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Cultivation of gilthead sea bream (*Sparus aurata* Linnaeus, 1758) in low salinity inland brackish geothermal water

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Abstract. In the course of attempting to culture gilthead sea bream in inland brackish geothermal water, indoor and outdoor research studies have been ongoing from early 2006 at the "Bengis Centre for Desert Aquaculture" of the Institutes for Desert Research in Israel, some of which are described below. Gilthead sea bream fingerlings with an average weight of 19 g were acclimated to and reared for 56 days in brackish water of three salinities: 2.5, 3.5 and 4.5 ppt collected from three different locations. At the salinity of 3.5 ppt the fish grew best ($P < 0.05$) increasing their weight by 121%, while at 4.5 ppt weight increase was by 98%, and at 2.5 ppt – by 90%. In another study gilthead sea bream larvae aged 45 days post hatching, with an average weight of 0.025 g were fed yeast extract enriched *Artemia* nauplii plus larval dry feed and were grown in brackish water of 2.6 ppt salinity for 8 weeks reaching a weight gain of 92% at a survival rate of 83%. The control groups at sea water (39 ppt) reached at the same time a weight gain of 95% at a survival rate of 98%. In a further study gilthead sea bream juveniles with an average weight of 2.24 g were reared in brackish water with a salinity of 3.6 ppt for 8 weeks and received salt added diets of 4% and 6%. Compared with the control diet with no salt added, both salt rich diets significantly improved the fingerlings growth and survival rates as well as the feed conversion ratio. The 6% salt rich diet promoted fish weight gain by 560% which was the best performance ($P < 0.05$) followed by 448% weight gain with the 4% salt rich diet while the lowest performance with a weight gain of only 360% was obtained with the control (no salt added) diet. The next study with higher levels of salt added diets showed that gilthead sea bream post larvae with an average weight of 0.58 g reared in brackish geothermal water of 2.9 ppt salinity for 10 weeks grew best ($P < 0.05$) obtaining a weight gain of 778% with the highest survival rate of 88% when fed a diet containing 12% salt. In the studies with the salt rich diets, the salt incorporated was obtained by the evaporation of brine produced during the process of desalination of the brackish geothermal water from the same well supplying the fish rearing water. Worth mentioning at this point is that sea bream, after the termination of the experiments, were further kept for several months in the same brackish water showing further growth with no detrimental effects. The above mentioned research findings show conclusively the possibility of utilizing inland brackish water for culturing gilthead sea bream as an additional alternative to traditional marine farming. This is not surprising, considering the biology of the euryhaline gilthead sea bream, the juvenile of which appears at some stage in their life cycle in low salinity lagoons and river estuaries.

Key Words: gilthead sea bream, desert aquaculture, geothermal water, low salinity.

Zusammenfassung. Im Laufe des Versuchs Goldbrassen in brackisch-geothermalem Wasser zu zuechten, wurden seit 2006 eine Reihe von Studien im "Bengis-Zentrum für Wuesten-Aquakultur" des Instituts für Wuestenforschung in Israel durchgefuehrt. Einige Ergebnisse dieser Versuche werden hier beschrieben. Saetzlinge von Goldbrassen mit einem Durchschnittsgewicht von 19 g wurden akklimatisiert und 56 Tage lang in Wasser mit drei verschiedenen Salinitaeten gezuechtet: 2.5, 3.5, und 4 ppt, das aus drei verschiedenen Brunnen stammte. Das beste ($P < 0.05$) Wachstum mit einer Gewichtszunahme von 121% erreichten die Fische in der Wassersalinitaet von 3.5 ppt. In der Wassersalinitaet von 4.5 ppt betrug die Gewichtszunahme der Fische 98% und in der 2.5 ppt Wassersalinitaet nur noch 90%. In einem anderen Versuch wurden Goldbrassenlarven 45 Tage nach Schlupf und mit einem Durschnittsgewicht von 0.025 g mit einer Diaet von mit Hefeextrakt angereicherten Artemianauplien und mit larvalem Trockenfutter angefuettert. Diese Larven wurden dann im Wasser mit einer Salinitaet von 2.6 ppt gezuechtet. Innerhalb von 8 Wochen erreichten die Larven eine Gewichtszunahme von 92% bei einer Ueberlebensrate von 83% Die Kontrollgruppe im Seewasser (39 ppt) erreichte im gleichen Zeitraum eine Gewichtszunahne von 95% bei einer Ueberlebensrate von 98%. In einem weiteren Versuch wurden junge Goldbrassensaetzlinge mit einem Durchschnittsgewicht von 2.24 g in Wasser von 3.6 ppt Salinitaet 8 Wochen lang gezuechtet. Die Fischgruppen wurden mit einer mit 4% oder 6% Salz angereicherten Diaet angefuettert, waehrend die Kontrollgruppen eine Diaet ohne Zusatz von Salz erhielten. Die Wachstumsergebnisse zeigten, dass das beste ($P < 0.05$) Wachstum

mit einer Gewichtszunahme von 560%, die mit der 6% Salzdiaet angefuetterten Fische erreichten. Durch die Anfuetterung mit der 4% Salzdiaet erreichten eine Gewichtszunahme von 448% waehrend die Fischgruppen, welche die Kontrolldiaet erhielten, nur noch eine Gewichtszunahme von 360% erreichen konnten. Der naechste Versuch mit einer hoeheren Zugabe von Salz in die Diaet zeigte, dass Postlarven von Goldbrassen mit einem Durchschnittsgewicht von 0.58gr., welche eine mit 12% Salz angereicherte Diaet erhielten, das beste ($P < 0.05$) Wachstum mit einer Gewichtszunahme von 778% und einer Ueberlebensrate von 88% im Brackwasser von 2.9ppt Salinitaet innerhalb 10-woechiger Zucht erreichen konnten. An dieser Stelle sei zu erwaehnen, dass nach Ende der Versuche, die Goldbrassen weiterhin im Brackwasser der entsprechenden Salinitaet einige Monate lang gezuechtet wurden ohne erkennbare negative Erscheinungen. Die oben gennanten Ergebnisse zeigen eindeutlich die Moeglichkeit der Nutzung von Inland-Brackwasser niedriger Salinitaet fuer die Zucht von Goldbrassen als eine weitere Alternative fuer die traditionelle Zucht im Seewasser. Dies ist keineswegs erstaunlich, wenn man die Biologie der Euryhalin Goldbrassen in Betracht zieht, deren jungere Stadien im Laufe der Entwicklung auch in Flussmuendungen wandern und einige Zeit in Brackwasserbuchten bleiben.
Schluesselworte: Goldbrassen, Wuestenaquakultur, Brackwasser, niedrige Salinitaet

Rezumat. Incercările de a cultiva dorada în apele interioare salmastre geotermale acoperite (în interior) sau descoperite (afară) au început prin studii și cercetări la începutul anului 2006 în incinta Centrului pentru Acvacultura Deșertului – Bengis – din cadrul Institutului pentru Cercetarea Deșertului din Israel, din care o parte vor fi descrie mai jos. Puietul de doradă cu o masă corporală medie de 19 g a fost aclimatizat și crescut timp de 56 zile în apă salmastră cu trei grade de salinitate diferite: 2.5, 3.5 și 4.5 ppt, din trei surse diferite. La salinitatea de 3.5 ppt, peștii s-au dezvoltat cel mai bine ($P < 0.05$) crescând în masă cu 121%, în timp ce la concentrația de 4.5 ppt masa lor corporală a crescut cu 98%, iar la 2.5 ppt – cu 90%. Într-un alt studiu, larvele de dorada în vârstă de 45 zile după eclozare, cu o masă corporală medie de 0.025 g au fost hrăniți cu nauplii de *Artemia* îngrășați cu extract de drojdie de bere și cu furaj de larve uscate, și au fost crescuți în apă salmastră de 2.6 ppt salinitate, timp de 8 săptămâni, atingând o masă corporală mai mare cu 92% la o supraviețuire de 83%. Loturile martor, crescute în apă de mare (39 ppt) au atins în aceeași perioadă de timp masa corporală de 95% la o rată de supraviețuire de 98%. Intr-un studiu ulterior, dorada juvenilă cu o masa corporală medie de 2.24 g au fost crescute în apă salmastră cu o salinitate de 3.6 ppt timp de 8 săptămâni și au primit diete îmbogățite cu sare cu 4% și 6%. În comparație cu dieta lotului martor, cărora nu li s-a administrat sare in hrană, ambele diete bogate în sare au îmbunătățit dezvoltarea creșterii puietului, rata de supraviețuire, precum și rata de conversie. Dieta cu sare 6%, a stimulat creșterea peștilor cu 560%, care a fost cea mai ridicată performanță ($P < 0.05$), urmată de cei care au crescut cu 448% la adăugarea de 4% sare în dietă, în timp ce o creștere cu doar 360% a fost obținută în lotul martor (dieta fără sare). Studiul următor, privitor la adaosuri mai mari de sare în dietă a arătat că dorada în stadiul postlarvar la o masă corporală medie de 0.58 g crescută în apă salmastră geotermală cu o salinitate de 2.9 ppt timp de 10 săptămâni a crescut cel mai bine ($P < 0.05$) obținându-se o creștere a masei corporale cu 778% și cu cea mai mare rată de supraviețuire - 88% - când dieta conținea 12% sare. În studiile cu deta bogată în sare, ea a fost încorporată în furaj prin evaporarea apei crustaceilor produși în timpul desalinizării apei salmastre geotermale din aceeași sursă, furnizând în același timp apa necesară creșterii peștilor. De reținut că dorada, după finalizarea experimentelor, a fost păstrată câteva luni în aceeași apă, crescând în continuare fără efecte detrimentale. Cercetările arată clar posibilitatea utilizării apelor interioare salmastre pentru creșterea doradei, ca o alternativă suplimentară la creșterea tradițională marină. Rezultatele nu trebuie sa ne surprindă, având în vedere biologia doradei eurihaline și frecventele cazuri în care juvenilii apar în anumite perioade ale ciclului de viață în lagune cu salinitate redusă și în estuarele unor râuri.
Key Words: doradă, acvacultură de deșert, apă geotermală, salinitate scăzută.

Introduction. Aquaculture is rapidly developing worldwide, as fast as 11% annually, making it the fastest growing food production sector, racing to meet the global demand for fish as world wild catch is stagnating and there is evidence of decline in the catch of some marine species. This review is mainly based on inland brackish water aquaculture development in Israel. The present study deals with the potential of using brackish geothermal water in the Israeli desert for the cultivation of the marine fish gilthead sea bream (*Sparus aurata*).

Limitation of freshwater in Israel. Israel faces a chronic fresh-water shortage, accompanied by high water costs (Appelbaum 1998). The only large inland fresh water body is the Sea of Galilee, which mainly supplies freshwater for irrigation and human consumption. Moreover, in the Central-North areas of Israel, where the majority of the rainfall occurs, the hilly and mountainous land can not naturally retain the water. Israel has distinct winter and summer seasons and a low rainfall of average 500 mm annually. In spite of the obvious climatic constraints and overall shortage of fresh water, both agricultural and aquaculture are highly developed in Israel.

Problems with marine fish cultivation in Israel. The traditional fish culture in floating net pens in the bay of Eilat, with the major species being gilthead sea bream, was terminated in 2008 due to environmental concerns. However, the local demand for this most popular marine fish, also known as Dorada or Denis, on the Israeli market, remains as high as nearly 3000 tons annually and can not be met by the current domestic production with its major operation in the harbor of Ashdod, which produces about 700 tons annually. Culturing fish in floating net pens along the Israeli Mediterranean coast line is ruled out because of destructive winter storms. Thus the termination of fish production in the bay of Eilat has urged the need for alternative means to cultivate this species.

Availability and usage of inland brackish geothermal water. Beneath the Israeli Negev desert are large aquifers holding huge quantities of fossil brackish geothermal water which has been used successfully for the past four decades to irrigate agricultural crops. This so called 'Desert water', with its moderate salinity ranging between 2.5-7 ppt of TDS, and constant temperature of nearly 40°C at the source, is available throughout the year and provides a reliable source for the fish farming industry. Although this water rests deep underground (600-1000 meters), artesian pressure raises it to approximately sea level and from there has only to be pumped up from an average depth of 300 meters, making it easily accessible.

Significant advantage of inland brackish water aquaculture. Appelbaum (1997) and Shmuel & Yacov (2002) listed a few significant advantages for aquaculture utilizing low salinity inland brackish geothermal water:

- The large amount of accessible subsurface unpolluted brackish geothermal water, the so called 'Desert water', is most suitable for fish culture;
- The cost of the 'Desert water' is lower than that of fresh water in the country;
- Land in the desert for aquaculture is plentiful and cost less than in other regions of the country.

The pollutant free 'desert water' allows a high quality fish product for the customers.

Table 1

Growth performances of gilthead sea bream reared in three different salinities for 56 days

Origin of water	*System 1*	*System 2*	*System 3*
	Ramat-Negev district, east	Ramat-Negev district, south	Dead Sea region
Water salinity (ppt)	2.5	3.5	4.5
Initial weight (g)	19.05 ± 3.95	19.01 ± 4.34	19.07 ± 5.21
Final weight (g)	36.11^{b} ± 9.65	42.01^{a} ± 12.47	37.59^{b} ± 10.6
Weight gain (g)	17.06	23.0	18.58
Average weight gain (%)	89.55	120.98	97.73
SGR ($\%d^{-1}$)	0.4960	0.615	0.5287
FCR	2.34	2.1	2.45
Survival (%)	70.5	73.3	60.0

* Values with the same letter did not differ significantly (t-test, $P < 0.05$).

Physiology of marine fish adapted to low salinity water. Fish development, growth and survival are influenced by various physiological factors; water salinity being one of the influential factors. Many studies (Schmidt-Nielsen 1997; Sangiao-Alvarellos et al 2003; Laiz-Carrion et al 2005) have indicated that the various developmental stages during fish embryogenesis depend on water salinity. Salinity also plays a key role in the regulation of growth. Water salinity influences growth rate, metabolic rate, feed intake and feed conversion. Marine fish adapted to low saline water show a passive outward flux of ions such as Na^{+} and Cl^{-} to the water via the gills, faeces, and renal system, which must be compensated by the active uptake of ions from the water and/or from the diet (Schmidt-Nielsen 1997). The gill is a major osmoregulatory organ in fish, which undergoes large morphological changes, at the influence of the environment's salinity, even at low salinities (Laiz-Carrion et al 2005). Sangiao-Alvarellos et al (2003) reported that adaptation of euryhaline fish to different environmental salinities induces activation of ion transport mechanisms usually accompanied by changes in oxygen consumption, suggesting variations in the energy demands for osmoregulation.

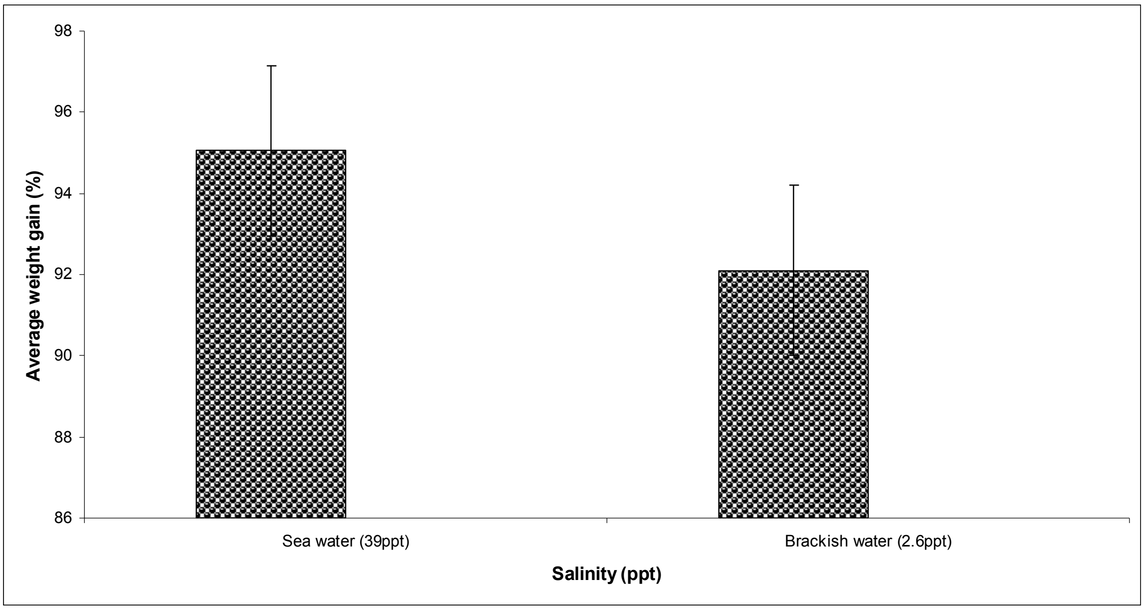

Figure 1. Growth performance of gilthead sea bream fingerlings reared in sea water and low salinity inland brackish water for 56 days.

Adapting gilthead sea bream to low saline water. Sea bream is a euryhaline teleost capable of living in environments of different salinities ranging from 2‰ to 60‰ (Chervinski 1984; Laiz-Carrion et al 2005). The natural habitat of the gilthead sea bream ranges from the Mediteranean and Black Sea to the eastern Atlantic Ocean from Senegal to the United Kingdom (Kissil et al 2000). It is commonly found in shallow lagoons along the coast, but migrates into deeper water to spawn after late autumn. Appelbaum & Arockiaraj (2008a,b) and Appelbaum et al (2008a,b) reported that sea bream were successfully reared in low salinity inland brackish water in indoor trials.

In the course of attempting to culture gilthead sea bream in inland brackish geothermal water, indoor and outdoor research studies have been on going from early 2006 at the 'Bengis Centre for Desert Aquaculture' of the Institutes for Desert Research in Israel, some of which are described below.

Gilthead sea bream fingerlings with an average weight of 19 g were acclimated to and reared for 56 days in brackish water of three different salinities: 2.5, 3.5 and 4.5 ppt collected from three different locations. At the salinity of 3.5 ppt the fish grew best ($P < 0.05$) increasing their weight by 121%, while at 4.5 ppt weight increase was by 98%, and at 2.5 ppt - by 90% (Table 1).

In another study gilthead sea bream larvae aged 45 days post hatching, with an average weight of 0.025 g were fed yeast extract enriched *Artemia* nauplii plus larval dry feed and were grown in brackish water of 2.6 ppt salinity for 8 weeks reaching a weight gain of 92% at a survival rate of 83%. At the same time point, the control groups reared in sea water (39 ppt) reached a weight gain of 95% at a survival rate of 98% (Figure 1).

A novel method: salt addition in diets. In a further study gilthead sea bream juveniles with an average weight of 2.24 g were reared in brackish water with a salinity of 3.6 ppt for 8 weeks and received salt added diets of 4% and 6%. Compared with the control diet with no salt added, both salt rich diets significantly improved the fingerlings growth and survival rates as well as the feed conversion ratio. The 6% salt rich diet promoted fish weight gain by 560% which was the best performance ($P < 0.05$) followed by 448% weight gain with the 4% salt rich diet, while the poorest performance with a weight gain of only 360% was obtained with the control (no salt added) diet (Figure 2).

The next study with higher levels of salt added diets showed that gilthead sea bream post larvae with an average weight of 0.58 g reared in brackish geothermal water of 2.9 ppt salinity for 10 weeks grew best ($P < 0.05$) obtaining a weight gain of 778% with the highest survival rate of 88% when fed a diet containing 12% salt (Figure 3).

In these studies with salt rich diets, the salt incorporated was obtained by the evaporation of brine produced during the process of desalination of the brackish geothermal water from the same well supplying the water for the fish rearing experiment. Worth mentioning at this point is that sea bream, after the termination of the experiments, were further kept for several months in the same brackish water showing further growth with no detrimental effects.

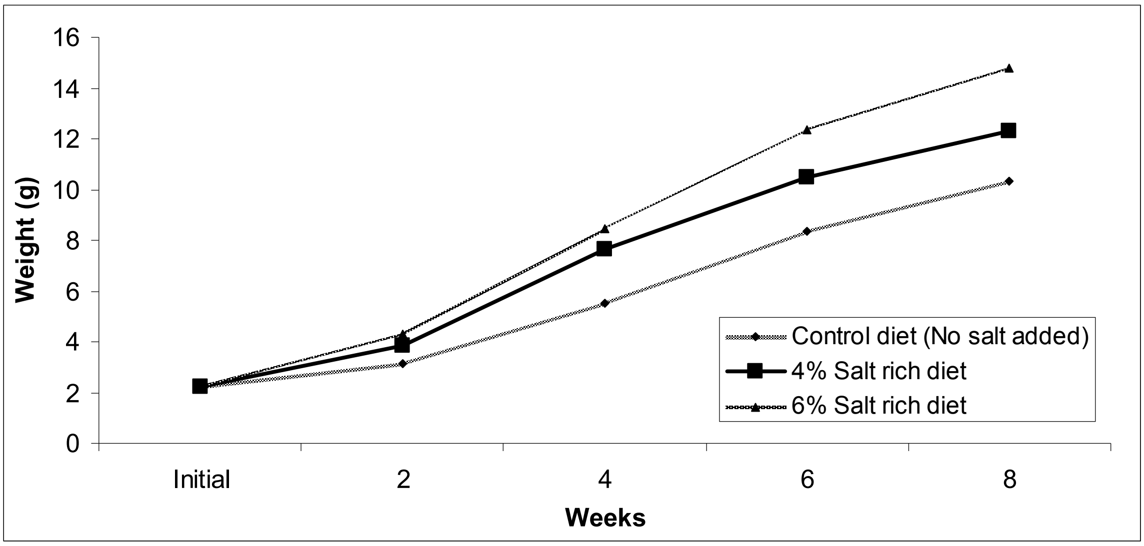

Figure 2. Growth of the juvenile gilthead sea bream reared in 3.6 ppt salinity brackish water and fed different salt rich diets for 8 weeks.

Discussion. Klaoudatos & Conides (1996) reported that the most suitable and favourable rearing water for the euryhaline species such as brown spotted grouper and European sea bass has been shown to be low salinity brackish water rather than sea water. They also found that gilthead sea bream grew faster and with a better survival rate when reared in low salinity brackish water (8‰) rather than in sea water at 38‰. Sadek et al (2004) cultured gilthead sea bream for 8 months in an extensive brackish water culture system with a salinity of 25 ppt achieving the best specific growth rate of 0.95% per day.

Fish adapted to low salinity water loose ions; this loss has to be compensated by uptake from the water or from the diet. A fish diet which contains salts to satisfy the fish osmotic requirements, at low water salinity, contributes in saving energy which is required for osmoregulation. This spare energy can then be diverted to benefit growth. Harpaz et al (2005) achieved better growth and survival results with barramundi (*Lates calcarifer* Bloch, 1790) reared in inland brackish water by adding the required 4% salt to the fish diet. Fontainhas-Fernandes et al (2000) reported that adding salt to fish diet increases appetite and digestibility. Salman & Eddy (1988) reported that the food intake and appetite of the rainbow trout were not adversely affected by adding salt to the diet, but did enhance growth.

Gatlin et al (1992) reported that juvenile red drum exhibited greater feed efficiency and significant weight gain when 2% NaCl was added to their diet. Harpaz et al (2005) reported that adding 4% salt to the diet of barramundi resulted in significant improvement in their feed conversion ratio and enhanced the activity of the brush border enzymes. Orino & Kamizono (1975) and Tacon & De Silva (1983) reported that a 4% or 5% salt inclusion in the diet of trout and carp produced better growth and feed utilization. Smith et al (1995) observed that 12% salt-enriched diets enhanced the feed uptake and benefited the growth of rainbow trout. Eroldogan et al (2005) found that 5% salt supplementation in the diet of European sea bass enhanced growth and feed utilization. All these findings show that salt addition to fish diet improve growth and survival rates.

Conclusions. The above mentioned research findings conclusively prove the feasibility of utilizing inland brackish water for culturing gilthead sea bream as an additional alternative to the traditional marine farming.

This is not surprising, considering the natural life cycle of the euryhaline gilthead sea bream, the juvenile of which appears at some stage in low salinity lagoons and river estuaries (Conides 1992; Klaoudatos & Conides 1996).

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