Interactions between chemicals used in aquaculture and environment in terms of sustainable development

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Abstract

Aquaculture that is the farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic plants, is the fastest growing animal production sector in the world. Global production from aquaculture for human consumption amounted to 73 million tonnes and the value of US$ 110 billion in 2009 and comprised almost fifty percent of the world's fish supply. Aquaculture, thus, plays an important role in global efforts towards eliminating malnutrition and brings significant health benefits by nutritional well-being. It significantly dominates most devoloping countries in terms of contribution to development by increasing gross domestic product, providing employment opportunities and improving incomes.

The potentially adverse impacts of aquaculture that is also threat the sustainability when the sector grows unregulated or under poor management, is of considerable current environmental and public interest in the world. Besides eutrophication and genetically modified organisms (GMOs), the main environmental pressure associated with intensive aquaculture is chemicals (antibiotics, hormones, fungicides, pesticides, antifoulants, anaesthetics and disinfectants) used in aquaculture. The intensive systems are often associated with various greater use of different types of antibiotics and chemicals generate very different effects on the environment, mainly on water and sediment quality (nutrient and organic matter loads), natural aquatic communities (toxicity, community structure, biodiversity), and microorganisms (alteration of microbial communities, drug resistant strains).

The interactions between humans, antibiotics, bacteria, fish and aquatic environments are poorly understood and recent studies show a significant pollution of surface waters with antibiotics and other chemicals which are potential risk to drinking waters. Moreover, as a vicious circle and often as well, aquaculture is also negatively affected by pollution of water supplies by other human activities (ie: agriculture and industrial activities).

The environmental approach to sustainable development can control the use of chemicals to eliminate or reduce any negative effects to an acceptable level. Sustainability requires global action, and therefore an effective solution can be achieved on the basis of environmentally-friendly management systems towards social-ecological aquaculture to integrate aquaculture, environment and society locally and globally. This paper, consequently, addresses the relevance of the environmental approach to the role of aquaculture in sustainable development.

Keywords: Aquaculture, Chemicals, Antibiotics, Environment, Sustainable Development

1.INTRODUCTION

Securing a safe and sustainable food supply for an increasing population is one of the world's biggest challenges. Fish and aquatic organisms provide an important source of protein. But, global population demand for aquatic food products is increasing while traditional wild-capture fisheries have reached a plateau.

Aquaculture is the farming of aquatic organisms such as fish, crustaceans, molluscs and aquatic plants in ponds and large net-cages. Farming of aquatic organisms is becoming an important source of food in both international trade and subsistence sectors. After growing steadily for the last four decades, it is now a substantial global industry supplying nearly half of the world's supply of fishery products (fish and other aquatic organisms) consumed as food. It may be an alternative supply to the increasing demand for aquatic products, strong international competition, constant change in consumer needs and expectations, and also depletion of fisheries, providing to reduce the pressure on wild stocks. In terms of its economic productivity, the contribution of aquaculture to trade, both local and international, is also increasing. The aquaculture industry has a potential for further development, but there are some problems with environmental concerns and market instability, locally and globally. Eutrophication, genetically modified organisms (GMOs), chemical pollution, exotic species wild fish stocks and pathogens are some examples of the main environmental impact concerns associated with intensive aquaculture (Naylor et al. 2000). Under potential risk of these impacts, without any rules in context of ecological assessment and sustainable practices, it is not to be expected that aquaculture will continue to supply the demand for aquatic products for a long time.

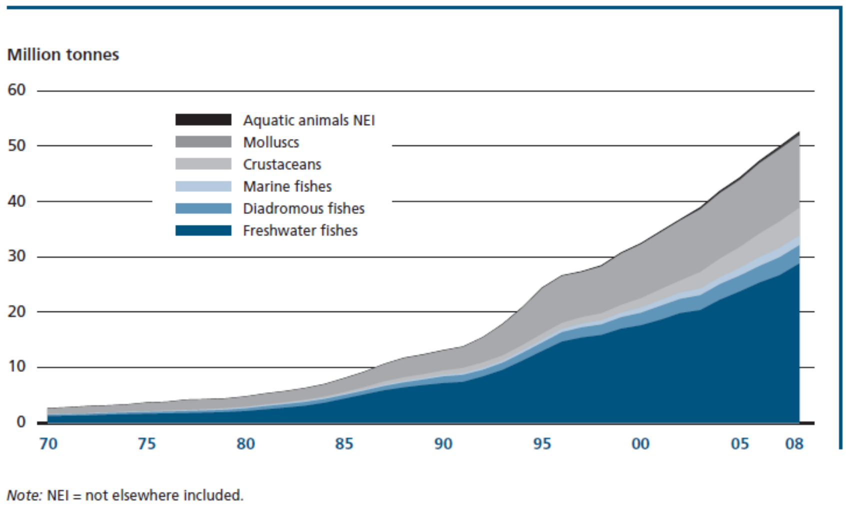
At this time of strong public concern throughout the world particularly about the impact of aquaculture on human health and environment especially regarding the use of chemicals are reflected in the FAO Code of Conduct for Responsible Fisheries (FAO 1995). In this Code there are several advices, such as the promoting effective farm and fish health management practices (favouring hygienic measures and vaccines), the ensuring safe, effective and minimal use of chemicals (e.g. therapeutants, hormones and drugs, antibiotics and other disease control chemicals), regulating the use of chemical inputs in aquaculture (if they are hazardous to human health and the environment).

Status and scope of aquaculture

Overall, 80 percent of the world fish stocks are reported as fully exploited or overexploited and are thus unable to withstand additional fishing pressure. The continuing depletion of the world's fish stocks has led to an increasing demand for aquatic food from aquaculture which has been expanded rapidly worldwide.

According to the Food and Agriculture Organization (FAO), the global total production of fish, crustaceans and molluscs, including wild capture and aquaculture, reached to approximately 145 million tonnes in 2009 consisted of 90 million tonnes captured which has been stayed level since 2001, plus 55 million tonnes produced by farms (Figure 1). Aquaculture production has continued increasing at an average annual growth rate of 6.1 percent from 34.6 million tonnes in 2001 to current level and the value of aquaculture production was estimated at USD 105.3 billion in 2009. It is the fastest growing sector of the food economy. About 84 percent of total fishery production (121.8 million tonnes in 2009) was used for direct human consumption. Global per capita consumption has been increased steadily and reached to an average of 18 kg in 2009 with the share of aquaculture production in total food supply at 46 percent. According to FAO projections, it is estimated that in order to maintain the current levels of consumption, an additional 40 million tonnes of seafood will be required by 2030 and global aquaculture production will need to reach minimum 80 million tonnes by 2050 (FAO, 2007). According to the international marketing records 38.5 percent (live weight equivalent) was exported in 2009 and the value reached USD 96.0 billion. The share of developing countries in this percent was 50.6 percent by value and 60.1 percent by quantity (live weight equivalent) in 2009.

Figure 1. Trends in world aquaculture production (FAO, 2010)



All of these statistics show the important role of aquaculture in global efforts against hunger and malnutrition for both developed and developing countries by supplying fish and other aquatic products contain excellent animal protein and other essential fatty acids, vitamins and minerals. It also contributes to food availability to improve global food security. In terms of food quality, aquatic products bring significant health benefits and contribute to nutritional well-being.

It can also make important contributions to the social and economic development of countries through improving incomes, providing employment opportunities and increasing the effective use of resources. It significantly contributes to the national gross domestic products in many developing countries. This may provide a more productive investment opportunity for local resources as well as playing important socio-economic role in rural regions.

2.What is sustainability or sustainable development?

In general, "sustainability" and "sustainable development" is a concept to guarantee a liveable environment for all people in the long term. In this concept, aquaculture is highly diverse and consists of a broad spectrum of species, systems and practices. Thus, several indicators, codes and guidelines for sustainable development in aquaculture have been evaluated in recent years (Folke and Kautsky, 1989; Subasinghe et al., 2009). Mostly these indicators can generally be grouped into two main categories: Ecological and socio-economical indicators. Ecologic indicators are aiming preservation of a functional environment, while socio-economic criterions are to provide clear economic advantages for aquaculture farmers and social equity to improve the community's welfare in the long term.

There is still little known, how sustainability can be increased in aquaculture and there is no complete practicable criteria to certify the sustainability status of aquaculture operations. According to the criteria systems in previous evaluations, sustainable development is an integrative framework involving ecological, economical and social sustainability. Although, all may seem of equal importance, the current focus is primarily on the economy to achieve the competitiveness. However, environmental issue is a very important part of the development process as no activity in aquaculture will take place if there is not good quality water resources left. Economy and society fundamentally rise up on the natural world and resources, and these are serving to improve the standing of environmental concerns. Therefore, sustainable development in aquaculture industry must be environmentally friendly that means conserving land, water and wildlife resources.

Along with too much complexity in sustainable development of aquaculture, there are many concerns about environmental indicators containing two important components, resource use and pollution. In this respect, the sustainable use of natural resources was described by EU Commission in 6th Environmental Action Programme (6 EAP) as: "the consumption of resources and their associated impacts cannot exceed the carrying capacity of the environment and the linkages between economic growth and resource use must be limited". Water resources are essential for life and health besides food and other products put huge demands. Globally, the problem of water shortage is getting worse as the needs for clean water increase in agriculture, industry and households because wastage and pollution is alarming critical limits day by day. Therefore, everyone must be a part of efforts to conserve and protect the water resources.

Aquaculture will continue to play an increasing role in fishery products to meet the globally rising demand but the chemicals used in aquaculture put pressure on the environment around the world (Costello et al., 2001). As a result of technical development and incorporation of advanced technology much of the fish farming systems have moved from extensive to intensive systems that pose environmental risks and threats to the surrounding ecosystem in rivers, water reservoirs and oceans. Much scientific literatures have identified the environmental risks and impacts of the farming of aquatic organisms in open systems (Costello et al., 200; Buschmann et al., 2009).

Another important concern is intensification implies increasing the number of individuals and increase potential for the spread of pathogens. This spreading is requiring greater use of inputs (e.g. disinfectants, drugs) and greater generation of waste products presenting a global threat to both the aquatic environment and consumer safety (Kümmerer, 2009). To date, however, aquacultural chemicals have not been paid sufficient attention to the significant risks that would accompany the growth of the industry.

Chemical inputs and current situation of chemical usage in aquaculture

Table 1: Analysis of the chemical usage in aquaculture.

Strengths	Wide range of potentially hazardous chemicals used in aquaculture operations. Disease problems worldwide. Uncontrolled and high local use of aquacultural chemicals.
Weaknesses	Inefficient control and regulations for chemical usage in aquaculture There is insufficient monitoring of chemical residues for aquatic products. Technical knowledge of chemical analysis specific to aquaculture practices is limited. Concept of carrying capacity models to aquaculture systems are non-existent for certain locations and particularly closed basins in countries. There is no certification system and guidelines developed for environmentally sound and sustainable aquaculture and not harmonized worldwide. Lack of successful environmentally friendly aquaculture demonstration sites for extension purposes nationally.
Opportunities	Sustainable and environmentally sound aquaculture practices will reduce the pressures on environment. Increasing awareness in local and international. Generating public environmental awareness and education Developing of technology and knowledge on the chemicals used in aquaculture.
Threats	Inefficient waste management in aquaculture. There is still no monitoring system for aquacultural chemicals in environment. Lack of institutional infrastructure to facilitate sustainable aquaculture

	development.
	Low technical level of fish farmers.
	Lack of knowledge of the environmental impacts of aquacultural chemicals.

The aquaculture industry is a kind of agricultural sector and chemicals developed originally for animal husbandry but now it common use in both. The chemicals are also essential for increased and controlled production of progeny in hatcheries, increased feeding efficiency, improvement of survival rates, control of pathogens and diseases, and reduction in transport stress (Howe et al., 1995). However, effects of chemicals on the aquatic environment have not been specifically evaluated. The lack of data on their use has complicated the problem. The chemicals used in aquaculture includes soil and water treatments, fertilisers, disinfectants, herbicides, antibacterial agents, other therapeutants, pesticides, feed additives, anaesthetics and hormones.

Antifoulants: are used on solid surfaces, ropes and generally on nets in cage aquaculture systems. Even if the antifoulants are generated and used for protection of boat surfaces, they are also used to treat nets and this usage must be of concern if used in fish culture.

Disinfectants: are applied as external treatment for fish and especially for eggs and fry. These agents are applied directly in aquatic environment and some of them could be very persistently toxic to aquatic life at low concentrations such as formalin. Farmers will be ensure that the potential for contamination of the environment will be able to minimised.

Pesticides: generally are used to control ectoparasits in fish culture. Some of them such as organophosphates may produce vital effects on the health of farm workers.

Anaesthetics: are used in stripping of broods and during transport of fish in aquaculture to sedate and calm the aquatic organisms.

Hormones: plays an important role to control and induce ovulation for the control of reproduction as well as sex control for mono-sex production in aquaculture.

Veterinary pharmaceuticals: are applied in aquaculture as medicated feed and diluted in water and most of them are preferred to prophylactic use rather than against diseases in many countries. Therefore, using of these therapeutic agents are controlled by drug licensing programmes, monitoring of limits on tissue residues and for environmental residues to minimise the risks in terms of human and environmental health.

Heavy use of antibiotics in aquaculture:

Antimicrobials have been applied in aquaculture for over 50 years and its use has grown both in numbers and quantity, as the problem of diseases has increased. Although they were highly successful at first, improper using led to problems, and concern is now centred on treatment failures. Moreover, it is now an expanding problem for human and animal health and for the environment.

Antimicrobial compounds are persistent and can exhibit toxicity in sediments, and can therefore affect the natural microbial community near aquaculture sites (Herwig and Gray, 1997). This residue potential may disturb the balance of the environmental micro-flora. One of the major concerns with use of antibiotics (from any source) is the potential for bacteria to develop resistance to the compounds and for the resistance traits to be manifested in other bacteria including human pathogens (Guardabassi et al., 2000). Treatments may fail for several reasons, but probably the most consistent and fundamental cause of their failure is the emergence of resistant bacteria. The risk posed to human health by disturbance of the gastrointestinal flora, selection of resistant strains and allergies is also addressed elsewhere.

Quantities of antibiotics used in aquaculture are small compared to other forms of food production and published data show the use of antibiotics in aquaculture has been diminishing in some areas by regulations. Despite the low relative usage of antibiotics in aquaculture compared to other food production systems, their use remains an issue of concern as aquaculture is often practiced in relatively pristine environments and the exact quantities applied directly to water.

All of the chemicals were not originally developed for aquaculture use and environmental residues have been ignored. Therefore, it is difficult to estimate the size of risk because of the lack of knowledge on the biological responses to chemical residues in receiving waters and on the concentrations in farm's surrounding environment (sea, effluents and sediments). It is also little known that fates of chemicals in the aquaculture system and the residues in cultured and wild organisms. The picture is yet more bleak for environment with regard to the interactive effects of multiple chemicals in relation to biological effects.

Human health and environmental concerns regarding the use of chemicals in aquaculture are reflected in the FAO Code of Conduct for Responsible Fisheries (FAO 1995). In this Code there are several advices, such as the promoting effective farm and fish health management practices (favouring hygienic measures and vaccines), the ensuring safe, effective and minimal use of chemicals (e.g. hormones, therapeutants, antibiotics and other disease control chemicals), regulating the use of chemical inputs in aquaculture (if they are hazardous to human health and the environment).

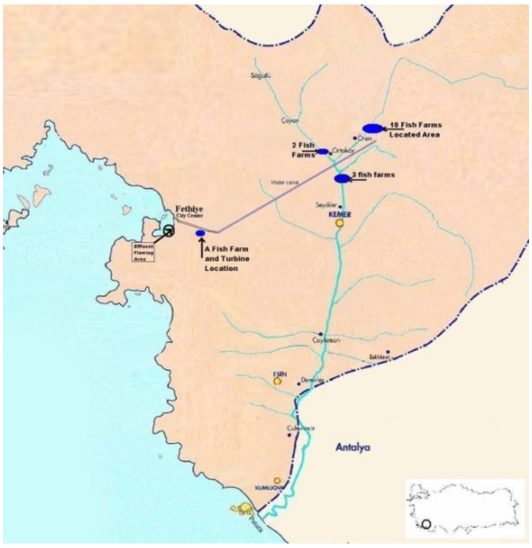
A demonstration of an aquaculture activity from Turkey

Aquaculture has been developed in Turkey rapidly. Commercial aquaculture production in marine and inland waters takes place all over the country. By 1995 there are approximately 800 fish farms (mainly producing rainbow trout) in inland waters and 400 marine fish farms (mainly seabream and seabass) in operation in the country. However, little detailed information is available on the environmental impacts of this industry.

Environmental assessment strategies for aquaculture operations were developed and proven in some countries. However, the application of such strategies would be inappropriate without modification and adaptation to the ecological particularities of the environments where aquaculture operations located. Problems and antimicrobials vary from farm to farm (e.g. cultured species, diseases, different capacities of surrounding environments, climate, level of eutrophication, composition and diversity of fauna and flora) and require site-specific environmental risk assessments.

Available data show that large quantities of antibiotics have been applied in the aquaculture operations in Turkey. As being reference for local intensity, the selected river basin is located in the south-western of Turkey. There are 16 trout fish farms in various capacities (totaly appr. 10.000 tonnes/year), including family farms (100 tonnes/year) and businesses (3.000 tonnes/year).

Figure 1. Fish farms on Esen River in Fethiye (Turkey)



Antimicrobials and disinfectants are generally used prophylactically and therapeutically in these farms; Oxytetracycline (appr. 700-800kg/year),Tribrissen (Sulphadiazine/Trimethoprim) (appr. 750 kg/year), erythromycin (appr. 400 kg/year) and the others which are used appr. 100-200 kg/year, e.g. enroflaxacin, amoxicillin, doxycyline, florfenicol and last one is formaldehyde used as a disinfectant (appr. 3500 liter/year), (Altunok, personal communication). Previously published literatures suggest that, in general, only 20-30% of antibiotics are actually taken up by fish from medicated food; thus, approximately 70-80% reaches the environment (Samuelsen, 1989). For example, the apparent oral bioavailability of oxytetracycline in rainbow trout was reported approximately 5-6% (Björklund and Bylund, 1990). Some of these chemicals and compounds have considerable adverse environmental effects, and, therefore their use in aquaculture must be carefully assessed. The fate of such compounds should be carefully addressed locally. Since the environmental impacts and risks are site-specific, environmental approach to sustainable aquaculture development requires the integration of its economic, environmental and social components at local levels towards global motion planning.

3. Sustainability criterions regarding to chemicals

The limited availability of natural resources coupled with increasing demand for fishery foods the need to move forward in aquaculture to become more sustainable. Compared to other animal production systems, aquaculture is put under special pressure to become more sensitive to environment because the industry uses important natural resources (freshwater, rivers, wetlands, coastal and open ocean areas). The aquaculture industry is working towards reducing use of chemicals and other artificial substances but there is still not effective precautions and conservation plans regarding to chemical use in aquaculture for the most part of the world. Thus, it appears that global efforts are needed to promote more judicious use of chemicals in aquaculture. These efforts should focus on;

-increasing the investment on aquaculture

-alternative environment-friendly substances and methods of treatment,

- developing of vaccines

-developing welfare conditions for fish and other aquatic animals,

-developing an overall management system that is widely applicable throughout the world, to monitor and control the chemicals.

-using of the chemicals in a manner that does not constitute a hazard to human health and the environment and in accordance with the appropriate legislation.

-legislations must be strict and include every possible usage of chemicals (e.g. antibiotics may be used on prescription from a veterinarian for the therapeutic (not prophylactic) treatment.

-the regulation of discharges. In this regard, site specific discharge conditions may include limits on the location, maximum biomass, types and quantities of chemicals due to requirement for monitoring water and sediment quality locally.

- Increasing government support to encourage organic and alternative aquatic food farming.

4.CONCLUSION

At present, the fish farms do not treat their effluents and discharge them to the environment increasing the environmental pollution worldwide. Pollution of water resources due to chemicals plays primary role in ecosystem degradation, but chemical analyses alone may not be sufficient to describe the adverse effects of the complex mixtures of chemicals present at contaminated sites. The potential utility of biomarkers for monitoring both environmental quality and the health of organisms inhabiting polluted ecosystems has received increasing attention during the recent years. The complexity of these issues and often the lack of data concerning their effects on aquatic environment as well as the lack of monitoring at field situations and surveillance systems, are the factors limiting the risk analysis process. In addition, the direct consequence of this lack of data is that many hazardous chemicals are not classified, and are therefore sold without appropriate labels or safety data sheets. Thus, many chemicals are used in the workplace while their potential effects on the health of workers exposed to them and on the environment are barely known, or known too late. This insufficiency of data is more pronounced in the most of countries, especially where technology and resources are limited or less available. Therefore, it is urgently needed to be determining the actual quantitative risk of aquaculture chemicals in the environment locally. Furthermore, the policy of safe and effective use of chemicals must be developed. Appropriate strategies must be chosen, according to individual requirements for country's and region's. Strengthening research efforts and programs for human training and development, as well as enhancing mechanisms for information exchange and technology transfer, may be encouraged through international collaboration. The development of an appropriate and effective impact assessment and monitoring system for aquatic farms is essential in order to ensure the sustainable development of aquaculture, while taking into consideration other aspects of integrated management of the areas, including tourism, fishery, other industries and environmental protection.

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Table 1 Monthly descriptive statistics and estimated parameters of length-weight relationships for both sexes of S. aurita in the Izmir Bay (central Aegean Sea) from November 2004 to October 2005. (M: male, F: female, n: number of individuals, a and b: parameters of length-weight relationships, 95% C.I of a and b: 95% confidence intervals of a and b, r2: regression coefficient).

			Length characteristics		Weight characteristics		Relationship parameters				
Months	Sex	n	TL Range (cm)	Mean TL (±SD)	W Range (g)	Mean W (±SD)	a	95% CI of a	b	95% CI of b	r2
November 2004	M	55	19.8-23.5	21.67±1.07	56.43-96.72	77.62±13.98	0.0020	0.0019-0.0021	3.425	2.703-4.147	0.874
	F	91	18.7-23.5	21.69±1.16	47.80-116.77	81.22±15.68	0.0021	0.0010-0.0032	3.429	2.899-3.959	0.880
December	M	119	19.0-24.0	20.04±1.16	45.46-117.10	58.78±14.47	0.0018	0.0007-0.0029	3.453	3.061-3.845	0.936
	F	129	18.8-25.5	20.49±1.56	42.84-138.40	64.41±21.05	0.0007	0.0004-0.0010	3.762	3.502-4.022	0.973
January 2005	M	44	21.2-25.3	22.56±1.01	72.30-107.95	85.83±11.24	0.0500	0.0059-0.0941	2.389	1.909-2.869	0.662
	F	102	21.7-25.6	23.22±0.90	102.31-143.32	94.25±13.90	0.0023	0.0006-0.0040	3.380	2.904-3.856	0.886
February	M	92	18.1-25.3	21.22±1.	37.15-	68.06±20.6	0.0006	0.0002-	3.777	3.327-	0.94

				71	131.12	7		0.0010		4.227	0
	F	90	18.7-24.6	21.85±1.50	42.70-123.23	73.32±19.03	0.0008	0.0004-0.0012	3.715	3.333-4.097	0.954
March	M	75	21.6-23.8	22.75±0.65	83.88-119.52	94.67±10.46	0.0067	0.0055-0.0079	3.058	2.300-3.816	0.693
	F	62	22.5-25.0	23.37±0.83	91.52-132.22	102.84±12.40	0.0083	0.0071-0.0095	2.989	2.135-3.843	0.875
April	M	129	20.4-23.6	22.03±0.97	62.40-94.87	77.29±11.47	0.0064	0.0008-0.0120	3.035	2.377-3.693	0.833
	F	74	21.3-24.6	22.68±1.18	96.16-112.47	89.63±14.46	0.0361	0.0036-0.0686	2.501	2.013-2.989	0.627
May	M	63	22.1-24.6	23.13±0.83	96.67-129.17	106.70±9.83	0.1361	0.0069-0.2653	2.121	1.883-2.359	0.681
	F	72	21.5-25.6	23.79±1.04	84.97-150.75	121.58±16.77	0.0060	0.0017-0.0103	3.130	2.670-3.590	0.930
June	M	20	20.3-23.7	22.47±1.68	62.72-101.50	91.55±26.41	0.0073	0.0072-0.0074	2.789	2.309-3.269	0.896
	F	81	19.7-25.7	23.38±1.90	64.54-141.00	102.39±22.55	0.0262	0.0058-0.0466	2.619	2.127-3.111	0.917
July	M	136	18.1-21.1	19.59±0.99	44.10-64.39	53.52±7.33	0.0203	0.0111-0.0295	2.645	2.341-2.949	0.959

	F	91	18.0-22.6	20.37±1.57	41.36-80.63	60.74±14.63	0.0074	0.0022-0.0126	2.984	2.520-3.448	0.954
August	M	56	15.0-26.5	20.57±3.33	23.48-165.29	73.26±41.05	0.0024	0.0019-0.0029	3.389	3.257-3.521	0.996
	F	84	14.2-28.5	24.55±3.95	22.39-205.80	140.47±57.74	0.0044	0.0022-0.0066	3.215	2.899-3.531	0.963
September	M	26	16.6-23.9	20.26±2.61	30.88-109.14	66.86±28.53	0.0016	0.0007-0.0025	3.517	3.125-3.909	0.991
	F	78	19.1-25.6	22.98±1.96	53.84-138.82	103.53±26.64	0.0048	0.0023-0.0073	3.174	2.842-3.506	0.966
October	M	106	19.6-22.0	20.75±0.53	64.85-87.35	77.02±5.12	0.1010	0.0423-0.1597	2.189	1.805-2.573	0.707
	F	60	19.5-22.0	21.02±0.58	71.71-91.73	80.06±5.88	0.0624	0.0213-0.1035	2.350	1.918-2.782	0.798
Overall	M	921	15.0-26.5	21.32±1.73	23.48-165.29	77.06±21.36	0.0033	0.0024-0.0042	3.279	3.109-3.449	0.873
	F	1014	14.2-28.5	22.29±2.08	22.39-205.80	90.87±31.27	0.0025	0.0019-0.0031	3.375	3.229-3.521	0.907
	M+F	1935	14.2-28.5	21.81±1.97	22.39-205.80	84.03±27.67	0.0027	0.0022-0.0032	3.340	3.232-3.448	0.898

All the LLRs values are given in Table 3. The values for coefficient of determination (r2) for all the length-length parameters of male, female and combined were >0.9, and highly significant ($p<0.001$). LLRs were measured as TL=a+bFL, FL=a+bSL and SL=a+bTL equation in all sexes and combined. In all the samples together, LLRs are as follows: TL=-1.3284+1.2087FL, FL=1.4623+0.9581SL and SL=0.0000+0.8382TL. The results further indicated that LLRs were highly inter correlated (r2>0.9, $p<0.01$).

Table 3 Length-length relationships between total length (TL), fork length (FL) and standart length (SL) of S. aurita in the Izmir Bay (central Aegean Sea) from November 2004 to October 2005 (n: number of individuals, a: intercept, b: slope, r2: regression coefficient).

Sex	Equation	n	a	b	r2
	TL = a + bFL		-1.0161	1.1915	0.984
Male	FL = a + bSL	921	1.1368	0.9761	0.984
	SL = a + bTL		0.0000	0.8462	0.999
	TL = a + bFL		-1.4792	1.2168	0.975
Female	FL = a + bSL	1014	1.6747	0.9469	0.974
	SL = a + bTL		0.0000	0.8330	0.999
	TL = a + bFL		-1.3284	1.2087	0.980
All	FL = a + bSL	1948	1.4623	0.9581	0.980
	SL = a + bTL		0.0000	0.8382	0.999

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