental predation tanks.

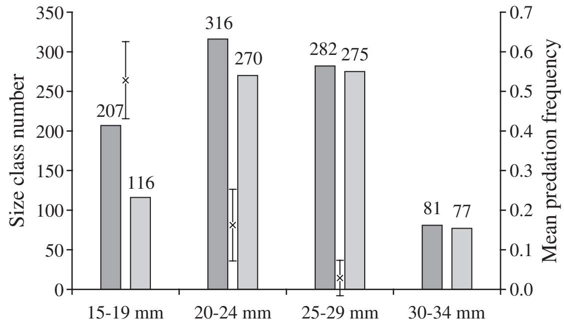

Fig. 2. Total initial (dark grey) and total final (light grey) size class numbers of scallop spat (*Pecten maximus*) and predation frequency (×) by Ballan wrasse (*Labrus bergylta*) in predation tanks (15/35). Initial spat total presented=886, final total recovered 738, for all size classes. Vertical bars indicate 95% confidence bands for predation frequency data. No predation was recorded in the 30–34 size class.

3.2. Sea ranching experiment

During the seven days after release of scallops into the experimental cages, 350 fishes were identified from the video. We identified 11 fish as Ballan wrasse, 143 as

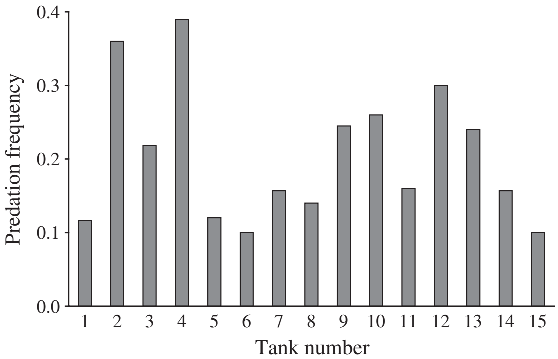

Fig. 1. Predation frequency of Ballan wrasse (*Labrus begylta*) on scallop spat (*Pecten maximus*) (15–34 mm shell height) in predation tanks (15/35 trials).

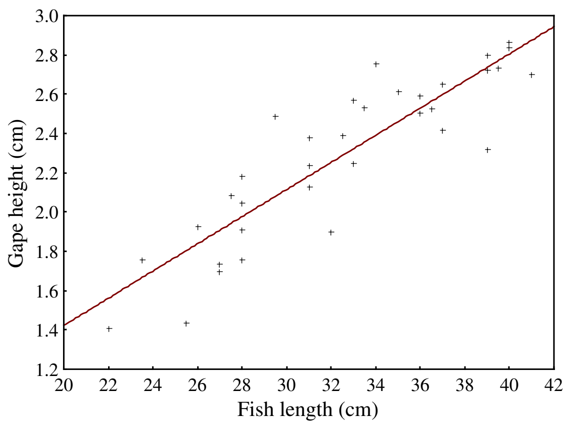

Fig. 3. Linear correlation between jaw gape height (centimetres) and Ballan wrasse (*Labrus bergylta*) length (centimetres).

Table 2
Field experiment: size classes of scallop spat (*Pecten maximus*) at start, end and preyed during the experiment

Shell height (mm)	Start (no)	End (no)	Preyed (no)
11–15	8	6	2
16–20	61	53	8
21–25	43	42	1
26–30	8	9	−1
Totals	120	110	10

Cuckoo wrasse (*Labrus bimaculatus*) and 196 were not possible to determine. Starfish, crabs or swimming scallops were not observed within the cages. Of the two smallest spat size classes (11–15, 16–20) there was a total loss of 10 scallops (14%) (Table 2). In the two largest size classes (21–25 and 26–30 mm in shell height) a loss of one and gain of one were recorded. *Pecten maximus* shell fragments were observed inside predation cages, but not in control cages. From the two control cages we retrieved 32 of 40 seeded spat.

4. Discussion

The results showed that predation by Ballan wrasse (*L. bergylta*) on the scallop (*P. maximus*) are dependent on prey size. The number of scallop spat preyed upon and thus predation frequency decreased as the shell height of spat increased. The mean predation rate, obtained from experimental data indicated that Ballan wrasse could eat more than 50% of the offered 15–19 mm spat. By comparison, the mean predation for all experiments and all size classes of spat (15–34 mm) was only 10%. Ballan wrasses may therefore cause severe losses to scallop sea ranchers if spat smaller than 20 mm are seeded and Ballan wrasses are abundant. The predation frequency for spat larger than 24 mm is low (0.03) and indicates that the Ballan wrasses were either choosing or where unable to prey on larger spat.

The variation in Ballan wrasse feeding may include aggressive behaviour associated with territorial defence. Aggressive behaviour associated with territorial defence is well documented (Sjölander et al., 1972; Hilldén, 1981a,b; Darwall et al., 1992). The net used to capture fish inflicted wounds and several wrasses were received. Nine wrasses died during these experiments and we assume that impaired fish may have influenced the amount of preyed spat, but probably not the size distribution of preyed spat. Neither sediment nor the sequence of introducing fish or scallop first influenced predation frequency. Predation avoidance caused by recessing (camouflage) is not documented and recessing behavior is still associated with feeding, (Brand, 1991).

The number of spat within the four size classes offered to the Ballan wrasse was not evenly distributed. Ideally this distribution should be identical to avoid selective predation of over represented scallops (Hart, 1996). However, since the results showed highest mean predation frequency in the smallest size group, which had fewer individuals than the other preyed upon groups (Fig. 2), we conclude that the predation was selective to shell height rather than to number of shells offered. Vacchi et al. (2000) studied the predator–prey relationship between the fish *Trematomus bernacchii* and the Antarctic scallop *Adamussium colbecki*. They found that *A. colbecki* was preferentially preyed upon in the size range 25–64 mm shell length and that prey size of scallops increased with size of *T. bernacchii.* They indicated that mechanical constraints such as mouth gape limitations or predation inability due to evasiveness of prey (swimming response) may enable predation avoidance for scallops larger than 65 mm. Our findings support that jaw gape limitations may determine an upper limit for predation as maximum gape height corresponded with maximum size of spat preyed upon (Fig. 3). Additionally, Grefsrud and Strand (in press) have shown increasing shell strength as shell height increases in *P. maximus* and it is therefore likely that small scallops are more vulnerable to predation, not only due to size, but also ease of consumption.

In the sea ranching experiment ten spat of 11–20 mm in shell height were recorded as preyed upon (14%), while no spat from 21–30 mm size class were consumed. We assume that the lost spat resulted from fish predation since there was no observation of predators other than fish, the spat were not observed swimming and we found shell fragments originating from the experimental spat. The predator may be the Ballan wrasse as it was observed 11 times, although other fish were more frequently observed within the cages (e.g., Cuckoo wrasse 143 times). The apparent fish predation preference of the smaller spat is in accordance with the size dependent predation found in the tank experiments. It might be argued that proportionally fewer spat were retrieved from the control cages compared to the predation cages. We assume that the loss of spat from the control cages was due to the spat being recessed in the sediment and therefore difficult to retrieve (e.g., no mesh under control spat). This is the most likely explanation as predator access was hindered to the control spat and we did not find any shell fragments in the control cages. In comparison, the treatment spat were easily retrieved by the mesh as the spat were cleared from the seabed.

The results from this study show that *Pecten maximus* spat larger than 30 mm in shell height can be released in fenced bottom-culture areas. This is an improvement on current practice, as it would be possible to seed spat directly from the hatchery and avoid the cost-and labour associated with intermediate culture. Future work on predator—scallop spat interactions should include field studies, especially fish predation success of larger spat (>25 mm).

While tank experiments do not fully resemble sea ranching conditions, there is some indication from our field experiment to support the laboratory results. In summary, fish predation, especially by Ballan wrasse, does appear to present a potential threat to smaller seeded scallops in high densities and it seems advisable to conduct preliminary seeding of spat where potential fish predators are abundant.

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