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Acoustic Conditioning and Ranching of Black Sea Bass *Centropristis striata* in Massachusetts USA

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Abstract：Acoustic ranching consists of training fish to school to an area via a sound stimulus that is coupled with a food reward (classical Pavlovian conditioning). It may present an opportunity to raise fish with less environmental impact and at less expense than typical open ocean fish farms. Some advantages include (i) low capital and operating costs to construct, install, and maintain a feeding and recapture station, (ii) low feed costs because fish have opportunities to forage on wild food as well as formulated diets, (iii) low impact on the environment due to natural dispersion of fish and their wastes, and (iv) the technology could aid stock replenishment efforts by weaning hatchery-raised fish from pelleted diets to fending for themselves in the wild.

This project represents the first attempt to farm marine fish with acoustic ranching in North America. In June 2008 we erected and installed an AquaDome™, a 10 m wide by 5 m high geodesic dome in Buzzards Bay, Massachusetts USA. The AquaDome™ was fitted with a feeding tube, an underwater speaker, and underwater cameras to monitor and record fish behavior. Approximately 5,000 tagged black sea bass (50 to 80 g) were stocked into the AquaDome™. The fish were trained in the cage by feeding them twice a day in tandem with a sound cue. Once the training was completed, 2.54 cm mesh on the AquaDome™ was replaced with 10.16 cm mesh so the fish could swim out and back in when cued to sound. Many set up residency on the nearby rocks. We conclude that fish have longer memories than previously thought and are readily adaptable to acoustic training. However, the application of this technology in the field is fraught with risks, especially when there is the threat of predators.

Key words：black sea bass, acoustic conditioning, aquaculture, sea ranching, *Centropristis striata*

Introduction

Open Ocean Farming Overview: Despite a decade of research and development and technological advancements, open ocean fish farming has not yet demonstrated a profitable future in the continental US. (Kite-Powell *et al.,* 2003; Posadas and Bridger, 2004). There are some bright spots in our tropical territories (e.g., Puerto Rico and Hawaii) with uniquely appropriate species such as cobia (fast growth) and pacific threadfin (high local demand and price). But experience and economic models have shown that the profitability of open ocean aquaculture in the Gulf of Mexico may only be viable with an exceptional species such as cobia (Posadas and Bridger, 2004). For open ocean

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fish farming to become economically and widely successful, the high expense of farming on the high seas needs to be significantly reduced. About 10% of the annual expenses associated with open ocean fish farming relate to the capital cost of submersible cages and moorings, and about 8% are for operating expenses, including insurance and maintenance according to a variation on a cage-based economic model (Kite-Powell *et al.,* 2003). Another 50 to 60% is associated with feed and supplying feed. If these expenses can be reduced, a variety of fish species in coastal environments could be ranched economically. Our economic modeling suggests that recapture rates of 55 to 70% of ranched fish could compete with open ocean cage culture operations depending on the amount of supplemental natural forage consumed by ranched fish. Our project tested methodologies that could significantly reduce these expenses by eliminating the capital and maintenance cost of the cage and potentially stressful confinement of the fish, and by allowing the fish to supplement their diet with natural forage.

The commercial future of open ocean finfish ranching as proposed here will depend on its economic viability. Prior work on the economics of ocean ranching has focused primarily on stock enhancement perspectives, particularly for salmon (Stokes, 1982; Whitmarsh, 2001). Other studies describe ocean ranching of cod in Norway (Midling *et al.,* 1993) and sea bream in Japan (Okamoto, 1982). In addition, there is some recent (in some cases unpublished) work on the economics of ocean ranching efforts in Japan (Nakahara R., personal communication; Nakahara, 1992). In this project, we examined the economics of open ocean finfish ranching of black sea bass in New England from both the public stock enhancement and the private commercial production perspectives.

Acoustic Conditioning of Farmed Fish: Operant conditioning is a widely understood phenomenon made famous by Ivan Pavlov and his experiments with dogs that salivated at the sound of a bell in anticipation of food. It requires providing a reward (e.g food) for a desired response to stimulus. Training fish to school to an area known to be associated with feeding via a sound stimulus that is followed shortly by feeding (hereafter referred to as acoustic conditioning) is a well established protocol and was first documented 40 years ago with trout (Abbot, 1972). Sound has broad efficiency in attracting fish that have been appropriately trained with operant conditioning procedures (Yan and Popper, 1991). It has been used as a means to enhance feeding response in larval and juvenile Atlantic cod (Oiestad *et al.,* 1987), for cageless ranching of cod in Norwegian fjords (Midling *et al.,* 1993), and as a means to feed wild cod populations in Iceland (Bjornsson, 1999; 2002). In all cases, cod of various ages were successfully conditioned to feed in association with an auditory stimulus. In Japan, acoustic conditioning and ranching have been used by several prefectural fisheries to help acclimate, reduce stress and keep newly released sea bream (*Pagrus major*) and striped jack (*Pseudocaranx dentex*) in specific habitats that are being restored (Okamoto, 1982; Kuwada *et al.,* 2000). In three experiments on acoustically conditioned and released juveniles around a net cage/feeding station, 85 to 95% of the fish were recaptured (Masuda and Tsukamoto, 1998). Willis *et al.* (2002) used acoustic conditioning with grass carp in a laboratory setting to test the utility of sound to attract fish for recapture. They predicted that 94% of the fish could be recaptured in lake management settings. Acoustic conditioning for fish ranching has not been attempted with marine fish in North America.

Background and Rationale for Black Sea Bass Aquaculture: Black sea bass (*Centropristis striata*; hereafter referred to as BSB) have been the focus of research and development over the last decade in the Northeastern USA (University of New Hampshire; University of Rhode Island; Massachusetts Institute of Technology; National Marine Fisheries Service Milford Laboratory; Great Bay Aquaculture, New Hampshire) and the Southeastern USA (University of North Carolina-Wilmington; Georgia Sea Grant; Harbor Branch Oceanographic Institute, Florida; and Southland Fisheries, South Carolina). We tested the ranching concept with BSB since this species is a good candidate for a number of reasons:

1. Fingerlings are available from commercial hatcheries.

2. Techniques for breeding and larviculture of the species have been researched and well described.
3. BSB grow relatively fast and under optimal culture conditions; juveniles suitable for stocking for open ocean ranching can be reared to market size in six months (May-October; Copeland *et al.*, 2002).
4. BSB are important recreationally and commercially with some markets having a very high return (e.g., fresh fish market price: US$11.00/kg, live fish price US$18.70/kg). The 2009 dockside price for BSB was US$5.50/kg (http://www.st.nmfs.gov/st1/commercial/index.html).
5. BSB are native to New England and tend to be seasonally residential around bottom structures like reefs and outcroppings; such locations would provide shelter for ocean-ranched fish and could also provide habitats for fisheries enhancement.

Objectives

Our goals for the two-year study were:

1. Develop acoustic conditioning methods for black sea bass so they will respond to feeding on prepared diets in a predetermined space for possible recapture, even when given opportunities to feed on natural forage, and test their memory to respond.
2. Complete field tests to grow acoustically conditioned BSB released in open waters without confinement and document the growth and recapture rates of BSB.
3. Develop an understanding of the economics associated with this project and these methods as models of open ocean finfish ranching and stock enhancement.

Materials and Methods

Determining an Effective Acoustic Conditioning Protocol for BSB and Limits of Memory: Twenty-five BSB (20 g to 25 g each) or 30 BSB (15 g to 20 g each) were placed into replicate round 250 L tanks, 1.25 m in diameter (six tanks total). The tanks were cordoned off using black plastic sheeting to isolate the BSB from any visual stimuli outside the tank. A semicircular barrier with a 10 x 25 cm opening (entrance) was placed into the tank (Figure 1). The area within the barrier was where all feeding occurred during conditioning and was referred to as the feeding zone. A 20 watt 4 ohm underwater speaker was suspended within the feeding zone and a PVC pipe was positioned above it though which feed pellets could be delivered into the feeding zone from behind the black plastic sheeting out of view of the fish. The speakers were connected to a Radio Shack MPA 20 watt amplifier and a Tenma 72-505 Audio Generator was used to produce a pure 280 Hz

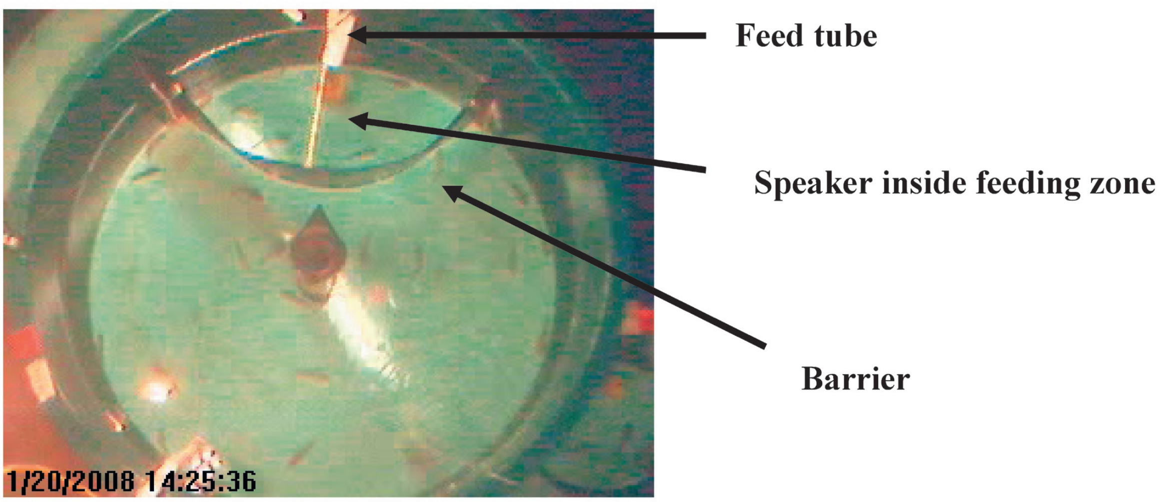

Fig. 1. Typical experimental tank set up (birds-eye view).

tone in the feeding zone. Trials were observed and recorded using 6 CCD video cameras (1 over each tank) and a computer equipped with a 120 fps (20 fps per camera) 16 channel GeoVision GV-800 DVR card with GV-800 surveillance software.

For our standard conditioning protocol, a 280 Hz tone was generated underwater for 20 seconds and then the tone was stopped for 10 seconds before feed pellets were delivered into the feeding zone. This procedure was continued three times a day with feed delivered at a rate of 1.5% body weight per day. When at least 80% of the BSB responded to the tone alone (before feeding) and moved into the feeding zone in at least one of the three daily feedings for 10 consecutive days, we considered that tank population conditioned for our study purposes.

Once the initial conditioning was completed, fish in three replicate tanks were subjected to alternating days of feeding inside (with acoustic stimulus) and outside (without acoustic stimulus) the feeding zone. This was increased to one day with acoustic conditioning and two days without acoustic stimulus for up to 15 days. The number of intervening days without acoustic stimulus increased as long as >80% of the fish responded on those alternate days with acoustic conditioning. When the number of fish responding fell below 80%, reconditioning was attempted for two more consecutive days. If response remained below 80% for all three daily trials at the end of three consecutive days, the trial was stopped, but if the response exceeded 80% then the tank was subjected to the next incremental number of days between reconditioning days.

Methods for the Field Trial:

We purchased 5,000 two to three gram fingerlings from Great Bay Aquaculture in August, 2007 and grew them to 75 gram stocking size by July, 2008. Depending on the speed with which we needed to grow them to meet that target, we selected a culture temperature between 15 and 25°C (Cotton *et al.* 2003). Fingerlings were stocked in several 3.05 and 3.66 m diameter round tanks as they grew. The final density was <10g/L. Fish were fed a standard commercial marine fish feed to apparent satiation twice a day. Water quality was monitored at least weekly to maintain dissolved oxygen at >8 ppm and acceptable ammonia and nitrite levels. Growth rates were tracked with monthly samples of weight and length. Once the fish reached 50 g on average, we tagged them with floy tags marked with a phone number and the word reward.

We selected a site near the northern most Weepecket Island in Buzzards Bay (N41°31' 33", W 70°43' 85"; Figure 2). The site is a flat seabed about nine meters deep (mean low tide) and about 10 meters from the margin of the rocky outcropping that composes the island. The substrate at the site is bare sand with some fine silt on top. In June, 2008 we installed an AquaDome™ structure for facilitating the acoustic conditioning, controlled fish release, occasional feeding, and potential recapture for census and survival estimates. The AquaDome™ is an aquaculture containment structure based on the commercial Aquapod™ fish cage manufactured by Ocean Farm Technologies LLC of Searsmont, Maine. The structure consisted of a hemispheric portion of a geodesic sphere (10 m in diameter and 5 m high) with a replaceable mesh cover. It was secured to the sea floor bottom by five 544 kg deadweight anchors and line (Figure 3). Additional modifications included a lighted marker buoy connected to a 7.6 cm feed hose that penetrated the AquaDome™ and extended 1.83 m from the bottom.

Once the fish were stocked in the AquaDome™, we fed them via acoustic conditioning daily. Underwater sound was generated by a commercial grade Lubell transducer and amplifier. Three different types of underwater video cameras were fitted with connectors (suspended on the surface buoy) so we could monitor the inside the AquaDome ™. The cameras were linked to a four channel DVR with a flash memory card for storing footage as well as a small video screen for field monitoring. Footage was downloaded to a computer for quantifying fish behavior. Feed quantity was based on video observations of feeding response (and compared to expected consumption based on percent body weight per day feeding rates (Copeland *et al.* 2002). The effectiveness of video monitoring was confirmed by periodic observations by SCUBA divers.

Fig. 2. Field site near Weepeket Islands (left) 3 nautical miles from Woods Hole.

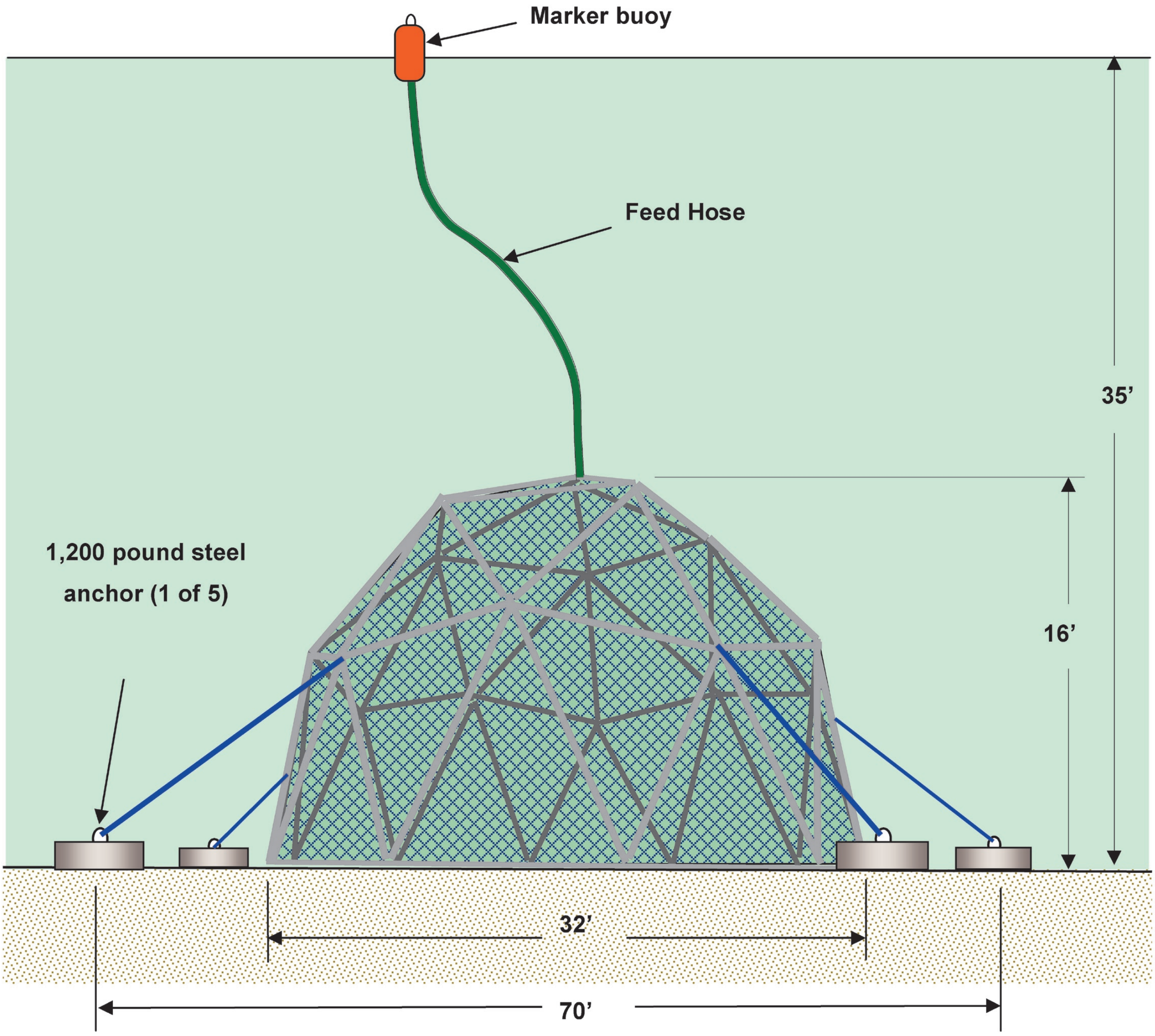

Fig. 3. Schematic of AquaDome™ and mooring setup in Buzzards Bay, MA.

Results and Discussion

Effectiveness of Acoustic Conditioning and Memory Response: Training trials typically followed the example below with slow response during the first week, improving response in the second week and steady response after two weeks (Figure 4). In our memory trials, two replicates performed almost identically with responses well over 90% after two and three days of no conditioning. However, after five days of no acoustic stimuli and conditioning, the response of both replicates dropped well below 90% (between 17% and 48%), and after three consecutive days of reconditioning their responses remained below the 80% required to graduate to a longer period of no conditioning. On the other hand, a third replicate responded well after a five-day absence of conditioning with daily averages well over 80% (Figure 5). They were then subjected to a seven-day absence of conditioning after which they attained a single trial response of 92% (66% average for that day). They were then subjected to 10 days with no conditioning and an additional seven-day no conditioning period. After the 10-day and seven-day conditioning lapse they required three days of conditioning to successfully attain the >80% response required.

The differences between the performance of the first two replicates and the last may be attributed to the amount of time on the conditioning regimen leading up to the trials. Conditioning of the first two replicates was started at the same time, and the last replicate had a full week longer conditioning period. The fact that the last replicate could withstand longer lapses in acoustic conditioning suggests that perhaps the length of time that BSB have been conditioned is correlated to the length of time they will remember. We can conclude that populations of fish retain good memory of the conditioned response for at least three days. Longer conditioning periods prior to memory testing may lengthen memory retention up to 7-10 days.

Field Trial and Assessing the Results from July 2008 to December 2008: From when the fish were stocked in the AquaDome™ on July 17, 2008 until their release on September 3, the bass were exposed to 47 days of training to tone and feed, sometimes twice a day. On September 4 we finalized the replacement of two 2.3 m^2 sections of 2.54 cm mesh with 10.16 cm mesh on the AquaDome™ so the fish could swim in and out. On September 5 we conducted a

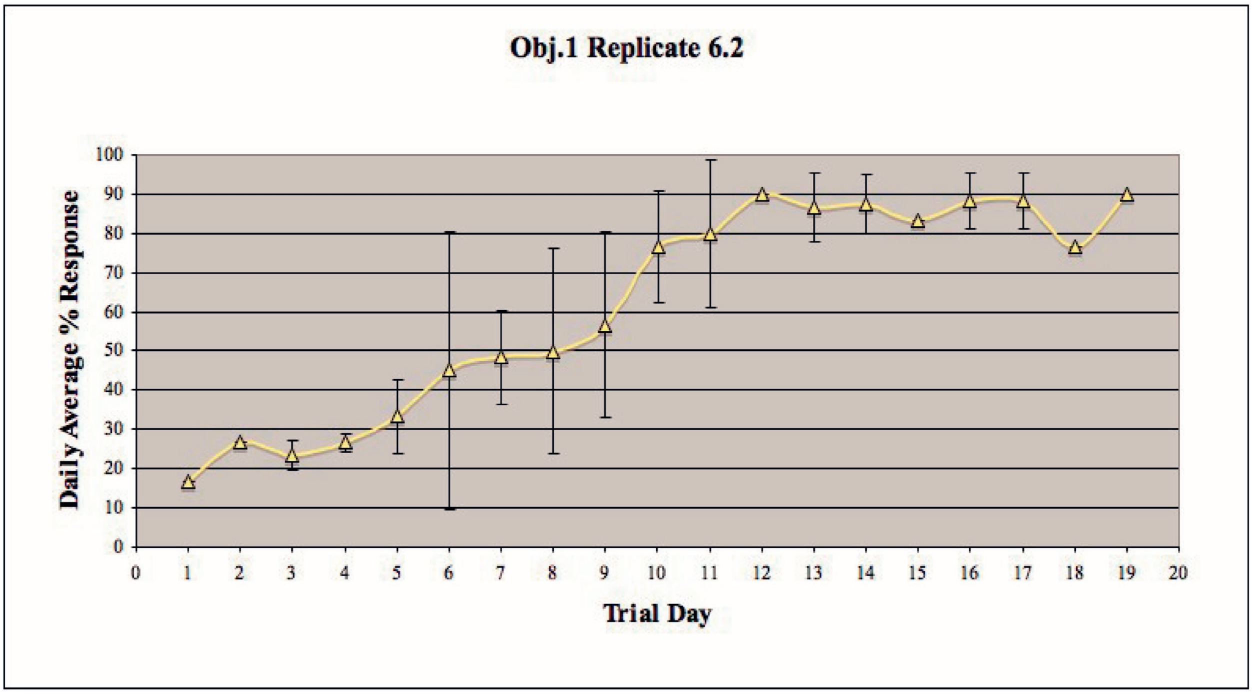

Fig. 4. Example of typical fish population response to initial conditioning and training protocol.

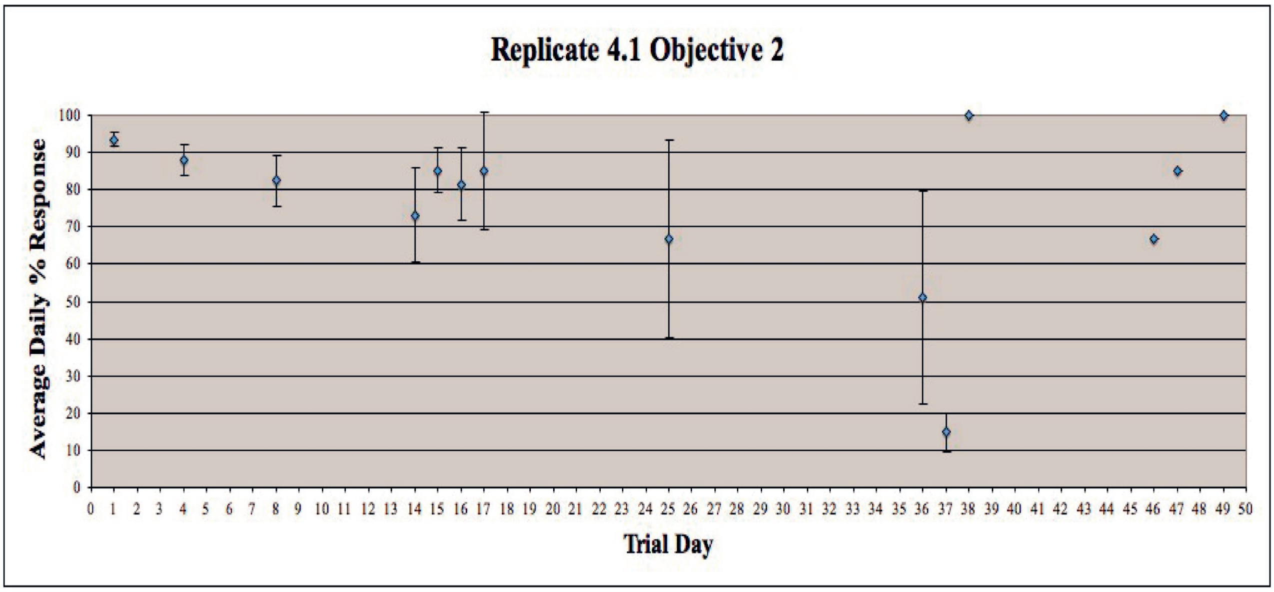

Fig. 5. Example of memory capabilities of a fish population as measured by acoustically conditioned feeding response interspersed with extended intervals of feeding without sound.

typical tone/feeding and the fish responded with typical interest and appetite. We then did not feed the fish for two days to encourage them to emigrate and begin to forage on their own. On September 12th, with observations by SCUBA divers we conducted a tone and feeding with typical response inside the AquaDome™ but few fish outside moved to it. We conducted a survey in the surrounding rocky habitat and found hundreds of BSB scattered to within 100 m of the Dome, but the majority of them remained within or immediately surrounding the Dome.

To encourage further emigration of the BSB, there was no feeding conducted for three successive days. On 16 September the response to our tone/feeding was remarkably poor. When we reviewed the video recording we noticed one of the camera views showed a predatory bluefish inside the Dome and other bluefish swimming around the Dome in a menacing fashion. Divers entered the Dome that afternoon to evict the bluefish which appeared to be too large (approximately 3 to 4 kg.) to have entered through the mesh. Examination of the Dome did not reveal other possible points of entry at that time though sand seemed to be eroding from under one side. Anchor lines had loosened and peak tides may have tipped the Dome to create a gap large enough for the bluefish to enter.

On subsequent feeding days and diver observations we did not see the robust feeding that we had expected. Via our cameras we continued to see bluefish swimming around the AquaDome™ that presumably discouraged the BSB from responding to food. We set fish traps among the rocks and made dive observations of hundreds of BSB but failed to draw them back to the AquaDome™. We sacrificed some trapped fish and noted fresh prey in the stomach of some of them — a good sign of adaption to the wild. By mid-October water temperatures were dropping, and we found it very difficult to trap more than couple BSB a day. This was expected since it was the season for the species to migrate to warmer waters for the winter. We hope to document some successful contribution to the local fishery from our release of the fish via tag returns in the years to come when they are legal harvest size.

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