Aquaculture Research, 2002, **33**, 359–367

The use of AquaMats® to enhance growth and improve fin condition among raceway cultured rainbow trout *Oncorhynchus mykiss* (Walbaum)

Ronney E Arndt, M Douglas Routledge, Eric J Wagner & Roger F Mellenthin
Utah Division of Wildlife Resources, Fisheries Experiment Station, Logan, UT, USA

Correspondence: Ronney E. Arndt, Utah Division of Wildlife Resources Fisheries Experiment Station, 1465 West 200 North, Logan, UT 84321, USA. E-mail: nrdwr.rarndt@state.ut.us

Abstract

AquaMats® are a type of artificial seaweed designed to provide structure in ponds used for fish culture and as a substrate for the growth of aquatic plants and invertebrates which in turn are a source of nutrition to cultured species. In two separate tests AquaMats® were placed into raceways used to rear rainbow trout *Oncorhynchus mykiss* (Walbaum) to evaluate their effect on fish growth and fin condition. In the first test, the AquaMats® were placed perpendicular to the raceway length similar to a baffle design. One treatment consisted of AquaMats® that were cleaned on a regular basis, and the other treatment consisted of AquaMats® that were not cleaned throughout the test. By the end of the test no differences were found between treatments with respect to final fish weight, specific growth rate, or feed conversion ratio. The use of AquaMats® did not improve fin condition, in fact several fins measured were significantly better among control fish. In the second test AquaMats® were placed on the raceway bottom parallel to their length and to the water flow. AquaMats® were also hung from the side of the raceway to provide cover. At the conclusion of this test no differences were found between treatments with respect to final fish weight, specific growth rate, or feed conversion ratio. The placement of AquaMats® did have a transitory impact on fin condition. Mid-way through the test, treatment fish generally exhibited longer fins compared with the controls. However, by the end of the test, these differences were no longer detectable. The results from both tests indicate that fish were not provided with additional nutrition to the extent it improved growth. However, the use of AquaMats® did make a significant, albeit transitory, impact on fin condition.

Keywords: AquaMats®, fin erosion, growth, rainbow trout *Oncorhynchus mykiss* (Walbaum)

Introduction

AquaMats® are a type of artificial seaweed with a high surface area that are designed to encourage colonization and growth of algae, zooplankton and other aquatic organisms. In the past they have been used in aquaculture to provide structure in ponds used for fish culture and as a substrate for the growth of aquatic plants and animals (Scott & McNeil 2001). They have also been used in coastal areas as artificial reefs. In an aquatic environment, once the AquaMats® are colonized, they may provide a secondary source of nutrition for fish. These invertebrate prey items might also contribute to improved fin condition among cultured rainbow trout *Oncorhynchus mykiss* (Walbaum). Crustaceans such as amphipods, ostracods, copepods, and aquatic insects may contain supplemental nutrients that enhance fin condition, serving a similar function as the krill-based diet used by Lellis & Barrows (1997). Steelhead trout fed a krill-meal-based diet exhibited improved fin condition compared with fish fed a fish-meal-based diet, and they theorized that the krill contained naturally higher levels of copper and in some way improved processes of collagen formation in fin rays (Lellis & Barrows 1997).

The spatial arrangement of AquaMats® in a raceway may also be beneficial in reducing fin erosion. It has been demonstrated, among juvenile steelhead trout, that dorsal fin damage can be attributed to aggression between fish (Abbott & Dill 1985). This aggression may be the result of dominant fish fighting for and protecting prime feeding sites within a raceway (MacLean, Metcalfe & Mitchell 2000). The preference of fish for habitats that contain structures has been documented (Johnson 1993); however, whether the presence of structure would break up a raceway environment to the point that aggression, and therefore fin erosion, was reduced has not been determined. However, structure in the form of baffles and cobble on raceway bottoms has been shown to contribute slightly to improved fin condition (Kindschi, Thompson & Mendoza 1991; Wagner, Routledge & Intelmann 1996). However, physical structure within a raceway may provide tactile or visual stimuli that provide fish with reference points from which they might establish territories, and increase their aggression by defending those territories (Hartman 1963). Steelhead trout reared in wild-type conditions that included physical structure were shown to be socially dominant over steelhead reared in barren tanks (Berejikian, Tezak, Flagg, LaRae, Kummerow & Mahnken 2000)

The purposes of the following two studies were to test for beneficial aspects of aquatic growth on the AquaMats® to cultured rainbow trout, and to evaluate any positive effects of the physical structure of the mats on reducing fin erosion.

Materials and methods

Test 1

Six raceways (11 m long × 1.2 m wide × 0.6 m deep) were fitted with Aquamats® (Model no. 10509, Meridian Applied Technology Systems, Calverton, MD, USA) which are sheets of high-density polymers bonded to a type of reinforced plastic tarp material. The sheets have vertical slits cut in them approximately 6 cm wide, cut from the top to within 10 cm of the bottom. These cuts allow the individual 6 cm sections to act as artificial seaweed when underwater. The bottoms of the mats are sewn back on themselves to allow for weights to be placed inside counteracting neutral buoyancy (Fig. 1). In our case we placed sections of iron re-bar inside this sleeve. The depth, bottom to top, of Aquamat® placement was controlled by tying rope to the bottom of the mats to 2.5 × 2.5 cm sections of wood that lay across the tops of the raceways. The Aquamats® were placed into the raceways perpendicular to the length of the raceway in a modified baffle type of arrangement (Fig. 1). Two dimensions of mats were used, 119 cm long × 61 cm high, and 119 × 46 cm. They were placed in the raceway in an alternating short-to-long pattern with the short ones being approximately 8 cm above the bottom and the long ones 15 cm above the bottom. The shorter mats did not reach the water surface, while the longer ones overhung the water surface in a down-stream direction by 20–30 cm.

A total of nine raceways were used; three served as controls, three contained mats that were removed twice weekly and cleaned, and three contained aquamats that were not cleaned during the entirety of the study. For the cleaned treatment, the mats were removed and scrubbed with a 600 mg L^{-1}

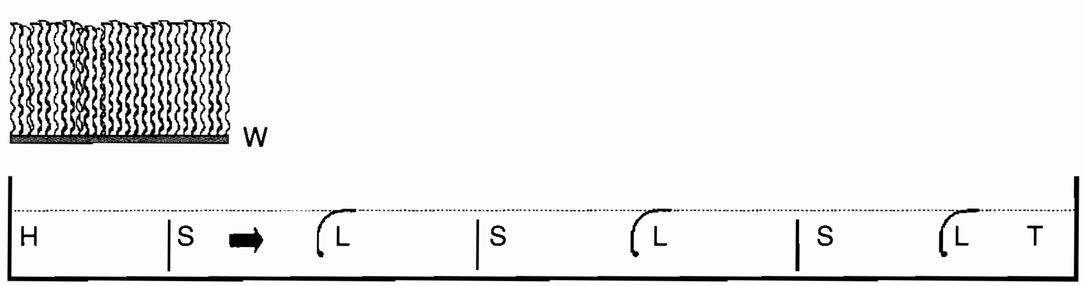

Figure 1 Test 1: diagrammatic view of an AquaMat® (a) and a side view of a test raceway (b) displaying AquaMat® placement. W: weighted sleeve; H: raceway head; T: raceway tail; S: short AquaMat®; L: long AquaMat®; arrow: direction of water flow.

hyamine solution, rinsed with clean raceway water, and then placed back into the raceways. The Aquamats® were originally placed into the raceway based on the length of rearing space being used. At the start of the study only three mats were used per raceway and they were spaced 1 m apart (water volume = 2.8 m^3). This arrangement resulted in a ratio of mat surface (m^2) area to raceway volume (m^3) of 0.7:1. On day 34 of the study raceway rearing volume was increased to 5.7 m^3 to accommodate fish growth, and three more mats were added per raceway using the same distance spacing which resulted in the same ratio of mat surface (m^2) area to raceway volume (m^3) of 0.7:1. On day 51 rearing volume was again increased and the distance between mats was increased to 1.6 m, resulting in a decrease in the ratio of mat surface (m^2) area to raceway volume ($m^3 = 6.8$) to 0.6:1. No additional mats were added at that point and rearing volume and mat numbers remained constant until the end of the 93-day trial.

Triploid rainbow trout eggs were obtained from Mt. Lassen Trout Farms, Inc., Red Bluff, California, and hatched at the Fisheries Experiment Station (FES), Logan, Utah. Once the fish had reached 1.7 g $fish^{-1}$ they were stocked into the raceways used for the test at a density of 8100 fish per raceway. The initial density index (Piper, McElwain, Orme, McCraren, Fowler & Leonard 1982) for all raceways was 0.23 and reached 0.40 for several raceways at the trial conclusion. The formula used to calculate density index was: DI = fish weight (lbs) ÷ [raceway volume (ft^3) × fish length (in)]. Densities were adjusted by increasing water depth and moving the tail screens in the raceways when the density index was projected to reach 0.40. The flow indices used during the study ranged from 0.46 at the beginning to 1.28 at the end of the study. The following was used to calculate flow index: FI = fish weight (lbs) ÷ [fish length (in) × water inflow (gpm)]. The water exchange rate in the raceways was four complete turnovers per hour at the beginning of the trial, and decreased to two turnovers per hour from day 51 to the end of the trial. Well water used for both tests had the following general characteristics: temperature = 17.8 °C, oxygen = 6.1 mg L^{-1}, hardness = 254 mg L^{-1}. Supplemental oxygen was added to the water via liquid oxygen injection through low head oxygenators, which raised incoming water to 8–9 mg L^{-1}.

Test 2

Three raceways (11 m long × 1.2 m wide × 0.6 m deep) were fitted with AquaMats® that were placed into the raceways parallel to their length and water flow. Two rows of mats were placed down the length of the raceway such that the distance between the raceway walls and the distance between the two rows of mats were approximately equal (Fig. 2). The dimensions of mats were the same as used for Test 1. The AquaMats® were placed in the raceway in an alternating short-to-long pattern such that one row began with a short mat followed by a long one with the next row following an opposite pattern. Mid-way along the length of each row one mat was hung off of the raceway wall at the water surface so that the entire surface area of the mats extended over the surface of the water. At the start of the study two rows of two mats with two overhanging mats were used for a ratio of mat surface (m^2) area to raceway volume (m^3) of 1.9:1. When the raceway volume was increased to 4.4 m^3 on day 47 of the study, the quantity of AquaMats® was doubled following the same configuration which resulted in a ratio of mat surface (m^2) area to raceway volume (m^3) of 1.7:1. Three raceways served as controls and three contained AquaMats®. The mats were not cleaned for the duration of the 106-day test.

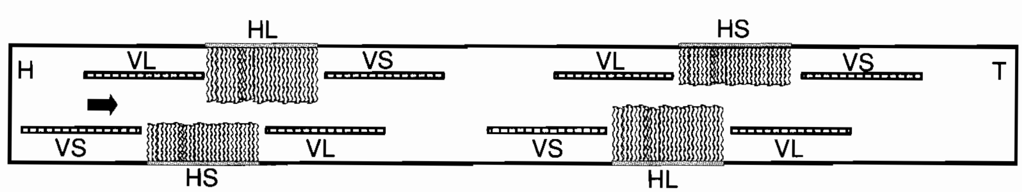

Figure 2 Test 2: overhead view of a test raceway displaying AquaMat® placement. H: raceway head; T: raceway tail; VL: long AquaMat® deployed vertically off raceway floor; VS: short AquaMat® deployed vertically off raceway floor; HL: long AquaMat® deployed horizontally across water surface; HS: short AquaMat® deployed horizontally across water surface; arrow: direction of water flow.

Eyed rainbow trout eggs of the Sand Creek strain were obtained from the J. Perry Egan State Hatchery, Bicknell, Utah, and hatched at the FES. Once the fish had reached 2.1 g fish^{-1} they were stocked into the raceways used for the experiment at a density of 5100 fish per raceway. The initial density index (DI) for all raceways was 0.15 and reached 0.43 for several raceways by the end of the test. Densities were decreased on day 47 by moving the tail screens to increase raceway volume. The flow indices (FI) used during the study ranged from 0.33 at the beginning to 0.79 at the end of the study. The same water supply was used as in Test 1.

For both tests, fish were hand fed a floating commercial trout formulation (Silver Cup, Nelson and Sons Inc., Murray, UT, USA). The feeding rate was four times daily at the beginning of both trials, and this was reduced to thrice daily at their conclusions. For Test 1, the daily per cent body weight fed at the start of the study was 5.4%, and by the end of the study the ration was reduced to 2.0%. For Test 2, the daily per cent body weight fed at the start of the study was 5.7%, and by the end of the study the ration was reduced to 2.6%. All raceways were inventoried monthly for weight gain by taking three subsamples for each raceway. Weight gain data and feeding records were used to calculate feed conversion ratios (FCR = total g feed ÷ total g weight gain) and specific growth rate ($SGR = [(\ln weight_{end\ study} - \ln weight_{beginning}) \div (no.\ of\ days)] \times 100$). Individual fish length and weight data collected from the necropsies (see below) were used to calculate condition factor $K_{TL} = [weight\ (g) \div (length\ (mm))^3] \times 10^5$.

Fin measurements were made at the start of Test 2 from 60 fish, and then on a monthly basis from 10 fish per raceway (30 fish per treatment) until the study conclusion. Fin measurements were only made at the conclusion of Test 1 from 20 fish per raceway. On the final day of both tests (day 95 for Test 1, day 106 for Test 2), necropsies were performed on 10 fish from each raceway (30 total per treatment) according to the Health Condition Profile (HCP) of Goede & Barton (1990). Goede's fin erosion classification system was used to quantify the degree of past or active fin erosion (Goede 1991). This system classifies fins by a numeric scale of 0–2, with 0 = no active erosion, 1 = mild active erosion, and 2 = severe active erosion. Fin measurements were made concurrently on the same fish. Additional fin measurements were taken the following day from 10 fish out of each raceway. Fin measurements were used to calculate relative fin index values for all fins except the adipose fin according to the method of Kindschi (1987).

For both tests, statistical analyses were conducted using SigmaStat® Statistical Software, Version 2.0 (SPSS Inc., Chicago, IL, USA). When data were not normally distributed or unequal variances were present, data were analysed by the Kruskal–Wallis one-way ANOVA on ranks test. Ordinal HCP data (thymus, fat, hind gut, bile, fin, opercle) were tested by the Kruskal–Wallis test. Categorical data from the HCP (eye, gill, psuedobranch, spleen, kidney, liver, sex) were arranged into contingency tables and analysed by the χ^2 test. Non-categorical data were analysed for significant differences by one-way ANOVA and multiple comparisons by Tukey's test. All percentage data were first square root-arcsine transformed prior to analysis. For comparisons of two means, a *t*-test was used; when data were not normally distributed or unequal variances present, data were analysed by the Mann–Whitney *U*-test.

Results

Test 1

During the course of this study and by its conclusion, no significant differences in weight gain were found between the treatments. By the end of the study the average weight for all fish was 36 g fish^{-1} (Table 1). No significant differences were found in specific growth rate or feed conversion ratio between the three groups of fish. Cumulative mortalities were significantly higher ($P = 0.013$) among fish in the non-cleaned group compared with the cleaned group, and the control group exhibited intermediate mortalities compared with the other two (Table 1). Two months into the study there was a small outbreak of what was cursorily diagnosed as *columnaris* in one of the non-cleaned raceways. The columnaris spread to other raceways and did not appear to affect any treatment group more than another. As a result, all nine test raceways were administered for 3 days with a 60-min hydrogen peroxide treatment. The first day the treatment concentration was 50 mg L^{-1}, followed by 75 mg L^{-1} on the second day, and 100 mg L^{-1} for the final treatment. During the week of the disease outbreak and subsequent chemical treatment mortalities averaged 12 for the control group, 13 for the cleaned group, and 15 for the non-cleaned group. Mortalities were not significantly higher for the

Table 1 Test 1: hatchery performance of rainbow trout *Oncorhynchus mykiss* (Walbaum) reared in raceways containing no AquaMats® (control), cleaned AquaMats®, or non-cleaned AquaMats® for 93 days.

	Control	Cleaned	Non-cleaned
Final fish weight (g fish^{-1})	35.6 ± 1.0	34.9 ± 0.9	34.3 ± 4.3
Specific growth rate (% per day)	1.74 ± 0.02	1.72 ± 0.01	1.71 ± 0.07
Condition factor (K_{TL})	1.20 ± 0.13	1.20 ± 0.07	1.21 ± 0.08
Feed conversion ratio (%)	0.69 ± 0.03	0.69 ± 0.03	0.74 ± 0.09
Cumulative mortality (%)	1.3 ± 0.2^{b}	1.1 ± 0.1^{a}	1.4 ± 0.0^{b}
Fat index	2.8 ± 0.5	2.7 ± 0.6	2.8 ± 0.5
Fin index	0.5 ± 0.7	0.5 ± 0.6	0.3 ± 0.5

A common superscript letter or no letter among mean values (± SD; $n = 3$) indicates no significant difference ($P \geq 0.05$).

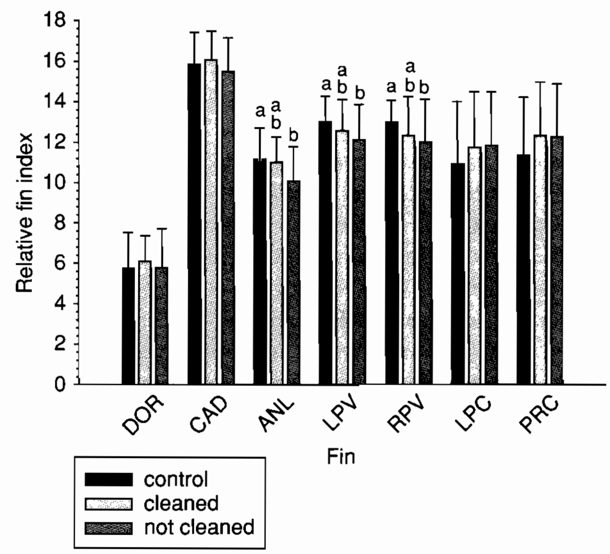

Figure 3 Relative fin lengths (% of total length) of rainbow trout *Oncorhynchus mykiss* (Walbaum) containing no AquaMats® (control), cleaned AquaMats®, or non-cleaned AquaMats® from Test 1. Fin abbreviations are DOR: dorsal; CAD: caudal; ANL: anal; LPV: left pelvic; RPV: right pelvic; LPC: left pectoral; RPC: right pectoral. For each fin, mean values that are significantly different from respective controls ($P < 0.05$) are marked by an asterisk.

non-cleaned group so the cumulative mortality for those fish must be attributed to some other reason.

Relative fin index calculations made from the fin measurements revealed several significant differences at the end of the study. The control fish had significantly longer anal and pelvic fins than those from the non-cleaned group, while fish from the cleaned-mat treatment were not significantly different from either group (Fig. 3). For all other fins, there were no significant differences between treatments. The fin scores tabulated during the HCP also revealed no significant differences. The control and cleaned-mat fish scored 0.5, and the fish in the non-cleaned treatment scored 0.3. All other HCP indices were within normal ranges for rainbow trout and none were significantly different between treatments with the exception of the leucocrit scores. Leucocrit scores were significantly higher ($P = 0.001$) for the control and cleaned-mat fish, 1.4% and 1.5%, respectively, compared with 0.8% for the non-cleaned group.

Dissolved oxygen concentrations at the conclusion of the study ranged from 9.2 to 9.6 mg L^{-1} at the raceway heads to 6.4–7.1 mg L^{-1} at the tails. Unionized ammonia averaged 0.0013 mg L^{-1}. Carbon dioxide levels appeared to be relatively high, 26 mg L^{-1} at the raceway head and 47–50 mg L^{-1} at the tails, but no health effects were evident.

The surface of the mats in the non-cleaned raceways did host a consistent quantity of algal growth that was not found among the control or cleaned treatments. Cursory substrate scrapings consisted of almost exclusively filamentous algae with an occasional, but rare, chironomid larvae.

Table 2 Test 2: hatchery performance of rainbow trout *Oncorhynchus mykiss* (Walbaum) reared in control raceways, or raceways containing AquaMats® for 106 days

	Control	AquaMat®
Final fish weight (g fish^{-1})	31.8 ± 1.4	32.1 ± 2.6
Specific growth rate (% per day)	2.57 ± 0.05	2.57 ± 0.08
Condition factor (K_{TL})	1.24 ± 0.62	1.22 ± 0.62
Feed conversion ratio (%)	1.06 ± 0.03	1.02 ± 0.7
Cumulative mortality (%)	1.8 ± 0.2	2.5 ± 0.7
Fat index	3.4 ± 0.6	3.3 ± 0.5
Fin index	0.6 ± 0.6	0.7 ± 0.7

Test 2

During the course of this study, and by its conclusion, no significant differences in growth were found between the treatments. By the end of the study both control fish and treatment fish averaged 32 g fish^{-1} (Table 2). No significant differences were found in specific growth rate or feed conversion ratio between the two groups of fish. Specific growth rates were 2.57 for both groups of fish. Feed conversion ratios were 1.06 for control and 1.02 for treatment fish. The cumulative mortality experienced by the treatment fish, 2.5%, was higher than the control, 1.8%, although this difference was not significant ($P = 0.157$).

There were some transient effects of AquaMat® use on fin condition. Relative fin index calculations made from the fin measurements revealed several significant differences throughout the course of the study. By day 35, both pectoral fins were significantly longer for fish reared in AquaMat® raceways compared with controls (Fig. 4). On day 74, all fins were significantly longer for the AquaMat® fish compared with controls. However, by the end of the study (day 106), only the left pectoral fin was significantly longer for the treatment fish than the controls. The fin scores tabulated during the HCP also revealed no significant differences between the controls (0.6), and the treatment fish (0.7). All other HCP indices were within normal ranges for rainbow trout and none were significantly different between treatments with the exception of the plasma protein scores. Plasma protein scores were significantly higher for the control fish, 3.9 g dL^{-1}, compared with 5.1 g dL^{-1} for the treatment fish ($P = 0.002$). The surface of the AquaMats® did host a consistent quantity of algal growth that was not found on the walls of any test raceways. Cursory substrate scrapings consisted of almost exclusively filamentous algae with occasional chironomid larvae.

Dissolved oxygen concentrations at the conclusion of the study ranged from 8.4 to 8.9 mg L^{-1} at the raceway heads and from 7.0 to 7.3 mg L^{-1} at the tails. Unionized ammonia, which averaged 0.0025 mg L^{-1} for all raceways, was well below the threshold level of 0.0125 mg L^{-1} discussed by Piper *et al.* (1982). Carbon dioxide levels appeared to be relatively high and ranged from 39 to 41 mg L^{-1} at the raceway head and 45–48 mg L^{-1} at the tails, but no health effects were evident.

Discussion

The results from both tests did not support the hypothesis that fish obtain additional food items from AquaMats®. The higher plasma protein values for the treatment fish from Test 2 may be indicative of supplemental feeding to some degree, or may be of no biological importance. There is a relatively wide range of plasma protein values that can be considered as normal among salmonids. Miller, Hendricks & Cairns (1983) defined a normal range of plasma protein to be 1.6–3.5 g dL^{-1} for the Wytheville strain of rainbow trout. Wedemeyer, Barton & McLeay (1990) defined the normal limits of rainbow trout to be 1.4–4.3 g dL^{-1} and 2.0–6.0 g dL^{-1} (Wedemeyer 1996). The 5.1 g dL^{-1} for the treatment fish from Test 2 falls at the high end of these ranges. Goede & Barton (1990) discussed low plasma protein readings as indicative of starvation or low energy stores. Plasma protein levels among salmonids may also vary with fish age (Sano 1960a), seasonality (Sano 1960b; Denton & Yousef 1975), and sexual status and spawning (Triplett & Calaprice 1974). Concentrations may also be depressed by stress and starvation (Satchell 1991); however, protein intake and salinity did not influence plasma protein among juvenile rainbow trout (Zeitoun, Ullrey & Tack 1974). Because both treatment and control fish were reared under like conditions, the higher plasma protein levels may be representative of supplemental feeding off of the AquaMats®. Storebakken, Hung, Calvert & Plisetskaya (1991) did find a strong positive correlation between feed ration level and plasma protein concentration. The surface of the AquaMats® hosted a consistent quantity of algal growth with occasional chironomid larvae that was not found

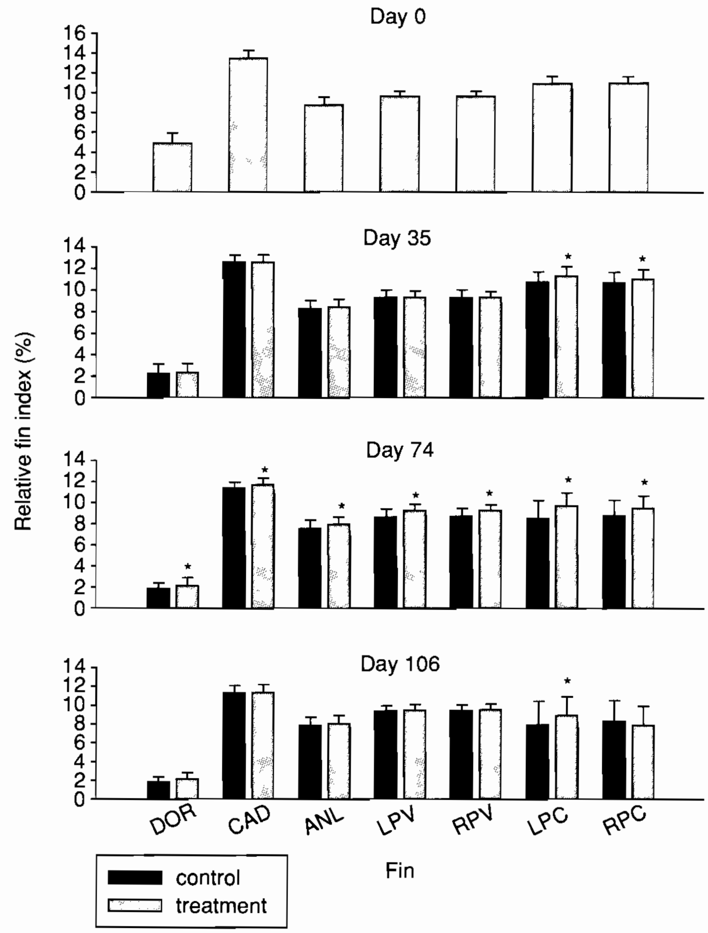

Figure 4 Relative fin lengths (% of total length) at day 0, 35, 74 and 106, of rainbow trout *Oncorhynchus mykiss* (Walbaum) reared in untreated raceways (control) or raceways with AquaMats® from Test 2. Fin abbreviations are DOR: dorsal; CAD: caudal; ANL: anal; LPV: left pelvic; RPV: right pelvic; LPC: left pectoral; RPC: right pectoral. For each fin, mean values that are significantly different from respective controls ($P < 0.05$) are marked by an asterisk.

on the walls of any raceways. In hindsight, to appropriately test the hypothesis of supplemental feeding off of AquaMats® a fish free AquaMat® treatment should be included to determine the actual production of aquatic growth on the mats in the absence of fish.

The main impact of using the mats in rainbow trout culture related to fin condition. The fin condition results from Test 1 may be explained partially by density problems derived from the AquaMat® configuration and disease problems experienced during the test. The baffle-type design we used was not conducive to reducing fin erosion as found by Kindschi *et al.* (1991); however, it has also been shown that baffles may have no effect on fin condition (Wagner 1993). For our test positioning the mats as baffles only served to congregate the fish into the zones between mats, which in effect reduced the usable raceway volume and increased the density index. Higher densities in intensive trout culture have been implicated in poor fin condition (Winfree, Kindschi & Shaw 1998). It is possible the poor fin condition found among treatment fish from Test 1 are a result of increased densities caused by the baffle-type placement of the mats.

The disease outbreak experienced during Test 1 may have also contributed to the fin results. Aside from the actual mortalities and diagnosis of columnaris, the lower leucocrit values indicate either latent infection or chronic stress. Low leucocrit values may be attributed to acute stress (McLeay & Gordon 1977) or a bacterial infection (Goede & Barton 1990). After hydrogen peroxide treatment, mortalities decreased, and there were no obvious signs of stress or infection within the non-cleaned group, but the lower leucocrit and higher cumulative values indicate the fish may have been fighting an infection or were subject to chronic stress. Because fin condition was better for control fish compared with those reared in raceways with non-cleaned mats, if the erosion was related to the presence of mats, then fish in raceways with cleaned mats should have been significantly different than controls too. It is possible the non-cleaned mats served as a reservoir for bacterial infection by *Flexibacter columnaris* and thereby negatively impacted fin condition. *Flexibacter* sp. has been implicated in fin erosion among Atlantic salmon *Salmo salar* L. (Schneider & Nicholson 1980).

The results from Test 2 did indicate a beneficial aspect of AquaMat® use on fin condition. Mid-way through this test all fins were better for treatment fish; however, by the end of the trial only the left pectoral was better. Because rearing conditions among raceways were kept constant throughout the study, variables such as density index, flow index, and feeding regimen, are probably not responsible for this transient effect on fin condition. It is possible the relative ratio of AquaMat® area to raceway volume may have been influential. After 1 month of the study, the quantity, and therefore the area of AquaMats® in the raceways was doubled. Subsequent fin measurements made after 2 months revealed a consistent trend of better fin condition among AquaMat® fish compared with controls. By the end of the study this trend had disappeared. It is possible that the relationship between the AquaMat® area to raceway volume and to fish density was conducive to reduced fin erosion, but that as fish grew, and density increased, the positive effect of AquaMats® on fin condition decreased.

Because we did not directly measure aggression between fish as part of our work it is difficult to assess the effect of AquaMats® on reducing aggression and fin erosion. A hypothesis we were partially trying to assess in Test 2 was that the presence of structure (AquaMats®) in the raceways would reduce the lateral site distance between fish and present a heterogenous environment that would reduce territoriality. The effects of rearing fish in a heterogenous environment may be reduced competition for food and space and thereby improved fin condition. Mikheev, Adams, Huntingford & Thorpe 1996) found that Arctic charr *Salvelinus alpinus* L. reared in an environment with a homogeneous substrate tended to swim closer together and fought more than their counterparts in a heterogeneous environment. Because fin erosion has been closely correlated with aggression (Abbott & Dill 1985; Moutou, McCarthy & Houlihan 1998; MacLean *et al.* 2000), it seems possible that, given the good fin condition found mid-way through the study, that the use of AquaMats® reduced aggression or territoriality. A higher density of mats than what we used may provide a more permanent effect on fin condition.

Acknowledgments

We wish to thank Mark Brough, Clint Brunson and Mark Smith for their help with maintenance of the studies. This research was supported by the Utah Division of Wildlife Resources and the Federal Aid in Sportfish Restoration Program.

References

Abbott J.C. & Dill L.M. (1985) Patterns of aggressive attack in juvenile steelhead trout (*Salmo gairdneri*). *Canadian Journal of Fisheries and Aquatic Sciences* **42**, 1702–1706.

Berejikian B.A., Tezak E.P., Flagg T.A., LaRae A.L. & Kummerow E. & Mahnken C.V.W. (2000) Social dominance, growth, and habitat use of age-0 steelhead (*Oncorhynchus mykiss*) grown in enriched and conventional hatchery rearing environments. *Canadian Journal of Aquatic Sciences* **57**, 628–636.

Denton J.E. & Yousef M.K. (1975) Seasonal changes in hematology of rainbow trout, *Salmo gairdneri*. *Comparative Biochemistry and Physiology* **51A**, 151–153.

Goede R.W. (1991) *Fish Health/Condition Assessment Procedures*. Utah Division of Wildlife Resources, Fisheries Experiment Station, Logan, Utah.

Goede R.W. & Barton B.A. (1990) Organismic indices and an autopsy-based assessment as indicators of health and condition of fish. *American Fisheries Society Symposium* **8**, 93–108.

Hartman G.F. (1963) Observations on behavior of juvenile brown trout in a stream aquarium during winter and spring. *Journal of the Fisheries Research Board of Canada* **20**, 769–787.

Johnson S.L. (1993) Cover choice by bluegills: Orientation of underwater structure and light intensity. *Transactions of the American Fisheries Society* **122**, 148–154.

Kindschi G.A. (1987) Method for quantifying degree of fin erosion. *Progressive Fish-Culturist* **49**, 314–315.

Kindschi G.A., Thompson R.G. & Mendoza A.P. (1991) Use of baffles in rainbow trout culture. *Progressive Fish-Culturist* **53**, 97–101.

Lellis W.A. & Barrows F.T. (1997) The effect of diet on dorsal fin erosion in steelhead trout (*Oncoryhnchus mykiss*). *Aquaculture* **156**, 229–240.

MacLean A., Metcalfe N.B. & Mitchell D. (2000) Alternative competitive strategies in juvenile Atlantic salmon (*Salmo salar*): evidence from fin damage. *Aquaculture* **184**, 291–302.

McLeay D.J. & Gordon M.R. (1977) Leucocrit: a simple hematological technique for measuring acute stress in salmonid fish, including stressful concentrations of pulp-mill effluent. *Journal of the Fisheries Research Board of Canada* **34**, 2164–2175.

Mikheev V.N., Adams C.E., Huntingford F.A. & Thorpe J.E. (1996) Behavioural responses of benthic and pelagic Arctic charr to substratum heterogeneity. *Journal of Fish Biology* **49**, 494–500.

Miller W.R. III, Hendricks A.C. & Cairns J. Jr (1983) Normal ranges for diagnostically important hematological and blood chemistry characteristics of rainbow trout (*Salmo gairdneri*). *Canadian Journal of Fisheries and Aquatic Sciences* **40**, 420–425.

Moutou K.A., McCarthy I.D. & Houlihan D.F. (1998) The effect of ration level and social rank on the development of fin damage in juvenile rainbow trout. *Journal of Fish Biology* **52**, 756–770.

Piper R.G., McElwain I.B., Orme L.E., McCraren J.P., Fowler L.G. & Leonard J.R. (1982) *Fish Hatchery Management*. U.S. Fish and Wildlife Service, Washington, D.C.

Sano T. (1960a) Haematological studies of the culture fishes in Japan 3. Changes in blood constituents with growth of rainbow trout. *Journal of the Tokyo University of Fisheries* **46**, 77–87.

Sano T. (1960b) Haematological studies of the culture fishes in Japan 2. Seasonal variation of the blood constituents of rainbow trout. *Journal of the Tokyo University of Fisheries* **46**, 67–75.

Satchell G.H. (1991) The blood. In: *Physiology and Form of Fish Circulation* (ed. by G.H. Satchell), pp. 58–79. Cambridge University Press, Cambridge.

Schneider R. & Nicholson B.L. (1980) Bacteria associated with fin rot disease in hatchery-reared Atlantic salmon (*Salmo salar*). *Canadian Journal of Fisheries and Aquatic Sciences* **37**, 1505–1513.

Scott S. & McNeil R. (2001) Aquamats: How to provide habitat, feed and biofiltration for hatchery and nursery tanks. *Hatchery International* **2**, 19–21.

Storebakken T., Hung S.S.O., Calvert C.C. & Plisetskaya E. M. (1991) Nutrient partitioning in rainbow trout at different feeding rates. *Aquaculture* **96**, 191–203.

Triplett E. & Calaprice J.R. (1974) Changes in plasma constituents during spawning migration of Pacific salmons. *Journal of the Fisheries Research Board of Canada* **31**, 11–14.

Wagner E.J. (1993) Evaluation of a new baffle design for solid waste removal from hatchery raceways. *Progressive Fish-Culturist* **55**, 43–47.

Wagner E.J., Routledge M.D. & Intelmann S.S. (1996) Fin condition and health profiles of albino rainbow trout reared in concrete raceways with and without a cobble substrate. *Progressive Fish-Culturist* **58**, 38–42.

Wedemeyer G.A. (1996) Basic physiological functions. In: *Physiology of Fish in Intensive Culture Systems* (ed. by G.A. Wedemeyer), pp. 10–59. Chapman & Hall, New York.

Wedemeyer G.A., Barton B.A. & McLeay D.J. (1990) Stress and acclimation. In: *Methods for Fish Biology* (ed. by C.B. Schreck & P.B. Moyle), pp. 451–490. American Fisheries Society, Bethesda.

Winfree R.A., Kindschi G.A. & Shaw H.T. (1998) Elevated water temperature, crowding, and food deprivation accelerate fin erosion in juvenile steelhead. *Progressive Fish-Culturist* **60**, 192–199.

Zeitoun I.H., Ullrey D.E. & Tack P.I. (1974) Effects of water salinity and dietary protein levels on total serum protein and hematocrit of rainbow trout (*Salmo gairdneri*) fingerlings. *Journal of the Fisheries Research Board of Canada* **31**, 1133–1143.