Environmental enrichment for fish in aquaculture

Glossary

Acetic acid: a type of acid commonly used to trigger pain response in pain research.

Acoustic telemetry: Acoustic telemetry is a method of transmitting information (e.g. location) using sound waves. This method uses tags which emit the signal and receivers which detect the signal.

Alvin: young salmonids who have just hatched. These fish still have a yolk sac attached to their body are not yet feeding independently.

Biofouling: biofouling is the accumulation of organisms (e.g. microorganisms, algae, molluscs) on surfaces such as nets and tanks.

Cortisol: a hormone produced in response to stress. It is often used as an indicator of stress in animal research.

Fingerlings: juvenile fish that have developed scales and working fins.

Fry: young salmonid who have consumed the yolk sac and who begin to feed on microscopic invertebrates.

Parr: larger juvenile salmonid with vertical stripes and spots for camouflage who feed on insects.

Pelagic: the pelagic area of the sea is the open sea (i.e. neither close to the shore nor close to the sea floor).

Respirometer chamber: Respirometer chambers are chambers used in research to measure the breathing and the metabolic rate of fish.

Smolts: smolt are salmon ready to migrate from the rivers where they were born to the open sea.

For a summary, see the enrichment for fish during rearing infographic[1].

This document provides a review of the welfare benefits environmental enrichment can provide for Atlantic salmon, rainbow trout, European sea bass, gilthead sea bream and pangasius, the five focal fish species for the Food Business team at Compassion in World Farming. Not all existing research on the topic is included for the five key species as protocols in some studies (e.g. prolonged feed restriction) make the results difficult to interpret in the context of improving fish welfare through environmental enrichment under standard aquaculture conditions. Other studies which were excluded from this review do not determine the effects of environmental enrichment on welfare (e.g. focus only on growth and weight gain). Details about the enrichment, the life-stage or size of the fishes, stocking density and the duration of exposure is provided in the review to allow an easier

[1] https://www.ciwf.org.uk/media/7443854/infographic-enrichment-for-fish-during-rearing.pdf

transfer of knowledge into practice. Where this information is not included, the authors did not make such information clear.

What is environmental enrichment?

Environmental enrichment has been defined as a “deliberate increase in environmental complexity with the aim to reduce maladaptive and aberrant traits in fish reared in otherwise stimuli-deprived environments” (Näslund & Johnsson, 2014). The authors also state that: “traits could be physiological, behavioural, morphological and psychological and considered maladaptive with respect to fitness components (health, survival, reproduction, etc.)” (Näslund & Johnsson, 2014). Environmental enrichment has also been defined as the addition of biologically relevant features to animals’ environment that foster and encourage natural behaviour and create a greater number of behavioural opportunities (Leone & Estévez, 2008). Taking the two definitions together, environmental enrichment is the increase in complexity of an animal’s environment to prevent negative welfare (preventing stereotypical behaviours, preventing poor health, preventing chronic levels of stress) and promote positive welfare (promote the display of natural behaviours and enable animals to experience positive emotions). Environmental enrichment in fishes can increase the suitability of rearing environments by mimicking natural environments (e.g. background colour) and increase the variability of environmental conditions (e.g. cover which provides areas of darkness and area of cooler water) thereby providing more choice to fishes over their environment.

Common environmental enrichment for fishes can be grouped into five categories:

- physical structures (e.g. artificial plants, shelter),
- sensory enrichment (e.g. coloured background, tank cover),
- dietary enrichment (e.g. flavoured feed, variable sized pellets),
- occupational enrichment (e.g. changes in water flow), and
- social enrichment (e.g. rearing with other species).

The response of fishes to environmental enrichment is diverse and can be positive (improved cognitive performance and behaviour, reduced stress levels, improved physical condition (Arechavala-Lopez et al., 2020; Batzina & Karakatsouli, 2012; Bosakowski & Wagner, 1995; Soares et al., 2011)) or negative (increase in aggression, increased stress (Barreto et al., 2011; Sabri et al., 2012; Woodward et al., 2019)). Responses can vary between species, between types of enrichment, between life stages and between group sizes. Therefore, it is crucial to monitor behavioural, physical, and physiological indicators of welfare when establishing a new environmental enrichment protocol.

Atlantic Salmon

Atlantic salmon are anadromous, meaning they hatch in freshwater streams, migrate to the sea where they mature and return to freshwater streams to reproduce. The different needs and wants of salmon during their freshwater and seawater phases must be considered to improve their welfare at each farming stage. The majority of studies on environmental enrichment for salmon focus on improving the post release condition of juvenile fish for conservation purposes and no study was found that investigated enrichment for salmon in grow-out facilities. In these studies, structural enrichment is used to increase the complexity of usually barren rearing environments to mimic the natural environment and increase the fishes’ chances to survive after they are released. Although aimed at conservation, some information can be taken from these studies which is relevant for the aquaculture industry.

<u>Structural enrichment</u>

Juvenile Atlantic salmon (approx. 12 g) reared for 31 weeks in a barren tank had significantly higher basal cortisol rates (a stress hormone) than fish reared in a tank enriched with either plastic shredding or plastic tubes. Salmon reared in barren tanks also had higher levels of fin damage than those reared in the enriched tanks (Näslund et al., 2013). Interestingly, a study on the effects of stocking density and physical structures (green plastic bags) on juvenile salmon for 10 months starting at first feeding, indicated that stocking density was more important for physical health than enrichment with fish reared in low stocking density (1.35 kg/m3) having less fin damage than fish reared in high stocking densities (3.75 kg/m3) (Brockmark et al., 2007). It is possible that the enrichment tested was sub-optimal and that a differing enrichment might improve fin condition. However, it was noted that the physical structures lead to more homogenised sized fish population, which could lead to a welfare benefit by requiring less grading thereby causing the fish less stress. The difference between the two studies is likely linked to the different age groups used, however, as the stocking density used by Näslund et al. (2013) is unknown, further research is needed to clarify the effect of structural enrichment on salmon fin damage at different densities.

In a study on the effect of enrichment on the brain of Atlantic salmon, Salvanes et al. (2013) reported that rearing 10 month old pre-smolts for 8 weeks with pebbles, cobbles and eight vertically suspended floating plastic fronds resulted in an improved spatial learning ability (50 fish/m^3, cobbles diameter 8–12 cm, fronds size: 5 cm wide x 50 cm long) . Näslund et al. (2012) investigated the brain size of juveniles which were reared for 3.5 months in barren trays or trays with a grid or stones as eggs and alevins (then reared in barren tanks from first-feeding). The authors found that alevins hatched in an enriched environment had significantly larger brains then those hatched in a barren environment (2000 eggs per tank). Following transfer to barren tanks at first-feeding, the difference in brain morphology was no longer significant at the fry stage and was no longer observed at the parr stage. This study shows the benefit in brain morphology of providing enrichment during the egg and alevin stage but research is needed to determine if continuous enrichment post-alevin stage would prevent the loss of the early-enrichment benefits. The complexity between environment and brain morphology was further highlighted in a study by Näslund et al. (2019) where no effect of enrichment was found on the size of the brain in Atlantic salmon but juveniles (~28.8 g) reared at ~14.4 kg/m^3 had larger brains than fish reared at ~4.8 kg/m^3. The authors suggest this is due to the manoeuvrability required at high stocking density (Näslund et al., 2019). The size of the brain is likely to be affected by many aspects of rearing environments beyond environmental enrichment and stocking density; further research is needed in this field.

Millidine et al. (2006) provided wild salmon parr with shelter (large stones and semi-circular piping) for 2 months followed by a metabolic rate analysis either with or without shelter (semi-circular ledge, min. 21h habituation in the respirometer chamber). Parr with access to shelter had a lower resting metabolic rate and were lighter in colour (dark colour indicates the fish are stressed) indicating that the availability of a shelter reduced stress during the metabolic rate test (Millidine et al., 2006). As all fish were reared with a shelter for 2 months, the removal of the shelter in the respirometer chamber might have been a source of the stress. Without comparing the results to the metabolic rate of fish never exposed to environmental enrichments, it is difficult to determine the potential effect of enrichment on the resting metabolic rate of salmon reared under standard aquaculture practices. Nordgreen et al. (2013) determined the time budget of Atlantic salmon parr (29.2 ± 8.6 g) housed individually with a hiding place, a water current, and a gravel box for seven

days. The authors found an increased use of the enrichment overtime with the hiding place and current being used the most. Overall structural enrichment improves the welfare of salmon and the combined use of structural enrichment and occupational enrichment needs to be examined under farming conditions where the fish are reared in groups. When providing structural enrichment, sufficient enrichment must be provided to prevent an increase in aggression due to territoriality.

Research needed

Research on structural enrichment in under commercial settings are needed to determine best practice protocols. In addition, research on other types of enrichment is also needed to identify the best types of enrichment for the specific needs of Atlantic salmon.

Research needed

While at sea salmon are pelagic; we often think of the pelagic environment as being simple and bare. This is could be a reason why no research was found on environmental enrichment for salmon during the grow-out phase. However, being a pelagic fish at this life-stage does not mean that Atlantic salmon cannot benefit from environmental enrichment during grow-out. Some anecdotal reports are available on potential unintended enrichment resulting from standard operating procedures. Aeration systems are used in sea cages fitted with sea lice skirts to ensure good water quality within the net. These aeration systems create bubble streams in which some salmon have been observed to swim (Kadri, 2020). This is a potential area for enrichment research as these bubbles can create a sensory enrichment in the form of a bubble massage or variable water current. Another potential unintentional enrichment for salmon could be the artificial kelp provided to cleaner fish as some salmon have been observed to swim through these (Kadri, 2020). The reason why some salmon have been observed to seek out bubble streams or kelp is unknown. Research is needed into the benefits bubbles, kelp and enrichment may provide to grow-out salmon.

Rainbow trout

Rainbow trout (*Oncorhynchus mykiss*) are freshwater salmonids who spend their lives in streams and rivers, however some trout migrate to sea to mature (known as steelhead trout). Similar to Atlantic salmon (*S. salar*), many enrichment studies for rainbow trout focus on improving the condition and survival of fish for restocking purposes.

Structural enrichment

A commonly studied environmental enrichment in rainbow trout is the addition of substrate during rearing. Eggs (n=2000, 27 days post-spawn) stocked in tanks with stones (~4·cm diameter, 1 stone/10·cm2) until first-feeding of alevins (45 days exposure to enrichment) resulted in improved brain growth (Kihslinger & Nevitt, 2006). The addition of cobblestone (2-4 cm) and gravel in the raceway of 3-months old fingerlings improved fin condition in hatchery reared rainbow trout (1300 fingerlings stocked, 6 months exposure to the enrichment) (Bosakowski & Wagner, 1995). Similar results were found by Wagner et al. (1996) who exposed 1000 albino fingerlings (mean weight: 2 g) to raceways enriched with cobble stones (2-4 cm) and gravel for 200 days and found no fin erosion whereas the fish not provided with cobble stones and gravel had considerable fin erosion. However, the authors noted that the condition factor, fat level and total body length were lower for the fish reared with cobble stones and gravel (Wagner et al., 1996). Structural enrichment has also been found to be beneficial for the swimming performance of 11 month-old rainbow trout under laboratory conditions. Enriched fish were reared for two months with one grey plastic plant (attached to the base of the tank, with 1m fronds), a single PVC pipe (25 cm long, 7 cm diameter) and connected PVC pipes to form a triangle (same size as single pipe), two floating green plants, and one new unfamiliar object every week. Enriched fish were more active and more agile than fish from the control group (Ahlbeck Bergendahl et al., 2017). Although this study indicated a benefit of environmental enrichment on swimming performance, less complex enrichment should be tested in swimming performance as the enrichment used by Ahlbeck Bergendahl et al. (2017) cannot easily be used in a farmed setting.

The specificity of enrichment can influence responses. One study tested two different layouts of artificial seaweed in raceways stocked with juveniles (1.7 g) for 95 days (lay out 1) and 106 days (lay out 2) (Arndt et al., 2002). In layout 1, where the artificial seaweed was perpendicular to the length of the raceways, the enrichment in half of the raceways was not cleaned, in the other half it was cleaned every other week. In the non-cleaned raceways, anal and pelvic fins of the fish were significantly shorter than the fins of the control group and there was an outbreak of suspected columnaris disease which spread to the other tanks. In layout 2 where the artificial seaweed was parallel to the length of the raceway, all fins of the enriched fish were significantly longer than those of the control fish on day 74 of exposure to the enrichment but by the end of the trial (106 days) only one fin was significantly longer in the enriched group than the control group (Arndt et al., 2002). The authors suggest that the fin shortening in layout 1 might be due to fish congregating in the sections between the artificial seaweed, resulting in a higher stocking density, which is known to cause fin deterioration (North et al., 2006). The results of the studies reviewed in this section highlight the need for careful consideration, planning and testing of environmental enrichment before it becomes standard protocol in a farming operation.

<u>Combined types of enrichment</u>

Combining structural enrichment with other enrichment has also been studied. Arndt et al. (2001) tested various types of enrichment (structural: gravel, sensorial: gravel photo, occupational: cross-flow system) on juvenile fish (1 month after first feeding, 0.8 - 1.4 g). In their first trial the fish were reared either in a raceway with gravel (average size: 11.9 mm) and a false bottom (which allowed the self-cleaning of the tank) or in a standard concrete raceway. The authors found that the use of gravel improved fin condition and fin length. In the second trial, the fish were exposed to gravel (average size: 11.9 mm, no false bottom), a raceway lined with a painting of cobble stones or no enrichment. In this second trial, anal fins were significantly shorter in the fish exposed to the painted cobble stones than for the other groups (Arndt et al., 2001). The authors note that without the false bottom, there was algal growth on the gravel despite regular cleaning. Cross-flow without gravel significantly improved the overall fin condition compared to the fin condition of the fish reared without cross-flow and gravel. The fish with cross-flow and gravel had intermediate fin conditions (Arndt et al., 2001).The swimming behaviour was also affected by the cross-flow system regardless of the substrate (with cross-flow, fish swam in a singular circular mass or in two groups in circular motions; without cross-flow systems, fish were concentrated in the upper-two thirds of the raceways with their heads into the currents). The results of this study highlight the benefits of combining two types of enrichment, structural (i.e. gravel) and occupational (i.e. cross-flow system).

Structural enrichment (the top of two dried fir trees, needles removed) with sensory enrichment (60% overhead shade) and dietary enrichment (demand feeders) improved fin condition of fry after 64 days of exposure when compared to fry reared in conventional tanks (Berejikian, 2005). In the same experiment, enrichment resulted in an increase in dominance and threat display when the fish were housed individually during behavioural observations (fish could see conspecifics but were separated by glass panels) but there was no difference in the number of aggressive attacks between the treatments (Berejikian et al., 2001). Rainbow trout reared at low stocking densities are known to be territorial which is a likely explanation for the increase in dominance and threat display (Laursen et al., 2013). When introducing enrichment in a farmed system, behaviour should be monitored to ensure levels of aggression do not become detrimental to the welfare of the fish. The combination of structural and sensory enrichment has also been found to accelerate recovery from a stressor. In the laboratory, when exposing juvenile rainbow trout (92.48 ± 2.72 g) to gravel, plastic plants and an area of cover, the breathing rate of fish recovered faster from air emersion and handling than fish reared in bare tanks, however, this was not observed for fish injected with pain inducing acetic acid (Pounder et al., 2016).

Sensory enrichment

Two studies were found that tested only sensory enrichment. In a study testing the effect of cover (ply wood) on juveniles (~1.46 g) for 216 days, there was no significant difference between the fish reared with a cover and those reared without a cover (body weight, feed conversion, fin condition). The preference of individual and groups of fish for cover was also tested. Individuals did prefer to stay under the cover regardless of their rearing environment, however there was no preference by groups to stay under the cover (there was a preference for cover by the enriched group for the first 15 min but this preference was not present in later observations) (Wagner & Bosakowski, 2011). One study on sensory enrichment was found which tested auditory instead of visual enrichment. One study exposed juvenile rainbow trout (6.7 ± 0.12 g) to classical music (Mozart K525 or Romanza) or white noise for 14 weeks (Papoutsoglou et al., 2013). Results varied between the types or music (and white noise), with the fish exposed to Mozart having lower dopamine-related activity, an indicator of lower stress. The authors noted that the responses of fish to music will be variable based on environmental conditions (e.g. light, stocking density, water quality and feeding regime) but will also vary between life stages and musical pieces played (Papoutsoglou et al., 2013).

Research needed

Research on all types of enrichment in under commercial settings is needed to determine best practice protocols and to identify the best types of enrichment for the specific needs of rainbow trout.

Gilthead sea bream

Gilthead sea bream (*Sparus aurata*) commonly swim between the surface and 30 m depth. They interact with the substrate to rest and hunt for food (Abecasis & Erzini, 2008; Jobling & Peruzzi, 2010), therefore the addition of substrate could provide welfare benefits to sea bream in aquaculture.

Structural enrichment

Gilthead sea bream (juveniles, 20.3 ± 0.22 g) reared for 75 days with blue substrate (glass gravel 6-12 mm in size) displayed less aggression behaviour and had lower basal cortisol levels than sea bream reared without substrate (Batzina, Kalogiannis, et al., 2014). Blue or red-brown gravel has been found to lowered aggression, however this was not observed in fish exposed to green gravel (68.3 ± 0.50 g exposed for 84 days, glass gravel 6-12 mm in size) (Batzina & Karakatsouli, 2012). In a substrate-colour preference test (glass gravel 6-12 mm in size), 2-year-old gilthead seabream (84.8 ±

1.9 g) preferred blue substrate over red-brown, green, or no substrate, but juvenile sea bream (21.9 ± 0.5 g) showed a preference of red-brown over green substrate but did not show a preference when offered the choice between blue vs. green or blue vs. red-brown substrate (Batzina, Sotirakoglou, et al., 2014). Substrate can benefit the welfare of sea bream but the reason why a difference in colour preference was observed between the two age groups is unclear and further research is needed to ensure optimal enrichment can be provided to gilthead sea bream at each life stage. When comparing the effect of exposing juvenile sea bream (20.2 ± 0.26 g) to blue substrate (glass gravel 6-12 mm in size, structural enrichment) vs. a photo of blue substrate (sensorial enrichment simulating structural enrichment) for 74 days, the fish exposed to substrate were less aggressive and were observed manipulating the substrate (Batzina & Karakatsouli, 2014). These studies show the importance of substrate and substrate colour on the welfare of gilthead sea bream. The observations made by Batzina and Karakatsouli (2014, 2012) and Batzina et al. (2014b) that sea bream manipulated the substrate is important. Gilthead sea bream interact in the wild with the substrate either to explore their environment (e.g. foraging) or as predator protection (Abecasis & Erzini, 2008; Jobling & Peruzzi, 2010) therefore providing captive gilthead sea bream with manipulable substrate could allow them to perform ethologically important behaviours. All the studies reviewed on the benefits of gravel substrate for the welfare of sea bream were carried out at a laboratory scale in small tanks. Research is needed that determines the effect of gravel on the welfare of gilthead sea bream in large aquaculture systems.

Studies have been carried out testing the effect of plant-fibre ropes in the water column on the welfare of gilthead sea bream. Arechavala-Lopez et al. (2019) reared 80 gilthead sea bream (3.8 ± 0.1 g, 135 days post-hatching) for 35 days in a barren cage or to cages containing three vertical plant-fibre ropes (10 fish per cage, 2 kg/m^3) in the laboratory. The ropes reduced the erosion of pectoral and caudal fins; reduced aggressive behaviour and increased the use of the inner areas of the cage. In a study of similar design, Arechavala-Lopez et al. (2020) added five suspended plant-fibre ropes to laboratory tanks containing 15 juvenile gilthead sea bream (21.9 ± 0.8 g, 5 kg/m^3) for 60 days while other gilthead sea bream were reared in barren tanks. Subsequent exposure to a maze revealed that exposure to the ropes improved learning, memory and reduced oxidative cell damage in the brain. The third study carried out by the same research team exposed 360 juvenile gilthead sea bream reared in a sea cage (6 m deep) with four vertical ropes in the centre hanging from a buoy (6 m length, 1 m distance between the ropes, forming a square, no information provided on the material used) for two weeks (Muñoz et al., 2020). Using acoustic telemetry, the distribution of 10 tagged fish (217.58 ± 55.96 g) was studied. When ropes were provided, space use increased at night. These studies indicate a simple enrichment of adding vertical ropes in sea cages could improve cognition, fin condition and behaviour, and special usage for gilthead sea bream (Arechavala-Lopez et al., 2019, 2020; Muñoz et al., 2020). However, the risks of biofouling on the ropes must also be considered when these are used over long periods therefore longer trials under aquaculture settings are needed.

Sensory enrichment

In a study researching sensory enrichment similar to that discussed above in rainbow trout, Papoutsoglou et al. (2008) exposed juveniles gilthead sea bream (1.51 ± 0.01 g) to Mozart for 2 or 4h per day using a hydrophone in either a high or low lighting environment for 117 days. Fish exposed to Mozart for 4 h per day with high lighting had lower levels of brain neurotransmitters, indicating reduced stress. Music has the potential to reduce stress for gilthead sea bream reared on land in hatcheries, ponds, or raceways but further research is needed. It is important to note that the points raised by the authors in the rainbow trout study about the possible effect of environmental and life-stage variability of on the benefits of musical enrichment must also be considered in gilthead sea bream and all other fish species exposed to this type of enrichment (Papoutsoglou et al., 2013).

Research needed

Substrate is a key enrichment to mimic the natural habitat of sea bream. Research is needed to determine best protocol for provided substrate or access to natural substrate in all farming systems. Further research is needed on prolonged exposure to structural enrichment in sea cages and on the potential benefits of non-structural enrichment for gilthead sea bream.

European sea bass

Research needed

No research on environmental enrichment has been found for European sea bass (*Dicentrarchus labrax*). Rearing techniques for European sea bass are often similar to those of gilthead sea bream however research is needed to determine what species-specific environmental enrichment is best to improve the welfare of European sea bass in aquaculture.

Pangasius

Sensory enrichment

Research on enrichment in *pangasius* spp. is very limited. Only one study was found that exposed pangasius (*Pangasius hypophthalmus*) to environmental enrichment. Mat Nawang et al. (2019) has shown that rearing juvenile pangasius with different coloured backgrounds affects growth and stress levels. Juvenile pangasius are commonly reared using white or blue backgrounds. White backgrounds were found to cause significantly higher number of mucous cells (an indicator of stress) compared to the fish reared with a green background (blue backgrounds were not tested). Unfortunately, as this is the only research which has been found on environmental enrichment for pangasius, caution needs to be taken when interpreting the results and their application in aquaculture. Further research on environmental enrichment in pangasius is needed. Naturland recommends that pangasius are reared in natural ponds or that the bottom of concrete ponds must be made from natural substrate or covered with natural substrate (Naturland, 2019). Although this regulation by Naturland is to ensure the biological functions of the pond, a natural pond or the addition of natural substrate is likely to increase the range of behaviours pangasius can display.

Research needed

So little is known about the natural behaviour and ethological needs of pangasius to experience good welfare that the FishEthoBase does not provide welfare recommendations and highlights the need for research (Castanheira, 2020). More research into the natural life and behavioural range of pangasius is needed and will help to better understand the need of these fish in aquaculture systems.

Conclusions

Structural enrichment is the most commonly tested environmental enrichment in Atlantic salmon, rainbow trout and gilthead sea bream. In general, structural enrichment benefits the welfare of these species either by reducing fin injuries, lowering stress, or improving the behaviour of the fishes (Arechavala-Lopez et al., 2019; Bosakowski & Wagner, 1995; Näslund et al., 2013). However, structural enrichment can be detrimental to the fishes if it is not planned out correctly as shown by Arndt et al. (2002). The main concern for aquaculture practices in using structural enrichment are the associated risk of waste management and biofouling which must be avoided to prevent an increase in the workload for farmers. This can be achieved (e.g. false bottom; Arndt et al., 2001) but the optimal solution is unlikely to be a "one size fits all" but must be adapted to the species, life stage, system and enrichment. Sensory enrichment could provide a low-risk and low-maintenance alternative to structural enrichment as the provision of shade, coloured background or musical stimulation is less likely to interfere with standards practices on farm. Little research has been carried out on sensorial enrichment for the species reviewed in this document and even less research has been carried out on occupational, dietary, and social enrichment. Further research is needed testing varied types of enrichment to establish best practice protocols in aquaculture.

Research needed

The majority of environmental enrichment research in Atlantic salmon, rainbow trout, gilthead sea bream, and pangasius (no research was found for European sea bass) aims to improve survival after release of salmonids, increasing weight gain and reducing physical damage such as fin damage(Bosakowski & Wagner, 1995; Brockmark et al., 2007; Huysman et al., 2019). Very little research has been done aimed at providing farmed fishes with positive welfare, such as enabling fish to display desired behaviours and experiencing positive emotions. However, this is feasible based on the observations made by Batzina and Karakatsouli (2014, 2012) and Batzina et al. (2014b) of sea bream manipulating the gravel provided. The provision of gravel allowed the sea bream to perform exploratory behaviours which are natural for them in the wild (Abecasis & Erzini, 2008; Jobling & Peruzzi, 2010). Providing fish with positive welfare through environmental enrichment must be further researched. See appendix 1 for a review of potentially enrichment which positive welfare for fish.

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