Effect of fish size, handling stresses and training procedure on the swimming behavior of hatchery-reared striped jack: implications for stock enhancement

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Abstract

The marine ranching of striped jack (Pseudocaranx dentex) in Japan is a new type of fishery enhancement that releases cultured juveniles and keeps them in coastal waters without cages, utilizing their behaviour of associating with floating objects. To improve the release strategies, the behaviour of released fish under different conditions was observed directly using SCUBA. We found that factors of fish size, the amount of handling stress and trained feeding behaviour had an impact on the potential loss of the juveniles from the release site. Large juveniles (115 mm) showed a greater potential for loss from the release site than smaller juveniles (59 mm) due to diving deeper immediately after release (an average of 5.4 vs. 4.1 m, respectively). Stressed fish dived deeper than fish provided with a vertical underwater structure (average of 8.5 vs. 3.8 m, respectively). Fish trained to respond to sound for feeding dived to a more shallower depth (3.3 m) and stayed near the release site. Handling stress before release may be the main cause of the loss of fish from the release site, while training showed great potential for improving fish retention at the release site. © 2000 Elsevier Science B.V. All rights reserved.

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Stock enhancement is flourishing in Japan, involving about 100 fish and shellfish species (Honma, 1993). Although successful results have been reported in some species, such as chum salmon and scallop, projects on marine fin fish have many problems yet to be solved (reviewed by Masuda and Tsukamoto, 1998a). While success of stock enhancement depends on many factors, ranging from planning, management, releasing tactics, harvesting method and marketing (Blankenship and Leber, 1995), our field and laboratory work suggested that in many cases, unsatisfactory results can be attributed to the behaviour of released fish (Tsukamoto et al., 1997; Masuda and Tsukamoto, 1998b).

Among stock enhancement projects, marine ranching of striped jack (Pseudocaranx dentex) is unique in that it utilizes the behavioural characteristics of schooling and association to floating objects. In typical stock enhancement, released juveniles feed on natural diets and either stay at the release site or migrate from there and are harvested at a different site. Released fish potentially suffer predation after release, and need to compete against wild conspecifics and other species to grow (Tsukamoto et al., 1989). The recapture rate is high only in some species and conditions such as: very high fishing pressure of Japanese flounder 30% recapture rate in Fukushima Prefecture; Fujita et al., 1993; release of red sea bream in a closed bay area 14% recapture rate in Kagoshima Prefecture; Ungson et al., 1993; or migratory behaviour and suitable environmental factors for salmon (Kaeriyama, 1996). In striped jack ranching in the sea, juveniles are released in a closed area that is at the same time utilized for net-cage culture of other species, such as yellowtail (Seriola quinqueradiata). Released fish are fed from a feeding platform, and are also expected to feed on natural diet and superfluous diet from net-cage cultures. As this species has a tendency to associate with floating objects (Kogane et al., 1996; Masuda and Tsukamoto, 1999) and has a high learning ability (Tsukamoto et al., 1995), we considered that released fish could be trained to associate with a platform at the feeding time. Based on this concept, we conducted release and recapture experiments at 1000-fish scale and attained 95% recapture rate (Masuda et al., 1997; Kuwada et al., unpublished data).

The success of striped jack ranching, however, has been limited. In many other cases, fish escape from the released site either right after the release or gradually over several months (Masuda et al., 1997). We hypothesized that losses of fish immediately after release are due to handling stress and can be mitigated by acclimation. To test this and to improve the releasing techniques, we conducted releasing experiments in natural waters.

Our previous experiment showed that released striped jack show spiral diving behaviour after release, then they swim up to the surface (Masuda et al., 1993a). In this study, we released juveniles after different pre-release treatments and observed their diving behaviour by SCUBA. For the pre-release treatments, we compared the effect of fish size and the effect of handling stress prior to release. We also trained fish to feed at a platform when a sound signal was provided and we observed the effect of this training procedure. Maximum and final depths to which fish dived were taken as dependent variables on these treatments, assuming that these variables indicate greater potential for loss of fish from release site.
2. Materials and methods

2.1. Release site, materials and procedure

Releasing experiments were conducted in the coastal area of Kamiura, Oita, Japan, from 24 to 26 June and from 26 July to 4 August, 1993. This area is calm because of the surrounding bank. The release points were randomly chosen from nine different locations with a mean depth of 13 m. The surface water temperature was 19.3–22.4°C, while bottom temperature was 18.7–19.1°C. The light intensity at the surface was between 20,000 and 40,000 lx, and the Secchidisk visibility of the water ranged from 6.5 to 9.5 m.

Artificially hatched striped jack (59–136 mm in FL and 81–222 days old; Table 1) were raised in a net cage (3 × 3 × 3 m³), and moved to a smaller net cage (1.2 × 1.2 × 1.2 m³) the morning of releasing experiments. About 10 min before releasing, 30 fish were counted and put into either a basket releaser or a net-cage releaser (Fig. 1). The mouth of both types of releasers opened automatically 50–60 s after opening the valve of an air float. Release with constant acclimation was thus obtained. As both types of releasers worked properly, we did not specifically compare the performance of the different types of releaser.

The releasers were attached to a buoy (300 mm in diameter) and a platform (a 3 × 3 m² rectangular flotsam made of 40-mm-diameter vinyl pipe frame and green canvas cover) at each station (Fig. 2). Fish were released and followed by a 5-min underwater observation. An underwater observer, equipped with SCUBA, depth gauge and diver’s watch (Citizen quartz), and either an underwater radio (Aquacom SSB-1000S, SSB-100E: Ocean Technology System) or an underwater cord phone (Aquaphone: Nihon Aqua Lung), waited at about 3 m depth. A snorkeling diver opened the valve of the releaser.

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Number of fish</th>
<th>Fish FL ± SD (mm)</th>
<th>Age (day)</th>
<th>Platform</th>
<th>Releaser</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large</td>
<td>6</td>
<td>115.3 ± 6.2</td>
<td>186</td>
<td>Surface</td>
<td>Basket</td>
</tr>
<tr>
<td>Small</td>
<td>6</td>
<td>59.4 ± 2.5</td>
<td>81</td>
<td>Surface</td>
<td>Basket</td>
</tr>
<tr>
<td><strong>Stress and vertical reference</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress</td>
<td>5</td>
<td>87.4 ± 4.8</td>
<td>116</td>
<td>Surface</td>
<td>Basket</td>
</tr>
<tr>
<td>Control</td>
<td>5</td>
<td>87.4 ± 4.8</td>
<td>116</td>
<td>Surface</td>
<td>Basket</td>
</tr>
<tr>
<td>Vertical reference</td>
<td>4</td>
<td>87.4 ± 4.8</td>
<td>116</td>
<td>Surface + vertical</td>
<td>Basket</td>
</tr>
<tr>
<td><strong>Training</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>5</td>
<td>135.8 ± 6.5</td>
<td>222</td>
<td>Surface + tunnel</td>
<td>Net cage</td>
</tr>
<tr>
<td>Unconditioned</td>
<td>5</td>
<td>135.8 ± 6.5</td>
<td>222</td>
<td>Surface + tunnel</td>
<td>Net cage</td>
</tr>
<tr>
<td>Conditioned, with signal</td>
<td>5</td>
<td>135.8 ± 6.5</td>
<td>222</td>
<td>Surface + tunnel</td>
<td>Net cage</td>
</tr>
<tr>
<td>Conditioned, without signal</td>
<td>4</td>
<td>135.8 ± 6.5</td>
<td>222</td>
<td>Surface + tunnel</td>
<td>Net cage</td>
</tr>
</tbody>
</table>
Fig. 1. A basket releaser (A1, 2) and a net-pen releaser (B1–3). In both types of releasers, a diver opens the valve of the buoy, the frame sinks, and the releaser opens automatically in 50–60 s.

float and the releaser opened automatically in 50–60 s. When the released fish dived, the observer followed them within about 1.5–3 m, keeping the same depth as the school of fish. The observer sent the depth of school data at 10-s intervals. The depth was measured in 0.1-m intervals. Other aspects of behaviour, such as school diameter and phase of school schooling, aggregation, or dispersed, were also observed and were reported occasionally.

An observer in a boat transcribed the reports from the diver and also recorded them in a voice recorder. Observations continued for at least 5 min after release. When the fish swam more than 30 m from the released point, or when the underwater observer lost sight of the released fish, the observations were ended. In the case of current released fish mixing with a previously released group, that set of observation was canceled. The underwater observer could influence the behaviour of released fish, but this would equally effect test and control sets, so the comparison between test and control is considered to be valid.

In order to get information on the horizontal movement of released fish, air bubbles of the underwater observer, who was following the school, were tracked by one of the on-board recorders (Fig. 2). A 15-m floating rope with buoys at 5-m intervals was set on the releaser for the calibration of horizontal distance. The on-board recorder sketched the track of air bubbles. This was then traced on paper. The length was measured, followed
by calibration, and this was divided by the time of observation. The mean velocity of released fish was thus estimated and was compared among the releasing conditions.

2.2. Experimental design

2.2.1. Fish size

Large fish (115.3 ± 6.2 mm) and small fish (59.4 ± 2.5 mm) were released separately from basket releasers by the standard method described above. The difference of size was due to their age (186 and 81 days old, respectively; Table 1).

2.2.2. Stress and vertical reference

2.2.2.1. Control. Thirty fish were released from a basket releaser.

2.2.2.2. Stress. Fish in the releasing basket were held out of water for 20 s, then put back into water just prior to opening the air valve. Released fish were thus stressed by air exposure before opening the basket. This method should have provided similar handling stress to that described by Olla and Davis (1989).

2.2.2.3. Vertical reference. In addition to the standard platform, another 3 × 3 m^2 flotsam (same frame as surface one but covered with a black fine mesh cloth) was set vertically to provide stronger visual reference for released fish. Fish were released under the surface flotsam.
2.2.3. Training

Fish were raised under three different treatments of training for 10 days before releasing.

2.2.3.1. Control. Three hundred fish were put in a net-cage (5 × 5 × 3 m³) and were fed using the standard method.

2.2.3.2. Unconditioned. Three hundred fish were fed under a platform with a tunnel-shaped structure beneath it (a 800 × 1000 mm² plywood board with 200 × 300 mm² feeding hole and a mesh vinyl tunnel underneath; Fig. 3). Formulated diet was fed 1 m apart from the tunnel.

2.2.3.3. Conditioned. Fish were fed in the same type of net cage with tunnel flotsam described above and under the conditioning of a sound signal. The signal was composed of a 3-s sound of 300 Hz and 2-s silence. This signal continued for 5 min, and feeding was started from 1 until 4 min of the signal. Formulated diet was fed from the central hole of the tunnel flotsam once every day until satiation.

The fish from the different treatments were released from a basket releaser with a platform and tunnel flotsam (Fig. 3). The sound signal used in iii) was presented 2 min before the releasing until finishing observations.

2.2.3.4. Conditioned and released without signal. For the conditioned fish, the release was conducted without presenting sound stimuli.

Fig. 3. Trained striped jack, just after the release, swimming around the platform with a tunnel. A sound signal was provided.
2.3. Data analysis

Maximum swimming depth, final depth (average swimming depth from 90 to 300 s after the release), and horizontal distance was compared by Mann–Whitney’s U-test. For the training experiments, the remaining fish were compared by Fisher’s exact probability test. Results were considered to be significantly different when \( P < 0.05 \).

3. Results

When the releaser opened smoothly and there were no other striped jack swimming nearby, all 30 fish formed a school and moved in one group. After leaving the releaser, they usually swam down until reaching a maximum depth and then swam up to 1–3 m depth. The behavior after release was generally divided into three phases: steep diving, swimming up, and final constant depth. The depths and swimming speeds differed depending on the releasing conditions.

3.1. Fish size

Large fish dived significantly deeper (mean of the maximum depth of six trials: 5.4 m) than small fish (4.1 m) \( (P = 0.045, \ U\text{-test}, \ n = 12; \text{Fig. 4}) \). The mean final depth of large fish (2.1 m) was not different from that of small fish (2.2 m).

3.2. Stress and vertical reference

The maximum depth after release was deepest for the stressed fish (mean maximum depth = 8.5 m, \( n = 5 \)), and most shallow with the reference (3.8 m, \( n = 4 \)), while control fish were intermediate (5.7 m, \( n = 5 \)) (Fig. 5). Although maximum depth of

![Fig. 4. Swimming depth (m) from time of release of released striped jack in the fish size experiment. Different symbols represent different sets of release. Large = 115 mm fish. Small = 59 mm fish.](image-url)
stressed or reference-provided fish was not significantly different from control fish, there was a significant difference between the stressed and reference-provided fish ($P = 0.014$, $n = 5 + 4$, $U$-test). The final depth was also deepest for stressed fish (5.0 m). Fish without stress (controls and reference-provided) showed final depths of 1.8 and 1.0 m, respectively.
Climax depth in the stressed fish was significantly deeper than the control ($P = 0.016, n = 5 + 5$, U-test). Mean swimming velocity of the reference-provided fish (0.2 m/s) was significantly slower than controls (0.28 m/s; $P = 0.050, n = 5 + 4$, U-test).

3.3. Training

The maximum depth of control fish was 5.4 m, while for conditioned fish, it was 3.3 and 3.2 m (with or without signal, respectively). Unconditioned fish dived to 7.3 m depth. The final depths of control fish, conditioned fish, with and without signal, were 1.9, 1.1, and 1.4 m, respectively. Unconditioned fish had a mean 5.3 m final depth; as in some cases, fish did not swim up but stayed near the bottom (Fig. 6). Conversely, conditioned fish constantly stayed in very shallow water when the sound signal was provided (Fig. 3).

The mean swimming speed of control fish was 0.33 m/s, while the means for conditioned fish with and without signal were 0.03 and 0.02 m/s, respectively. There were significant differences between the control and the conditioned fish ($P = 0.009$ and 0.014 with and without signal, respectively, U-test). Unconditioned fish showed swimming speeds of 0.35 m/s, which was close to the value of the controls.

For controls, no fish remained around the released site in five trials. For conditioned fish, with or without signal, fish remained around the release site in four out of five and four out of four trials, respectively. Conditioned fish, released with or without signals, remained at a significantly higher rate than the control ($P = 0.024$ and 0.008, respectively, Fisher’s test), although there was no significant difference between with and without signals ($P = 0.55$). Unconditioned fish remained around the release site in only one of five trials.

4. Discussion

Although the maximum swimming depth of released fish differed among trials and treatments of experiments, ranging from 2.0 m for conditioned fish to 12.1 m for stressed fish, the behaviour of released fish was generally similar. All fish reached a maximum depth within about 30 s and swam up, then staying at a final depth, with only a few exceptions (Fig 7). This confirmed our previous releasing experiment (Masuda et al., 1993a), which showed that fish released from a 101 bucket reached maximum depths ranging from 5 to 20 m depth, then swam up to near the surface and stayed at about 3 m depth.

In the fish size experiment, large fish reached deeper maximum depths than small fish, which may reflect a difference in swimming ability, but not a difference in behavioural characteristics. In most cases, fish in both size groups reached a maximum depth at about 30 s after release and then swam up later. The depth may also reflect a reaction difference to the releasing stress. Deeper maximum depth, however, has a higher potential for fish to stray from the release site under the same visibility condition. As 60 mm striped jack suffer little predation risk, the smaller fish may be suitable for releasing.
We compared only two sizes and there remains the possibility that larger sizes of fish could behave differently. According to field observations, wild striped jack shift their habitat from shallow to offshore reef at about 150 mm (Masuda et al., 1993b). We do not know if hatchery-reared and released fish may have an innate drive to migrate offshore when they attain a certain size. Therefore, to prevent straying of large fish, their developmental changes in behaviour should be understood through laboratory experiments.

The stress and vertical reference experiments clearly showed that stressed fish dive deeper and will stray, while a vertical reference structure is effective in preventing this. The stress we used (air exposure) is similar to the routine handling process of scooping fish by hand net or gathering fish in a net cage. These results strongly suggest that such handling processes can be a major reason for missing or straying released fish.

Olla and Davis (1989) examined the effect of air-exposure stress on the vulnerability to predation in coho salmon. They found that when coho encountered predators within 1 and 60 min after the stress, they were captured more than controls, whereas coho given 90 and 240 min to recover from stress survived predation as well as controls. Their findings suggest that a relatively short period of recovery may greatly improve the behavior of fish after release.

In our previous experiment (Masuda et al., 1993a), we released from a 101 bucket. This method might be stressful for the fish and resulted in a relatively deep maximum swimming depth (5–20 m: equivalent to the stress condition in the present study). Therefore, release from a bucket is not suitable for practical use to prevent the straying of fish. Release after a period of acclimation and with little disturbance is recommended.
The vertical reference treatment resulted in a more shallow maximum swimming depth for released fish than the other two sets. Our results are consistent with the field experiment by Hunter and Mitchell (1968), who reported that tent-shaped flotsam was much more effective in attracting juvenile fish, predominantly carangid fish, compared to simple horizontal or vertical flotsam. Relatively complicated structures should work best as a platform for striped jack ranching.

In our conditioning experiment, fish were released from large net-cage releasers, which should have worked as references. In this experiment, conditioned fish dived only a little and stayed in shallow water, their swimming speed was slow, and they remained at the release site longer compared to control fish. These results suggest that the training procedure is effective in mitigating stress after release and results in successful marine ranching. Trained fish remained whether a sound signal was present or absent at release. In the training process, we tried to condition the fish to sound, reference and feeding, but these results suggest that once this conditioning was accomplished, the presence of a reference can work as a stimulus for fish to remain at the released site.

Tsukamoto et al. (1995) compared the learning ability of striped jack at different sizes: 100, 160 and 210 mm. They showed that 100-mm-sized fish learned more quickly and lost memory more slowly than the other two sizes. As striped jack ranching utilizes the fish’s learning ability, large fish are not suitable in this respect.

Association behaviour is essential for striped jack ranching; thus, we trained these fish to associate with the platform. Critical factors of stock enhancement differ among species. Indeed, Olla and Davis (1989) considered predator avoidance as critical in coho salmon and they succeeded in training them to avoid cod.

5. Conclusion

We have developed a releasing and a behavioral observation system to estimate effects of pre-release conditions. We found that stressed fish dived deeper and left the release site, whereas fish trained to associate with a platform tended to remain at the release site (Fig. 7). This system should be applicable for the stock enhancement projects of other species to evaluate their pre-release treatments and behaviour.

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H. Kuwada et al. / Aquaculture 185 (2000) 245–256


