

Review on rainbow trout (*Oncorhynchus mykiss*) farming in desert underground brackish water in Iran

Alizadeh M.^{1*}; Dadgar Sh.²; Hafezieh M.²

Received: May 2015

Accepted: December 2015

Abstract

Inland saline aquaculture may offer an opportunity for income diversification and a potentially productive use of land that can no longer support traditional agriculture in salt-affected parts of inland production and investment levels are characteristically low. It needs to develop in a manner that both prevents the further degradation of agricultural land and provides opportunities for an alternative and sustained economic base for dependent rural communities. Most central areas of Iran are under high risk of salinization through shallow water tables. Using saline groundwater for aquaculture production is a potential adaptive use of this otherwise degraded resource. Expansion of aquaculture in these areas is limited by some factors such as shortage of suitable sites and strict environmental regulations. These limitations, together with an abundance of salt-affected land and water resources, have led to the logical progression of investigating the suitability of these resources for aquaculture. Rainbow trout, which appear to be well adapted to rapid changes in salinity, have been promoted as a potential candidate for aquaculture in these regions. By using appropriate production system well-set to climate condition, trout farming in brackish water is a profitable method to develop inland aquaculture in Iran

Keywords: Aquaculture, Inland saline water, Rainbow trout, Underground brackish water, Earth pond

1-Iranian Fisheries Science Research Institute, Inland Brackish water Fish Research Center, Agricultural Research, Education and Extension Organization, Bafgh, Iran

2-Iranian Fisheries Science Research Institute, Agricultural Research, Education and Extension Organization, Tehran, Iran

*Corresponding author's Email: m_alizadeh47@yahoo.com.

Introduction

Secondary salinization is a major environmental problem in many arid and semi-arid areas of the world, adversely affecting up to 380 million hectares of land, including 100 million hectares of arable land (Ghassemi *et al.*, 1995; Lambers, 2003).

Inland saline aquaculture has the potential for positive economic, social and environmental outcomes from groundwater in salt affected land. The issues are closely interlinked. From a social perspective, declines in crop production on salt-affected farms reduce income and decrease capital value, with the result that many farmers are opting to leave the land, thereby compromising the structure and capability of rural communities (Anyanwu *et al.*, 2007). Beresford *et al.*, (2001) described increased incidence of stress and depression in rural communities as a consequence of the economic impacts of salinization. New, economically viable industries such as inland saline aquaculture could capitalize upon an established workforce experienced in animal husbandry and agribusiness, thus helping to maintain the fabric of rural communities. From an environmental perspective, inland saline aquaculture production is typically an adaptive approach to salinity and will therefore not directly remediate this environmental problem (Braaten and Flaherty, 2002; Starcevich *et al.*, 2003). Salt-affected land is significantly cheaper than other land and of added benefit is the fact that it is typically

freehold. Where inland saline aquaculture can be successfully integrated with salinity interception schemes, then the costs of pumping water can be shared, resulting in significant savings for both enterprises (Doupé *et al.*, 2003). The isolation of inland farms from pathogens and parasites may provide additional economic benefits through reduction or elimination of costly disease outbreaks and the production of certified disease-free seed stock. Also, the occurrence or severities of certain diseases that occur in fresh water are sometimes reduced by increasing salinity (Altinok and Grizzle, 2001).

Over half of the world's aquaculture production currently occurs in marine or brackish coastal waters (Partridge *et al.*, 2008). Salinity can change the amount of available energy for growth of fishes by altering the energetic cost of ionic and osmotic regulation; however, the relation between salinity and growth is complex and not readily predicted (Iwama, 1996). The major criteria in selecting fish species suitable for commercial-scale, inland saline aquaculture are essentially the same for any aquaculture industry. The selected species must be robust, have a rapid rate of growth, well established hatchery techniques and good market acceptance. Rainbow trout appear to be well adapted to rapid changes in salinity and are often directly transferred from fresh to oceanic waters in aquaculture grow-out situations (Crespi & Lovatelli, 2011). Finstad *et al.* (1988) reported that *O. mykiss* (40 - 120 g) tolerated

direct transfer from freshwater to 260/00 saline water without any visible signs of stress. Johnsson *et al.*, (1994) also stated that *O. mykiss* were better able to acclimatize to seawater during winter when water temperatures were lower, although not extreme. Tsintsadze (1991) reported that rainbow trout had the highest growth rate in 15–18‰ salinity (highest tested), slower growth in lower salinities, and had the lowest growth rate in fresh water.

Although some reports related to last years are available on rainbow trout culture in sea water through different systems (Sottovia, 1983; Ford, 1984; Philips, 1985; Cowey, 1989; Saunders, 1991; Bromage *et al.*, 1991), but no previous record was observed on rainbow trout aquaculture in inland underground brackish water having particular characteristics especially high temperature and inconstant of salt composition.

The idea to action

Rainbow trout culture began in Iran since 1960. This activity initially found little development, so only three farms constructed until 1985. Then the development of rainbow trout aquaculture entered into a new phase, so production of trout rose from about 500 tons in 1990 to more than 70,000 tons in 2009. Culture of rainbow trout has grown noticeably in the past two decades (Kalbassi *et al.*, 2013). This considerable production mainly obtained from freshwater resources, while the country is located in low-rain region. Abundance of salt-affected land

rich in underground saline water resources with different salinities (5–40g/l) resulted in specific climate conditions, have led to investigating the suitability of these resources for aquaculture. Using saline groundwater for aquaculture production is a potential adaptive use of this otherwise degraded resource.

The first experiment on trout aquaculture in inland underground saline water was conducted in Inland Brackish water Fishes Research Station in 1995 in central area of Iran where the climate is dry-warm, involved extensive plains rich in underground brackish water. Regarding to availability of relatively cheap land in salt-affected areas and also low cost construction, earth pond was selected as culturing system. Since well adaptation of rainbow trout to rapid changes in salinity and profitability of its production in state of Iran, this species promoted as potential candidate for aquaculture in these areas. Base on theory of experiment, it was contemplated semi-annual production system of rainbow trout in earth pond during cool seasons including fall and winter. Certainly, the main criterion specific to fish production in inland saline waters is that the water quality requirements for optimum performance of a species must be matched to the characteristics of an available water source (Doupé *et al.*, 1999). The aim of the current review is to summarize the science based knowledge associated with selected key issues relating to the welfare of rainbow trout in inland saline

aquaculture. Perhaps due to the nature of the aquaculture setting and the importance of product quality, the behavior and needs of rainbow trout in the brackish water environment and optimization methods to increase production in unit area is necessary to understand constructing an appropriate trout inland brackish water aquaculture. As fish welfare is a growing area of research this is by no means a comprehensive review covering all aquaculture fish species or indeed all situations where welfare maybe a concern but can be expanded as general guidelines to develop rainbow trout aquaculture in inland waters.

Stocking density

Stocking density is pivotal factor affecting fish welfare in the aquaculture industry, especially where high densities in confined environments are aimed at high productivity. The stocking density at any point in time will increase as fish grow or decrease following grading. Stocking density is, therefore, hard to measure in the field. The concept of minimum space for a fish is more complex than for terrestrial species as fish utilize a three-dimensional medium (Ellis, 2001; FSBI, 2002; Conte, 2004). Because fishes are dependent on this medium for both physiological and behavioral needs, the welfare concerns associated with stocking density should address both the carrying capacity of the holding environment and the spatial and behavioral needs of the species. Carrying capacity refers to the

maximum number of fish that an environment can support through oxygen supply and removal of metabolic waste and will be determined by, amongst other things, the oxygen consumption rate of the fish and their response to metabolic waste products such as CO₂ and ammonia (Ellis, 2001). Beyond providing for the physiological needs, fish needs sufficient space to show most normal behavior with minimal pain, stress and fear (FAWC, 1996). Stocking density is, therefore, an area that illustrates both the significance of species differences and the existence of a complex web of interacting factors that effect fish welfare.

Because of specific conditions of desert area, stocking density of rainbow trout in brackish water earth pond system is an important parameter which must be evaluated to achieve more production in selected breeding system and its economic assessment. The best growth performance of rainbow trout in inland brackish water earth pond obtained in density 1.5 fish/m² in 0.3 ha earth ponds were stocked by rainbow trout juveniles with initial weight of about 15g for 150 days by 5% water exchange rate (Nafisi *et al.*, 1998).

According to some measured environmental factors it seems by increasing density per earth pond area unit, water quality will be decreased which result in low growth performance and increase of feed conversion ratio. In such condition, it is also inevitable exchanging pond water more than 5%, while high temperature of well water probably can increase pond water

temperature up to thermal tolerance threshold of rainbow trout during culture period. Therefore, regarding to the type of utilized water source which greatly affected by climatic conditions, it claims that low stocking density (1-1.5fish/m²) brings about better access to optimal growth performance. It should be considered by growers that perform this density only in cold months in semi-annual production.

Protein and energy requirements

In the aquaculture industry, feeds represent 40–60% of the production costs. Formulated fish feeds based on fish nutrition have advanced dramatically in recent years, which promotes optimal fish growth and health. Feeding regimes should be also modified and developed according to regional environments (climate, geography, economic condition, etc). As well as, nutritional requirements for optimum growth of the fish seem to be affected by numerous factors such as temperature, salinity, fish age and size, etc. (Cowey, 1976). Realization of the optimum protein and energy level for cultured fish would help reduce the costs and maximize the feed conversion efficiency (Charles *et al.*, 1984; Sampath, 1984; Chiu *et al.*, 1987).

Taking into consideration introduce rainbow trout in brackish water as a new culturing medium and also diet may play an important role in stress sensitivity (Merchie *et al.*, 1997), it is important to recognize some basic dietary requirements in order to prepare balanced feeds leading to optimum

growth and feed utilization. In various ratios of dietary protein to energy (P/E) in growing stage of rainbow trout in brackish water medium, by increasing energy level from 370 to 430 Kcal/100g, weight gain (WG %), average daily growth (ADG %), protein efficiency ratio (PER), apparent net protein utilization (ANPU %), specific growth rate (SGR), condition factor (CF) increased and feed conversion ratio (FCR) decreased (Alizadeh, 1997). In inland brackish water medium the best growth performance attained in 35% protein level and 430kcal/100g digestible energy level.

Most of published results on rainbow trout in different mediums particularly in fresh water emphasized that protein level of 35% is the optimum in growing stage in balanced energy diet. So, it can be decreased up to minimum need if required energy and amino acids supplied in adjustment (Murai, 1992; Wilson, 1994; Kaushik, 1997). Lever *et al.* (2004), reported specific growth rates of 1.09 and 1.21%/day from intensive and semi-intensive rainbow trout farms respectively that in both systems, water temperature, salinity regimes and initial size of experimented fish were the same with Alizadeh (1996). Under small-scale experimental conditions, Okumus and Mazlum (2002) achieved an SGR of 2.0 and an FCR of 1.0 in rainbow trout grown for 22 weeks in water 7 – 10ppt salinity.

Altinok and Grizzle (2001) demonstrated that rainbow trout grew faster in 3 and 9‰ salinities with the

highest SGR and lowest FCR than in 1‰ salinities. In 9‰ salinity, the digestibility of feed in energy terms in 3 and 9‰ salinities is highest for rainbow trout, so by increasing salinity Digestibility of energy in feed increased for this species. Therefore, salinity of 9‰ can be used to improve growth and FCR in rainbow trout, so there is no noticeable difference in fresh and brackish water in growth performance.

Utility improvement in cultural earth ponds

The culturing system improvement in aim of increasing in production and economic benefit is the important goal in aquaculture systems. Some technical approaches which seemed to be efficient in utility amelioration of earth ponds according to climatic condition, describe as bellows:

Pond aeration

Aeration, like feeds and feeding, is one of the most frequently discussed topics in aquaculture. This is true because, at any given temperature, the availability of oxygen plus nutritionally adequate food are defining factors in determining the extent to which oxygen consuming organisms such as finfish and shellfish thrive and grow, both in nature and in aquaculture systems. One basic principle of pond aquaculture is that natural aeration and biological and chemical processes affecting the concentration of dissolved oxygen and other gases normally far exceed anything that can be achieved by mechanical aeration. The latter can be

used to good effect to provide emergency or supplemental oxygen, but such beneficial uses can be readily overwhelmed by poor pond design or management practices.

Referring to specific condition of farms in desert area, this factor maybe needfulness in utility improvement or not. Higher growth performance and lower water utilization in inland earth pond obtained without aeration (Nafisi *et al.*, 2002). It probably was due to higher turbidity and increasing suspended particles in aeration treatments. Soil condition in aquaculture should be given the same degree of consideration as water condition. Just as there is a condition of equilibrium between the water and the air, there is also a condition of equilibrium between the water and the soil. Water quality can be greatly affected by its interaction with the soil. Many of the suspended particles found in the water are derived from its contact with the soil. According to Boyd (1997) earth pond aeration caused soil disturbance of benthic sediment and consequently re-suspending them. It can be claimed that in such circumstances especially in case of adapted water temperature, increasing plankton growth affects food consumption by fish. It also intensifies the exchange of water that can cause rising in pond water temperature maybe more than tolerance threshold of rainbow trout. In the fish culturing earth ponds, where the water is full of biological and chemical activity, the aerators will not be so efficient for rainbow trout farming.

In contrast, different aeration methods are widely-used in earth pond warm water aquaculture. Aeration in these systems provides economical advantages in aquaculture. Nightly Aeration to increase production of channel catfish by Hollerman and Boyd (1980) demonstrated that aerated ponds yielded an average of 5,307 kg/hectare of channel catfish and had a net economic gain of \$1,500 per hectare. The unaerated ponds yielded an average of 1,400 kg/hectare and were an obvious economic failure. Hybrid carp, *Ctenopharyngodon idella* × *Aristichthys nobilis*, were stocked into 0.04 ha ponds with and without paddlewheel aeration, grew at significantly greater rates in the paddlewheel ponds (Shireman *et al.*, 1983). The average shrimp production was 2,852 kg/ha in the aerated ponds and only 2,061 kg/ha in unaerated ponds. The net value of the shrimp crop of the aerated ponds was 42 percent greater than that of the unaerated ponds (Martinez *et al.*, 1998). The net returns to land, management, and equity capital were found to be 92% higher for the aerated ponds than they were for unaerated ponds (Abdalla and Romaine, 1996). Nighttime aeration for 5h enhanced the growth of tilapia in the treatment with 4cages/pond, and increased the carrying capacity in the integrated cage-cum-pond system (Yang and Kwei Lin, 2001).

Therefore, it seems application of aerators such as Force group which inject the air in the water is not suitable for rainbow trout earth ponds where the depth is less than 2 meters. Apparently

these devices have not a significant effect either on increasing production or decreasing required water in semi-intensive earth pond system of rainbow trout farming by using warm-brackish well water. In such environment with this type soil bottom, it can be suggested that the aerator must work at a depth sufficient enough that its oxygenating and circulating efforts can treat the pond bottom soil, keeping it oxygenated and free of deadly toxins that can pollute the water and harm or kill aquatic animals, but it must do so without eroding the pond bottom soil.

Reuse of earth ponds wastewater:

Nutrient recycling efficiency and economic aspects should be explicitly stated when reporting the efficiency of aquaculture system. Reporting overall purification results (effluent/influent) is not enough. Sound nutrient budgeting is an important step towards improving the functioning of aquaculture plants (Das, 2000). So, reuse of wastewater for aquaculture may be a proper approach to consider multiple exploitations of water resources and development in aquaculture sector through using non drinkable water to cultivate protein products.

Study on some limnological parameters of rainbow trout brackish water earth pond proved reasonable quality of waste water as well as water in pond (Mashai *et al.*, 2003; Kolkovski *et al.*, 2011; Castine *et al.*, 2013). Taking into consideration importance of water in semi-arid area and appropriate quality of earth ponds

wastewater, fish production in an aquaculture wastewater reuse system would be an environmental as well as economic occupation.

According to Alizadeh *et al.* (2004), waste water reuse of rainbow trout brackish water earth ponds with aim of utility improvement of farm resulted in increasing yield quantity and gross income of farm up to 31% and 41%, respectively. This additional yield obtained by constructing a 30m³ round cement tank at the end of earth pond and regulating outlet flow water to them by both pumping and gravity. During culture period in cement tank none of environmental factors was critical for rainbow trout. It can be claimed that reusing wastewater of rainbow trout earth pond in semi-intensive method is a good approach for farmers to better exploitation of possibilities and facilities in order to get more yield and revenue.

Establishing enclosure medium (net pen):

Fish production from enclosures could be increased through the implementation of a number of strategies, all of which would result in a better utilization of much pressurized resources. Cages and pens have several advantages over other methods of culture. Because they use existing water bodies, require comparatively low capital outlay and use simple technology, they are popular with farmers, extension workers and development programs. They can be used not only primarily as a method for

producing high quality protein cheaply but also, as is happening in Malaysia and Singapore, to clean up eutrophicated waters through the culture and harvesting of caged planktivorous species (Yang, in press; Awang Kechik *et al.*, in press) and to improve conditions in acid lakes in Scandinavia (Swedish Research Council, 1983). Thus, despite accounting for only 5–10% of current inland water aquaculture production, growth in this sector is rapid.

Establishing enclosure medium in earth pond of rainbow trout to increase yield of farm performed by separating 20% of earth pond's space via a fixed net wall with 15 mm in mesh. Fish density in enclosure part is 7.5fish/m² so number of fishes in this area was as amount as open pond. Since there was a connection between pen medium with free one, no signs based upon disturbance observed in measured environmental factors in this space. The percentage of harvested marketable size (larger than 250g), production net income and total yield were also increased significantly in enclosure medium rather than open medium (Alizadeh *et al.*, 2009).

In introduced semi-intensive rainbow trout farming in large earth pond, low fish density maybe led to dispersion of some fishes throughout the pond which may be result in unequal access to food and consequently dissimilarity in final weight. Culturing fish in the enclosed part of pond is effective to remove or moderate these limitations in this

system. Therefore, through pen culture of rainbow trout in 0.5ha earth ponds and likely larger ones, utility and production of farm can be improved considerably.

Maturation

Growth and development of animals are affected by inner and outer factors such as genetic (Glebe and Saunders, 1986; Ritter *et al.*, 1989), biologic (Chadwick *et al.*, 1986) and environmental conditions. In despite of determinant role of genetic and biological factors on growth rate and correlation between high growth rates and underage maturation (Thorpe, 1986), water quality among the outer factors, is the most important and it seems the salinity effects on growth, gonad development and maturation of fishes. About rainbow trout, there are many reports on circulating of gonadic growth and maturation in fresh water, while a few in brackish or saline water.

Regarding to rapid growth and maturation of rainbow trout in semi-intensive brackish water earth pond system, it probably seems that salinity plays an effective role in growth and gonad development in rainbow trout. Somatic and gonadic development of one-year old rainbow trout with initial weight of 250g was compared in fresh and brackish water for 180 days. Somatic growth of rainbow trout along with culture period until sexual ripening is about 20% higher in brackish water than fresh water. It was also demonstrated that needful time for passing any sexual stage of testis and

ovary of rainbow trout is different in brackish and fresh water, so process of gonadic development of rainbow trout is faster in brackish water (Falahati Marvast, *et al.*, 2001). According to Albrektsen and Torrissen (1988), brackish water environment is particularly favorable for pre-grown generating in waters with higher temperatures. It was also proved that in different light regimes, during the stage before making the yolk and yolk with internal origin, it affected by environmental factors, but which with external origin was under internal biological rhythms (Bon *et al.*, 1997). sexual ripening and artificial propagation of two years old rainbow trout that had reared in brackish water in salinity about 14g/l from initial weight of 20g, indicated maturity 80% of fishes in which 55% were female and 45% were male. Fertilized eggs were incubated in fresh water with a desired result of 92% hatching. The larvae in weight of 250mg were able to direct move in brackish water without any unusual behavior or mortality (Alizadeh, 2008). Therefore, it can be claimed that the salinity as a factor along with other environmental, genetic and biological factors, accelerate the growth of reproductive material in a variety of male and female rainbow trout.

Cocclustions

Inland brackish and saline waters have high potentialities for aquaculture. Rainbow trout is a euryhaline fish and base on studies this is a very important

species for development of inland saline aquaculture. Salty underground waters according to the geographic conditions differ in composition and salts of water as well as temperature at the time of pumping. Despite the resistance of trout to salinity, water temperature has a determining and main role in how to exploit water for culture. Some investigations conducted on potential of rainbow trout for inland saline aquaculture based on the use of underground saline and warm water which is mostly in areas with low altitude and hot climate. The results offer the right acceptable solution to the exploitation of these water sources for trout culture based on the construction of 0.25ha earth ponds and culture in cold months in semi-annual production. Semi-intensive system (1.5fish/m²) and water exchange rate of at least 5% pond water volume in a day determined for production and can produce 5-7 tons trout per hectare in each growing period.

To increase production in ponds, aeration, however, as an important part of commercial aquaculture, because of water turbulence, re-suspension sediment particles and also reduction the water quality is not acceptable method for utility amelioration in semi-intensive earth pond system. However, the use some techniques such as the reuse of earth ponds waste water and establishing enclosure medium (net pen) considerably increase production and utilization trout farms.

Some of the essential nutritional requirements of trout, including protein,

fat and energy in brackish water are not particular different with fresh water and the best growth performance attained by diet in level of 35% crud protein and 20.6% crud fat. In other words, common commercial feed fed trout have a high efficiency in the brackish water conditions.

It was also proved that the somatic and gonadic growth in brackish water is higher than fresh water. Thus, importance of these water resources for pre-grown generating and meat production in the event of water temperature management is considerable. Also inland saline aquaculture can be considered as the intermediate environment for creating pre-grown generating herds of trout.

Overall benefits and consequences of researches can be summarized as follows:

1. Aquaculture development in inland saline waters, particularly in unsuitable areas for agriculture.
2. Economic exploitation of brackish water as non-consumption water resources in agricultural, industrial and etc.
3. Meat production according to its growing market demand and high economic value.
4. Developing exports and foreign exchange income.
5. Increase in employment opportunities in less developed areas and prevent migration.
6. Increasing the per capita consumption of fish to help improve people's nutrition.

Therefore, high capability the brackish underground water resources are admitted for inland saline aquaculture. However conducted researches provided approaches to exploit these resources for inland saline trout aquaculture, but optimized and scientific utilization along with economic benefits and more income regeneration more investigations required.

References

- Abdalla, A.F. and Romaine, R.P., 1996.** Effects of timing and duration of aeration on water quality and production of channel catfish. *Journal of Applied Aquaculture*, 6 (1), 1-9.
- Albrektsen, S. and Torrissen, O.J., 1988.** Physiological changes in blood and seminal plasma during the spawning period of maturation rainbow trout held under different temperature and salinity regimes and the effect on survival of the brood stock and the eyed eggs. Inter. Council. Exp. Sea; pp. 1-24.
- Alizadeh, M., 1996.** Rainbow Trout (*Oncorhynchus mykiss*) culture in earth ponds in underground brackish water. Abzi prvar magazine, IFO publication, pp. 13-15.
- Alizadeh, M., 1997.** Effect of dietary protein and energy levels on rainbow trout (*Oncorhynchus mykiss*) reared in brackish water. *Iranian journal of fisheries science*, 4(1), 77-88.
- Alizadeh, M., Rajabipour, F. and Sarsangi, H., 2004.** Wastewater reuse of rainbow trout earth ponds to increase production in earth farms. Research project final report, IFRO, 38p.
- Alizadeh, M., 2008.** Cultured breeders of rainbow trout in brackish water, Bafgh, Yazd. IFRO newsletter, No.54 & 55, Spring & Summer 2008.
- Alizadeh, M., Bitaraf, M., Sarsangi, H., Mohamadi, M., Mashaiee, N. and Rajabipour, F., 2009.** Utility improvement of brackish water cultural earth ponds of rainbow trout through establishing enclosure medium (pen) Research project final report, IFRO, 37P.
- Altinok, I. and Grizzle, J.M., 2001.** Effects of low salinities on *Flavobacterium columnare* infection of euryhaline and freshwater stenohaline fishes. *Journal of Fish Diseases*, 24, 361-367.
- Bekibele, D. and Onunkwo, D., 2007.** Brackish water aquaculture: a veritable tool for the empowerment of Niger Delta communities." *Scientific Research and Essays* 2(8): 295-301.
- Beresford, Q., Bekle, H., Phillips, H. and Mulcock, J., 2001.** The Salinity Crisis - Landscapes, Communities and Politics. University of Western Australia Press, Perth, 324P.
- Bon, E., Corraze, G., Kaushik, S. and Le, Menn, F., 1997.** Effect of accelerated regimes on the reproductive cycle of the female rainbow trout: seasonal variation of plasma lipids correlated with vitellogenesis; comp; biochem. *Physiol*; 118A (1), pp. 183-190.

- Boyd, C.E., 1997.** Advanced in pond aeration. Info fish- int 1997, No. 2, pp. 24-28.
- Braaten, R.O. and Flaherty, M., 2002.** Salt balances of inland shrimp ponds in Thailand: implications for land and water salinization. *Environmental Conservation*, 28, 357-367.
- Bromage N., Sheilds, R., Gillespie, M. and Johnsyone, R., 1991.** UKmariculture: experiences and prospects. Conference of marine fish culture and enhancement, seattle, USA, 4-6 Oct. 1993.
- Castine, S.A., McKinnon, A. D., Paul, N.A., Trott, L. A. and de Nys, R. 2013.** Wastewater treatment for land-based aquaculture: improvements and value-adding alternatives in model systems from Australia. *Aquaculture Environment Interactions* 4: 285-300.
- Crespi V. and Lovatelli, A., 2011.** Global desert aquaculture at a glance. In V. Crespi & A. Lovatelli, eds. *Aquaculture in desert and arid lands: development constraints and opportunities*. FAO Technical Workshop. 6-9 July 2010,
- Charles, P.M., Sebastian, S.M., Raj, M.C. and Marian, M.P., 1984.** Effect of feeding frequency on growth and food conversion of *Cyprinus carpio* fry. *Aquaculture*, 40, 293-300.
- Chawick, E.M.P., Randall, R.G. and Leger, C., 1986.** Ovarian development of atlantic salmon, *salmo salar* Smolts and age at first maturity; In: Meerburg D.J.(Ed), *Salmonid age maturity*, Canadian special publication of fisheries and aquatic sciences, 89,pp. 15-23
- Chiu, Y.N., Sumagaysay, N.S. and Sastrillo, M.S., 1987.** Effect of feeding frequency and feeding rate on the growth and feed efficiency of milkfish (*Chanos chanos*). *Asian Fisheries Science*, 1, 27-31.
- Conte, F.S., 2004** Stress and the welfare of cultured fish. *Applied Animal Behavior Science*, 86, 205-223.
- Cowey, C., 1976.** Use of synthetic diets and bio-chemical criteria in assessment of nutrients requirements of fish. *Journal of Fish Research Board. Canada*, 33, 1040-1045.
- Cowey, C.B., 1989.** The present status and problems of world Aquaculture with special reference to fish feed. *Aquaculture in the U.K. Book conference symp. On nutrition of fish* (1990), pp.13-25.
- Das, F.B., 2000.** Ecological engineering for wastewater treatment. In Jana, B.B., Banerjee Guterstam, B.R.D., Heeb, J., eds. *Waste recycling and resource management in the developing world*. University of Kalyani, India and International Ecological Engineering Society, Switzerland. pp.125-133.
- Doupé R.G., Alder, J. and Lymbery, A.J., 1999.** Environmental and product quality in finfish aquaculture development: an example from inland Western Australia. *Aquaculture Research*, 30, 595-602.
- Doupé, R.G., Lymbery, A.J. and Starcevich M.R., 2003.** Rethinking

- the land: The development of inland saline aquaculture in Western Australia. *International Journal of Agriculture Sustainability*, 1, 30-37.
- Ellis, T., 2001.** What is stocking density? Trout News, CEFAS, 32, 35–37.
- Ellis, T., 2002.** The effects of stocking density on the welfare of farmed rainbow trout. In: Report of the Workshop on Farmed Fish Welfare held on Monday 28th October 2002, DEFRA.
- Ellis, T., North B., Scott, A.P., Bromage, N.R., Porter, M. and Gadd, D., 2002.** The relationships between stocking density and welfare in farmed rainbow trout. *Journal of Fish Biology*, 61, 493–531.
- Falahati Marvast, A., Mojazi Amiri, B., Abtahi, B. and Alizadeh, M., 2001.** Comparative study on ovarian development of rainbow trout reared in brackish water. *Iranian journal of Marine Sciences*, 2 (1), 47-58.
- FAWC (Farmed Animal Welfare Council), 1996.** Report on the Welfare of Farmed Fish. Surbiton, Surrey.
- Finstad, B., Staurnes, M. and Reite, O.B., 1988.** Effect of low temperature on sea-water tolerance in rainbow trout, *Salmo gairdneri*. *Aquaculture*, 72, 319-328.
- Ford, R.J., 1984.** Norwegian salmon and trout farming. *Marin fish REV.VOL 46.No 3.* pp. 44-47
- FSBI (Fisheries Society of the British Isles), 2002** Fish Welfare. Briefing Report 2. Granta Information systems.www.le.ac.uk/biology/fsbi/welfare.pdf.
- Ghassemi, F., Jakeman, A.J. and Nix, H.A., 1995.** Salinisation of Land and Water Resources: Human Causes, Extent, Management and Case Studies. University of New South Wales Press, Sydney, 526P.
- Glebe, B.D. and Saunders R.L., 1986.** Genetic factors in sexual maturity of cultured Atlantic salmon, *Salmo salar* parr and adults reared in sea cages. In: Meerburg, D. J. (Ed), Salmonid age at maturity. *Can. Spec. Pulb. Fish. Aquatic Sciences*, 89, pp.24-29
- Hollerman, W.D. and Boyd, C.E., 1980.** Nightly Aeration to Increase Production of Channel Catfish. *Transactions of the American Fisheries Society*, 109, 446-452
- Iwama, G.K., 1996.** Growth of Salmonids. In Principles of Salmonid Culture (Pennell, W. & Barton, B. A., eds), pp. 467–516. Amsterdam: Elsevier.
- Johnsson, J.I., Clarke, W.C. and Blackburn, J., 1994.** Hybridization with domesticated rainbow trout reduces seasonal variation in seawater adaptability of steelhead trout (*Oncorhynchus mykiss*). *Aquaculture*, 121, 73-77.
- Kalbassi, M. R., Abdollahzadeh, E. and Salari-Joo, H., 2013.** A review on aquaculture development in Iran. *Ecopersia* 1(2): 159-178.
- Kaushik, S.I., 1977.** Influence de la salinite sur le metabolisme azole ET le besoin en arginine chez la truit arc-en-ciel. 230P.

- Kolkovski, S., Simon, Y., Hulata, G. & Ayaril, N., 2011.** Desert aquaculture. pp. 107–125. In *Aquaculture: Farming Aquatic Animals and Plants*. Paperback Wiley-Blackwell 648 pp.
- Lambers, H., 2003.** Dryland salinity: a key environmental issue in Southern Australia. *Plant Soil* 257, v-vii.
- Lever, C., Lymbery, A.J. and Doupé, R., 2004.** Preliminary comparisons of yield and profit achieved from different rainbow trout, and production systems in inland Western Australia. *Journal of Applied Aquaculture*, 16, 63-73.
- Martinez cordova, L.R., Porchas Cornejo, M.A., Villarrial Colmenares, H. and Calderon Perez, J.A. 1998.** Winter culture of yellow leg shrimp (*Penaeus californiensis*) in aerated ponds with low water exchange. *Journal of the world aquaculture society*, 29(1), 120-124
- Mashaiee, N., Alizadeh, M., Rajabipour, F. and Sarsangi, H., 2003.** Study on limnology of rainbow trout brackish water earth ponds. Research project final report, IFRO, 120P.
- Merchie, G., Lavens, P., Verreth, J., Ollevier, F., Nelis, H., DeLeenheer, A., Storch, V. and Sorgeloos, P., 1997.** The effect of supplemental ascorbic acid in enriched live food for *Clarias gariepinus* larvae at start feeding. *Aquaculture*, 151, 245–258.
- Murai, T., 1992.** Protein nutrition of rainbow trout. National Research Institute of Fisheries Science. Japan. *Aquaculture*, 100, 191-207.
- Nafisi, M., Sharifiyan, M. and Dehmobad, D., 1998.** Culture of rainbow trout (*Oncorhynchus mykiss*) brackish water earth ponds system. Research project final report, IFRO, 45P.
- Nafisi, M., Sharifiyan, M., Akhondi, A. and Alizadeh, M., 2002.** Increase in production of rainbow trout (*Oncorhynchus mykiss*) brackish water earth ponds through aeration. Research project final report, IFRO, 86P.
- Okumus, I. and Mazlum, M.D., 2002.** Evaluation of commercial trout feeds: Feed consumption, growth, feed conversion, carcass composition and bio-economic analysis. *Turkish Journal of Fisheries and Aquatic Sciences*, 2, 101-107.
- Partridge, G.J. and Creeper, J., 2004.** Skeletal myopathy in juvenile barramundi, *Lates calcarifer* (Bloch), cultured in potassium-deficient saline groundwater. *Journal of Fish Diseases*, 27, 523-530.
- Partridge, G.J., Lymbery, A.J. and George, R.J., 2008.** Finfish mariculture in inland Australia: A review of potential water sources, species and production systems. *Journal of the World Aquaculture Society*, 39, 291-310.
- Philis, M.J., 1985.** Behavior of rainbow trout in marine cages. *Aquaculture fish management*. Vol 16. No 3. Pp. 223-232

- Pickering, A.D., 1992.** Rainbow trout husbandry–management of the stress response. *Aquaculture*, 100, 125–139.
- Refstie, T., 1977.** Effect of density on growth and survival of rainbow trout. *Aquaculture*, 11, 329–334.
- Ritter, J.A., Farmer, G.J., Farmer, G.J., Misera, P.K., Goff, T.R., Bailey, J.K. and Baum E.T., 1988.** Parental influences and smolt size and sex ratio effects on sea cage at first maturity of Atlantic salmon, *Salmo salar*. Canadian special publication of fisheries and aquatic sciences, 89, 30-38.
- Sampath, K., 1984.** Preliminary report on the effect of feeding frequency in *Channa striatus*. *Aquaculture*, 40, 301-306.
- Saunders, R.I., 1991.** Salmonid mariculture in Atlantic Canada and Maine, USA. Special session on Salmonid aquaculture. World aquaculture society. No. 1831. pp. 21-36
- Shireman, J.V., Aldridge, F.J. and Rottmann, R.W., 1983.** Growth and food habits of hybrid carp, *C. idella* × *Aristichthys nobilis*, from aerated and non- aerated ponds. *Journal of Fish Biology*, 23 (5), 595 – 604.
- Sottovia, J.L., 1983.** Trout culture in marine waters. Thesis doct. Vet. 17P.
- Starcevich, M.R., Lymbery, A.J. and Doupé, R.G., 2003.** Potential environmental impacts from farming rainbow trout using inland saline water in Western Australia. Australian. Journal of Environmental Management, 10, 15-24.
- Swedish Research Council, 1983.** The environmental impact of aquaculture. Stockholm, Sweden, Publishing House of the Swedish Research Councils, 74P.
- Thrope, J.E., 1986.** Age at first maturity in Atlantic salmon, *Salmo salar* fresh water period influences and conflicts with smolting. *Canadian special publication of fisheries and aquatic sciences*, 89, 7-14.
- Tsintsadze, Z.A., 1991.** Adaptational capabilities of various size age groups of rainbow trout in relation to gradual changes of salinity. *Jour. Ichthyology*, 31(3), 31-38
- Turnbull, J., Bell, A., Adams, C., Bron, J. and Huntingford, F., 2005.** Stocking density and welfare of cage farmed Atlantic salmon: application of a multivariate analysis. *Aquaculture*, 243, 121–132.
- Wilson, R.P., 1994.** Utilization of dietary carbohydrate by fish. *Aquaculture*, 124, 67-80.
- Yang, S.L., (in press).** Fish culture and reservoir management in the Republic of Singapore. In Proceedings of the Seminar on production and exploitation of open waters. (In press).
- Yang, Y.I. and Kwei Lin, C., 2001.** Effects of biomass of caged Nile Tilapia (*Oreochromis niloticus*) and aeration on the growth and yields in an integrated cage-compound system. *Aquaculture*, 195, 253–267.