Global NEST Journal, Vol 13, No 4, pp 369-384, 2011
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ORGANIZING A PUBLIC AQUARIUM: OBJECTIVES, DESIGN, OPERATION AND MISSIONS. A REVIEW

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Received: 24/12/09
Accepted: 03/11/11

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ABSTRACT

Many Public Aquaria have been designed and constructed all over the world during the last three decades. The serial arrangement of relatively small, rectangular, concrete tanks has been replaced by fewer large, irregularly shaped tanks, replicating habitats. The "taxonomic concept" of displaying specimens in the old aquaria has now been succeeded by the more ecological, "community concept" type of display. At the same time most of the "old aquaria" have been renovated. Aquarium missions have also been broadened nowadays including research, conservation and education. Aquaria are ideal places for research on husbandry, life cycles, reproduction, behavior, autoecology and fish pathology. Collaboration with Universities and Research Centers increases the research potential in scientific disciplines such as ecology, genetics, physiology and biochemistry. Collaboration also provides mutual benefits in both infrastructure and personnel: The research background in aquaria also forms a sound platform to materialize conservation projects, focusing either on the *ex-situ* conservation of animals in the aquaria or on environmental protection of surrounding areas and re-introduction of endangered species. In addition to formal educational opportunities, non formal education to visitors, schools and undergraduates seems to become a major mission of aquaria. Aquarium tank displays, preserved biological material, film projections, seminars / lectures and book magazine publications enhance environmental awareness, encouraging people to adopt Environmentally Responsible Behavior. All these missions are feasible because most public aquaria are making a good profit mainly due to their high popularity. There are also benefits for the community in the area; aquaria have enlivened declining water front areas and increased the income of tourist resorts mainly by "stretching out" the tourist season. In the present work the objectives of a public aquarium are reviewed and the main infrastructure subsystems and operational procedures are described; Know how on aquarium systems can also be applied in research laboratories of academic institutions if live organisms have to be kept for experimentation. Aquarium missions on research, conservation and education are discussed.

KEYWORDS: Aquarium Design; Environmental Education; Aquarium Systems; Conservation Projects; Aquarium missions; Aquarium Research; Environmetally Responsible Behavior; Caring for the Environment.

INTRODUCTION

The history of Public aquaria goes back to 19th century. The concept of display was series of rectangular, concrete tanks with glass fronts; Fishes and some invertebrates were placed in the tanks using taxonomic criteria as species taxonomy was then the "bible" among the biological sciences. The first large public aquarium was opened in the London Zoo in 1853 and was known as the "Fish House" (Brunner, 2003). The Berlin Public Aquarium was the second large aquarium that opened in Europe followed by the aquarium of Paris. Meanwhile the interest of the public in aquatic life showed an upward trend; the New York Aquarium Journal was first published in 1876 and was considered as the first aquarium magazine. The first Aquarist's society in the United States was founded in New York in 1893 followed by many other societies on aquaria and aquatic life.

Nowadays there are many public aquaria in Europe, United States, Canada and the Far East. The serial rectangular tanks have been replaced by a few large tanks characterized by irregular geometry where various types of habitats are replicated promoting normal animal behavior (Cains and Meritt, 1998). Specimen introduction is based on the aquatic community concept highly influenced by aquatic community ecology concepts.

The development of aquaculture technology during the last three decades has provided to public aquaria a number of technical solutions (Barnabe, 1989; Huguenin and Colt, 1992), covering almost all aspects of aquarium construction, aquarium operation and fish husbandry (Goertemiller, 1993). Modern tank design and structure, new materials, advanced pumping technology, aeration systems, flow rate control, new systems for water abstraction and water treatment technology are among the “new weapons” in the hands of aquarium designer’s. Know how on disinfecting drinking water using ozonation and UV technology has also been transferred to aquaria and used as a routine practice. Mechanical filters used in swimming pools and aquaculture farms as well as purification methods based on biological treatment of the used water, have solved water quality problems in aquaria. In addition, operation practices such as water quality control, artificial lighting, use of chemical disinfectants, fish feeding techniques, fish pathology know how and reproductive success have greatly been benefited from aquaculture practices (Landeau, 1992; Pillay and Kutty, 2005)

At the same time the objectives and missions of public aquaria were broadened. The aquarium environment became the ideal “laboratory” to study animal and plant biology, ecology, animal behavior, diversity and conservation issues, fish maintenance, fish diseases and fish reproduction. The tank collections together with the laboratories and other ancillary facilities have formed a “platform” for the public aquaria to expand their missions to research, environmental education, diversity and conservation. Research directions in the aquaria derive from the fact that a variety of aquatic plant and animal species can be kept and studied in a confined location. Public Aquaria are nowadays aiming at educational objectives at many levels including environmental awareness of the visiting public, laboratory and technical training of the curatorial and keeper staff, special programs for schools; training of undergraduate, graduate and postdoctoral students (Evans, 1997). The contribution of aquaria to marine environmental education is vital since not many members of the public, experience the marine environment often. Expose of the swimmers to the marine environment does not contribute significantly to their experience and knowledge since beach areas are characterized by low diversity.

Recently special emphasis has been given by public aquaria on conservation aspects. It has been emphasized the role of conservation on stimulating environmental awareness of the visitors since visitors are more interested in pollution problems rather than in conservation and diversity issues. Aquaria are also ideal facilities for *ex-situ* diversity conservation especially after the global interest on biodiversity conservation and the United Nations convention on Biological Diversity (United Nations, 1993); The *ex-situ* keeping of organisms is strongly recommended if all other measures of conservation have failed or are difficult to apply.

The present work is a review of the basic information for planning, building and operating a public aquarium. The missions of a modern aquarium concerning expectations – benefits of the visitors, research, environmental education and conservation of marine life are also discussed.

AQUARIUM OBJECTIVES

The first but more critical step when designing a public aquarium is a clear definition of the objectives of the aquarium: is it going to cover all aspects of aquarium activities that is visitor’s recreation, research, education and conservation or some of them?

(a) Recreational activities: what are the target groups for the visitors? Are the visits going to be combined with environmental awareness (Ballantyne *et al*., 2008) or the public will be educated by the “show and tell” practice common in public aquaria? The aquarium is aiming only at individual visitors or families? Is it also aiming at schools and various societies related to environmental aspects such as botany, zoology, natural history or aquarium societies? Do they have to plan specialized facilities not available to the public such as tanks and research laboratories? Is research going to be carried out in the aquarium premises or is going to include field work? Are research projects going to be carried out by the aquarium research staff only or collaboration between aquarium and academic institutions is going to be sought for mutual benefits (Fernadez and Timberlake, 2008)?

(b) Education: What are the educational goals? Is it going to be a kind of comprehensive guided tour? Is it going to be only informal education (Price *et al*., 2009). Alternatively, the aquarium staff will be involved in more formal educational activities of pupils and students in collaboration with school authorities and universities in the form of seminars, summer schools, undergraduate teaching? What about small projects involving experimental work?

(c) Species and biodiversity conservation: what groups of organisms, sources of financing aiming at, forms and types of collaboration with research centers and local authorities?
The aquarium objectives should be based on: (a) the availability of funds and the present needs (b) future prospects: the aquarium can focus on recreation at the beginning but expand to other missions with time (c) planning future needs and (d) combination of (a), (b) and (c). Relative priorities of the objectives mentioned above can influence design decisions. The aquarium design and operation should consider missions concerning education, research and conservation not as fixed but as dynamic processes. Evaluation of research (Kleiman, 1985) and education projects can provide a useful feedback for further developments of public aquarium future targets.

AQUARIUM DESIGN

Defining requirements

Building design should take into account a number of points. There should be a rather large lobby for receiving the visitors; it is a usual practice for public aquaria to receive groups of people: school classes, groups of tourists, visits from universities and visits organized by societies. The entry to the aquarium display should be slightly delayed for the adaptation of the visitors to the dim light of the surroundings. Information referring to the exhibits and aquarium activities in the form of posters or power point projections can keep the visitors occupied while they proceed slowly to the tank display area. The whole way should be flat for safety reasons. The display area should be viewed on the “one way” pattern and the exit should lead, if possible, to a small museum or exhibition place providing additional information mainly through preserved specimens and panels, posters and computer programs. This supplementary information will also prolong the time spent in the aquarium building. Eventually the visit should lead to an aquarium shop near the exit. Visitors should not have any access to aquarium installation, laboratories or other ancillary facilities unless a specific visit has been arranged, programmed thoroughly and all safety measures have been taken.

Space requirements for pumping facilities, the master tank, the control room, laboratories, storage place, tanks for fish quarantines and tanks for the reserve fish stock have to be taken into account. In addition, a small lecture theatre and a reading room are necessary for research and educational activities. Research laboratories in addition to the laboratories designed for the operation of the aquarium are needed if research activities are among the aquarium objectives.

Site selection

It is an advantage if a seafront area is chosed. The selection parameters are a tradeoff between high quality environmental conditions and vicinity to a town that will be the potential source of visitors and academic activities. The most important factors to the technical aspects of the aquarium as far as the marine environment is concerned are: (a) high water quality is absolutely necessary for the tank supply (b) wild populations of desired species in the area, form a good source of living organisms. Although aquaria tend to import living organisms from all over the world, small aquaria largely rely on the local marine ecosystem (c) endemic diseases and parasites (d) microbiological populations i.e. possible pathogens and (e) coastal seawater circulation and wave regime: related to water renewal as well as to possible resuspension of the sediment in the water abstraction area. The most important factors concerning the accessibility of the site area are: (a) distance from the nearest city (b) regular public transport (c) size of school population in the area (d) academic and research institutions in the area (e) national parks, conservation areas, ongoing plans in the area on conservation and biodiversity issues.

Sea water abstraction

The quality of the seawater supply to a public aquarium is the “foundation” for good, trouble free and successful operation of the facility. High marine water quality can be described by a number of desirable features: (a) very low concentration of suspended matter (b) low microbial load deprived of pathogens (c) limited presence of fouling organisms (d) absence of water pollutants (sewage, hydrocarbons, heavy metals etc) and (e) water temperature less than 20°C throughout the year. The type of water abstraction facility depends very much on the local conditions. As it is expensive both to install and run, the system is usually a tradeoff between economy and acceptable water quality. The major technical solution for the water supply is:

Open intake in shallow waters: shallow waters are not the best choice; the water is characterized by high concentration of suspended matter, fluctuating according to weather conditions (current, waves). There are also many fouling organisms and the temperature can exceed 20ºC during summer time. Resuspension of the sediment might enrich the water column with nutrients (phosphate, nitrite, nitrate, ammonia) and possibly pollutants if the history of the area was connected with industrial activities. However, technical solutions can be applied to face the problem (Cansdale, 1981): (a) the pipeline can be designed in a flexible way making easy dismantling and cleaning (b) Installation of a twin system: one of the two systems will be “dormant”. The organisms of the dormant system will die due to low availability of oxygen; the twin system provides extra security in case of failure in the operating system. It must be noted that repairs in the water abstraction system can be a difficult job depending on weather conditions, locally available expertise and specialized equipment. The site of water abstraction can be chosen after careful consideration of the above mentioned problems. The site that shows minimal disturbance in the area should be selected; the intake point should not be near bottom to eliminate input of suspended matter.

Open Intake in Deep Water: This is the best solution as it supplies the aquarium with low temperature water (below the thermocline), and low concentration of suspended matter while the inlet is near the facility. This is the case the Bergen Aquarium (Rollefsen, 1962). The Public Aquarium of Monaco and the Public Aquarium in Rhodes (Greece), operate the same way. The temperature of the deep water may be lower than the desired temperature under operating conditions and the same applies for oxygen concentrations. Both shortcomings can be easily corrected at a low cost.

Seawater Wells: Water abstraction can be performed by opening wells near the shoreline. Although this is an economical way with limited risk of mechanical failure from storming conditions and there is easy access to service the installation there are three main shortcomings (a) the temperature can be high (b) the oxygen concentration low and (c) salinity can be low if there is mixing with the freshwater horizon. This depends on the local layering that can be complex and therefore the solution is not always applicable.

Sub-Sand Abstraction: A sub-sand system can solve many of the problems mentioned above (a) during this process most of the particulate material is removed (b) as the system develops, it becomes aerobic due to oxygenated water passing through. Hydrogen sulphide and methane production stops while ammonia is oxidized to nitrate (c) the system is unaffected by surface pollutants (e.g. oil spillages) and (d) as the whole system can be completely buried is protected from overheating, damage due to weather conditions and possible vandalisms (Cansdale, 1981). Sub-sand intake systems can be elaborate structures placed on the sea bed. Systems like those have been installed a long time ago (Hettler *et al.,* 1971; Kinne, 1976) and they are still working successfully.

Aquarium Pumps

The pumps are the “heart” of every aquarium system. It is important to select the right type of pump and the right size. One of the criteria for selecting a pump is the servicing facilities and expertise in the area. Among many types of pumps used in aquaculture there are two types popular in aquaria: the centrifugal pump and the displacement pump. As seawater is corrosive, care has to be taken to select pumps made of material resistant to oxidation: stainless steel pumps, pumps made of polymers and pumps with rubber parts seem to suit all service conditions. The design of a centrifugal pump is rather simple: there is a pump chamber and a fast rotating impeller in it. The water is running into the pipes under the centrifugal force applied by the impeller. The main advantage of this kind of pump is lack of wear under normal aquarium conditions and proper service. Suspended matter will also damage the impeller. Priming should be avoided and therefore the pump should be placed below the sea level (working then as a suction pump), otherwise a foot valve should be fitted at the intake point. Alternatively, a priming tank can be installed in the piping system.

Displacement pumps operate by moving water through the pump in discrete quantities using a rotor having the shape of an eccentric cam, or a screw type rotor or a spirally shaped rotor. In this type of pump the rotor is generally of stainless steel whereas the inner part of the stator is made of rubber. Displacement pumps are self-primed and deliver fixed volume of liquid to the system. Small organisms have a better chance to survive through a displacement pump and this can be an advantage if the planktonic community should be kept alive especially in re-circulating systems. The housing for types of pumps should be kept as dry as possible for the good maintenance and long life of the equipment. Another type of pump not very often used in aquaria is the submersible pump. Being in the water is self primed but most of them suffer from electrolysis which gradually deteriorates the casing and the impeller (Hawkins, 1981; Huguenin and Colt, 1992).

Piping and Valves

Among a wide variety of materials used for aquarium piping the most commonly used are the unplasticized polyvinyl chloride (uPVC) and the acrylonirile butadiene styrene or ABS (Hawkins, 1981). They are both strong, easy to mount, low toxicity and not corrosive materials. Due to smooth bore resistance, flow is kept to a minimum. However, care has to be taken to prefilter the water so as to prevent fouling. A twin pipeline system can also be useful in the antifouling “combat”. It is important not to glue pieces together but to join them using either “O” rings or threaded fitting. The same applies for valves, meters, pressure gauges and other fittings along the pipeline. Easy dismantling is important for replacements and general maintenance.

The valves used in the aquarium piping systems are mainly ball valves, but also diaphragm, butterfly and needle valves are used. When ball valves open allow full bore flow but the flow control is difficult to be achieved. Needle valves are the best for flow control but show the highest resistance to flow. Non return and foot valves in the system are necessary to avoid line draining should cessation of pumping occur.

Tanks

The Master Tank: A master tank (also known as the head tank) is a necessary component of every aquarium water system as it serves a number of functions. The master tank being the general distributor of the system is placed higher than the display tanks and the tanks for research to provide gravity flow. This way it functions as a transition zone between pump supply and demand, smoothing out any irregularities in water demand. Irregular demand may be due to cleaning or refilling procedures. Irregular supply may be due to pump failure, pump service, pipeline servicing or provisionally unsuitable water quality due to storms (intense resuspension of the sediment). If the residence time is more than an hour the head tank can act as sedimentation chamber. However, master tanks cannot act as temperature regulators. The high specific heat capacity of the water in combination with the limited residence time does not allow temperature conditioning. It advisable that master tanks must be roomy as well as easily and safely accessible by the staff for installing and servicing heating elements, filters, meters and other pieces of equipment.

Display tanks: The tendency nowadays is to get away from the box shaped tanks used for display purposes. The modern idea is to replicate a particular ecosystem in each tank. This ecosystemic approach requires tanks with water capacity a few dozen cubic meters or even bigger. In this “aquarium ecosystem” the wall effect is undesirable. If the sides of the tank have a 45º slope, forming a trapezoidal shape they are not visible by the visitors (Hawkins, 1981). Similar effects are produced by curving the back and the sides of the tank (Fraser-Brunner, 1960; Garnaud, 1977). Display tanks are usually constructed in cement or fiberglass. These tanks should generally contain a minimum substrate such as sand or gravel to allow easy cleaning and disinfection. The access to the tank for servicing purposes must be easy and emptying / refilling procedures should be done without disturbing the public or wetting areas used by the public.

Research Tanks: A basic requirement in research is flexibility on the size, number and tank arrangement according to the experimental design. Research tanks can be made of glass, fiberglass, plywood embedded with epoxy resins, stainless steel or PVC. It is important that the surfaces will not be toxic and cleaning of the surfaces will be easy. They are usually of rectangular shape as they do not take up too much space and they are easy to handle. The laboratory where the tanks are kept should have water and draining facilities at regular intervals so that different tank arrangements can be easily set under working conditions. It is advisable that their depth should not exceed 60 or 70 cm so they can easily be handled inside. If special care should be taken about the fishes, then round tanks seem to be the best solution. This way fishes will not be injured and circulation can be easily induced. Elongated tanks known as raceways are required if fish need to swim for a long time possibly against a water flow. Raceways can be built either from plywood or fiberglass panels. Due to their length they need external of internal bracing.

Aquarium Filtration – Water Treatment

Mechanical filtration: In modern aquariology the term "filter" means at least four different things: straining, sedimentation, chemical bonding and biological degradation. Filtering requirements should be considered cautiously: they are a costly procedure, they need very good maintenance and can also raise many problems referring to anoxia and bacterial contamination under careless operating conditions. Straining refers to mechanical filtration; it can take place at the water intake or along the pipelines before the pumps, for the removal of coarse material such as sand and small gravels. This stage is important not only to improve viewing conditions in the display tanks but also to protect mechanical equipment from serious damage. The most usual type of mechanical filters is the cartridge filters. They are commercially available as they are used in swimming pools. Cartridge filters can be easily inserted directly into the water circulation systems and can be replaced on a routine basis. If high flow capacity is needed, multiple filter systems can be used in parallel arrangement. There is a wide choice in sizes, materials and filtration performances so the aquarium staff should make the right choice taking into account the quality of the seawater at the pipe intake, the volume to be treated per hour as well as the water quality requirements in the tanks. The system of mechanical filtration needs good maintenance: disposable cartridges should be replaced regularly, whereas, permanent filters need frequent back flushing. Sand filters are the commonest filtering system in public aquaria. The sand used for filtering is characterized by the grain size, grain shape, specific gravity and grain distribution. The lower limit of sand media is about 20 μm and the filtering action occurs in the first few centimeters.

Biofilters: Chemical bonding and biological filtration are more delicate and expensive processes; they are recommended only for closed circulation systems. A closed system supported by biological filtration can be an independent subsystem in the aquarium if special conditions such as high temperature are required for keeping tropical fishes. In addition to particulate organic material, dissolved organic compounds also need treatment. The aquarium organics are mainly metabolic wastes; their quantity depends on the total biomass, feeding practices, the characteristics of different foods used, the water temperature as well as the assimilation efficiency of the animals. If solid wastes are removed by mechanical filtration or sedimentation what is left in the seawater is ammonia, nitrite, nitrate and dissolved organic compounds. These organics can be toxic to the captive animals depending on their concentration, the different species, the life stage of the organism and the environmental conditions (Rand, 1995). In addition, accumulation of nitrogenous compounds will gradually establish eutrophic conditions in the tanks. The treatment of these compounds requires biological filtration. The process that either removes nitrogen from the aquarium or converts it to less toxic compounds are called mineralization, nitrification, dissimilation and assimilation. Biological filtration converts ammonia and nitrite into nitrate. Aquatic organisms can tolerate nitrate concentrations up to 200 mg l^{-1}. Nitrate beyond being toxic, is associated with growth of microalgae that settle on the aquarium glass fronts as well as with inhibition of coral growth in marine aquaria (Tal *et al.*, 2003). This means that even for a recycling system, gradual water replacement is necessary. A flow though varying between 5 and 10% of the water volume per day is adequate in aquaria to keep nitrate concentration low. Bacterial denitrification i.e. conversion of nitrate into nitrogen gas is not recommended due to methodological complexity, high cost and high oxygen consumption. Nitrification is the oxidation of ammonia, carried out in two steps aerobically. The bacterium genus *Nitrosomonas* oxidizes ammonia to nitrite, whereas the genus *Nitrobacter* completes the oxidation reaction producing nitrate. The complete oxidation requires 4.57 mg of oxygen per mg of ammonia nitrogen (Spotte, 1979) and therefore the oxygen demand should be taken into account (Manthe *et al*., 1988). Recently an ion exchange bioreactor has been proposed (Matos *et al*., 2009) that converts accumulated nitrate into molecular nitrogen. This system was applied in a public marine aquarium (Oceanario de Lisboa) and allowed the removal of nitrate at concentrations of 251 to 380 mg l^{-1} down to about 27 mg l^{-1} exchanging it for chloride. High nitrate concentration can also affect the pH of sea water, shifting to lower pH values. Nitrification takes place in a separate container called biofilter. Biofilters are usually submerged and is preferable for the water flow to take place downward (down flow). Technical details on construction and operation of biofilters have been given by Kaiser and Wheaton (1983). The performance of a biological denitrification system installed in Ocean Tank at the New Jersey State Aquarium has also been described (Grguric *et al.*, 2000).

Foam fractionation: Air bubbles are introduced into the water column. As the bubbles raise, a skin of particulate and dissolved organic compounds surrounding the bubbles, form a foamy water between the air and water interface. The foam produced is collected and removed to the drain. Foam formation depends on organic load, chemical composition of the compounds, air – water ratio, surface tension, temperature, viscosity, pH, bubble size and control time. The optimal bubble size diameter is 0.8mm (Spotte, 1992). Foam fractionation is also known as protein skimming, air stripping and froth flotation. Foam fractionation has been described for aquaria by Spotte (1979) and for aquaculture units by Wheaton *et al*. (1979).

Activated Carbon: An alternative method to remove dissolved organic carbon from the aquarium water is to use activated carbon either in powder or granular form. It can absorb organic wastes, therapeutic drugs (Marking and Piper, 1976) and some trace elements such as copper (Huguenin and Colt, 1992). Carbon is efficient at low concentrations of organic matter and this is why it is preferable to be used at a “final polishing” stage in the water treatment procedure to remove persistent non-biodegradable organics. The carbon performance depends on the composition of the organics adsorbed, contact time, concentration of organics, biological films on the carbon, particle size, pore surface area, selectivity, temperature and pH (Huguenin and Colt, 1992). Although activated carbon can be regenerated, the adsoptive capacity becomes less and less by the time. It is an expensive method for treating water and it should be applied only if necessary at the final stage of water treatment.

Ion exchange systems: Zeolites such as clinoptilolite can be used for water treatment as they selectively absorb ammonia form solution. Ion exchange resins have limited use in aquaria. They have limited capacity and high cost although they can be regenerated several times (Hawkins, 1981).

Aeration

Ventilation of the display tanks is important because oxygen is necessary for all respiring organisms. As the concentration of dissolved oxygen in sea water varies between 5 and 7 mg l^{-1} that is about 30 times less than the oxygen concentration in the atmosphere, continuous aeration is vital for keeping animal in good condition. In addition to oxygenation, aeration sets up circulation in the tank breaking up possible stratification. Accumulated carbon dioxide can also be removed through air bubbles.

There are many methods used for aeration. The most common in public aquaria is by using air diffusers. This type of aerator is a porous material supplied by low pressure air usually through a blower. The efficiency of submerged aerators mainly depends on temperature, salinity, barometric pressure, bubble size, average dissolved oxygen concentration and saturation values for oxygen solubility. The air required for every type of aerator, the transfer efficiency and the absorption efficiency that is the percent oxygen transferred from air to water can be calculated (Spotte, 1979; Huguenin and Colt, 1992). There is a wide selection of blowers. They must all be oil free and the recommended working pressure ranges between 3 and 5 psi. Among the various types of blowers available in the market, the high flow – low pressure blowers are recommended for use in public aquaria.

OPERATION

A wide range of organisms kept in public aquaria comes from different types of habitat and different geographic zones: species from temperate areas, tropical species, species from rocky shores, and species from sandy bottoms. Some aquaria keep even deep sea fishes. All these organisms need specific methods of collection; the adaptability of every species is species specific depending on the biology, life cycle and behavior of each species. There are also different feeding requirements, different habitat arrangements in the display tanks, different lighting and different aeration conditions. The variety of tanks used in a public aquarium complicates the problem even more. There is also a unique design in the building and the infrastructure of almost every public aquarium and all these peculiarities make operation practices to be sometimes something between craft and science. Operation methods seem to be aquarium specific and many “tips” successful in one aquarium may not work in another unit. However, in the present section the basic principles referring to fish capture, fish transportation, feeding routines, fish disease and disinfection practices will be described.

Fish capture

Capture of fish for display in public aquaria differs from commercial fishing. Specimens should be caught and handled alive, without injuries and without skin bruises as bruised fishes are not only vulnerable to skin microbial infections but also they should not be displayed for aesthetic reasons. In addition, fishes should be transported and arrive to the aquarium in good condition. Delicate muccoid and epidermal layers cover the scales and provide waterproofing. Superficial wounds can also be infected by pathogens. If fishes come from deeper waters, there are also problems of decompression (Kayama *et al.,* 2002). This problem usually results into the busting of the swimming bladder. Various practices are applied to ensure successful decompression before surfacing of the fishes (Solomon and Hawkins, 1981). The choice of the fishing method depends on the species of interest, the type of habitat, the fish density, local conditions and possible legal restrictions for the selected type of fishing or the area. As fishing for aquarium enrichment is a costly operation, demanding a great deal of equipment and manpower, other sources of supply have to be sought before organizing a fishing expedition. Pet shops, aquaculture farms, marine stations, other aquaria and anglers can be potential suppliers of good fishes and invertebrates. The rest have to be caught by the aquarium staff, possibly with the help of local fishermen, applying the following techniques:

Netting: Trawling is not recommended because as fishes are dragged along the bottom of the sea, they can suffer from stress, skin damage and loss of scales. Gill nets are used for a fixed size of fish and they are caught by the head or the gills as they are trying to swim through. Even if fishes do not suffocate before landing, they can be damaged on the head, the gills and their trunk. Only a fraction of the fishes is alive upon landing and a small fraction of the live fishes will eventually survive. Then the curator has to decide which ones can be used for display purposes. Circular cast nets with small lead weights fittings on the outside circles are suitable for small groups of fishes. As a rule fishes are not damaged but this type of netting is limited only to few species and the technique is suitable for flat sandy bottoms. Encircling nets with very small “eye” seem to work well; it is rather unlikely that fishes will be damaged. Fishnets in the form of a bowl can also be an efficient way for catching small fishes near the surface. It is preferable to use knotless nets and fishnets to avoid fish bruising (Coles and Butterworth, 1976).

Trapping: These are usually baited traps and can be used in almost every type of habitat. They are particularly useful in rocky bottoms and reefs where netting is either impossible or very risky for net damage.

Electrical Fishing: The method is suitable for freshwater fishes and is not recommended for seawater fishing. Some of the fishing devices use AC current, other DC current (Vibert, 1967; Hartley, 1975). They are both efficient but based on different principles: AC stuns the fish and caught by a dipnet; DC attracts the fish to the anode and also collected with a dipnet. Fishes recover quickly from the electric sock without further problems.

Chemical Methods: They have limited use. They can only be used in streams and ponds. Use of chemicals is forbidden by the fishing legislation of many countries.

Angling: The experience and expertise of the local fishermen is inevitable. The rate of catchment is slow but different species can be caught usually with minimal damage. Damage can result in case of angling from the jaw or if the fish shallows the bait.

Fish Transport

Literature on transporting live fishes has been mounting up due aquaculture practices; transportation of juveniles and brood stock is a routine in fish farms (Portz, 2006) as well as transportation of ornamental fishes (Lim *et al*., 2003). As the objective of transportation is the fishes to arrive at the aquarium in good condition, small number of fishes should be carried out at a time. Tanks used for transportation play an important role in the whole operation. The shape of the tanks is either rectangular or cylindrical; it is advisable to be insulated so that temperature can be kept constant as much as possible. Toxic materials should be avoided. Aeration is usually necessary during transportation depending of the fish load, the water temperature, the duration of the journey and fish condition. If continuous supply of air is difficult or impossible, fishes can be placed in air tight bags that will be blown with air. Plenty of air volume should be above the water surface, the recommended seawater: air ratio being 1:4 (Taylor and Solomon, 1979a). Fish biomass should not exceed 100gr per liter of seawater. If transportation takes place in air tight bags, the whole operation should not last more than 4-5 h as carbon dioxide and ammonia build up in the bag and may harm the fishes (Taylor and Solomon, 1979). It is advisable to use a tranquillizer during transportation. The drug will slow down fish metabolism and therefore decrease oxygen demand and carbon dioxide/ ammonia production. In addition, fishes with less stress are less likely to be injured on the tank walls because of anxiety and intense movement. Information on tranquillizers has been given in literature (Gibson, 1967; Taylor and Solomon, 1979b; Solomon and Hawkins, 1981; Taylor and Roberts, 1999).

Fish Quarantine

The stock brought to the aquarium should be kept separately from the aquarium organisms for about a month. This is necessary for the acclimatization of the fishes in their new environment; at the same time they will be inspected for wounds or diseases. This is the quarantine stage. Disinfection of the tank should be carried out using iodine based disinfectants. High quality sea water should be supplied to the tanks. Fishes should be checked for physical damage due to captive and transportation procedures. Skin, fins and gills should be thoroughly inspected as bacteria and fungi often cause diseases. Skin abrasions are also prone to bacterial and fungi attacks. Fishes in quarantine should be also treated for parasites (nematodes, cestodes) as well as for external protozoa usually affecting gills and skin. When the fishes settle well in their new home and are disease free, they can be transferred to display or reserve tanks and mixed with the old fish stock.

Food and Feeding

Feeding aquarium organisms shows some complexity as they are many different species including vertebrates and invertebrates; the aquarium stock varies not only in species composition but also in age and size within the same species. Feeding aquarium animals is not therefore easy as some species do not easily accept routine feeding as feeding behavior plays an important role in some species. This is why four categories of fish food should be available in a public aquarium: (a) commercial foods used in aquaculture farms usually in the form of pellets (b) commercial foods used in home aquaria usually in the form of flakes (c) fresh food such as fish flesh and invertebrates (Cisse *et al*., 1995) and (d) live food (i.e. *Artemia*). The present section will be therefore limited to general guidelines concerning fish foods and feeding. Feeding practices should take into account ration size, growth rate, temperature and body composition (Cowey, 1981). Many fishes locate food by eye others by movement. They can also detect the food through the sense of smell. As fishes rely on chemoreceptors they examine food thoroughly before eating. Rejection of commercial foods may be due to pellet size, shape, tast and hardness. The situation can be improved if taste attractants are added to the food. It has been found a long time ago (Fujija and Bardach, 1966) that several amino acids act as attractants causing a positive response of the fishes to food pellets. Fish food was also becoming attractive for some species if nucleotides were added (Kiyohara *et al*., 1975). Among the amino acids, glycine and alanine were found the most effective when added to food. Nowadays, commercial aquarium foods are well balanced in nutrient and attractants to fishes.

Abiotic parameters can also affect feeding behavior: light intensity can affect feeding habits; the optimal light intensity is depending on the species. Noise is always a negative factor for fish appetite. It has been found that low frequency noise (below 100Hz) caused fright reaction to herring (Cowey, 1981). Aquarium “scenery” can also affect feeding behavior. It has been reported by some authors (Hawkins, 1981) that sandy bottom helps flatfishes to eat, whereas pipes seem to improve eating habits of eels.Social factors can also be critical. Overcrowding or dominant individuals may cause problems that affect the feeding of fishes. Overcoming the difficulties in fish feeding is more a matter of craft and experience of the curators. Different conditions from one public aquarium to another or even from one tank to another need special attention.

It is necessary sometimes to use live food. Water fleas (*Daphnia*) have been recommended for a number of fishes (Bardach *et al*., 1972). The brine shrimp (*Artemia*) has been found attractive as a live food source and produces much better survival in juveniles. Mosquito larvae can also be used. They are attractive as food and do not consume dissolved oxygen as they surface and breathe atmospheric air. There are no strict formulations for fish food and therefore empirical preparations can work well. It has been reported (Vigayagopal *et al*., 2008) that formulated foods consisting of fish meal, shrimp meal, squid meal and soybean meal were used successfully for marine ornamental damsel fish (Dasyllus arnanius) and this food has been proposed for rearing and aquarium keeping of damsel fish worldwide. Hence or otherwise fish curators should not have in mind the fish growth as the main objective of a public aquarium is to display healthy fishes. As uneaten food increases the organic load of the system, it is advisable that aquarium staff will stick to the old rule (Innes, 1966). “*Feed only enough prepared food at one time so that practically all of it is consumed within 5 minutes*”.

Aquarium Fish Diseases

Fish diseases in an aquarium can be a continuous headache for the fish curators due to a wide range of species and sizes kept in captivity. As the origin of the specimens can be regional, from other areas or from other aquaria and fish farms, fish pathology becomes a complicated problem because the previous health history of fishes introduced to the aquarium tanks is not known. In addition to the admission of diseased fishes, a fish disease may also be due to environmental conditions (light regime, temperature, dissolved oxygen), water quality (dissolved organic compounds, ammonia, residues from toxic compounds used as disinfectants and other toxic compounds). Capture and transportation can also cause a traumatic shock. Handling routines in the quarantine and the display tanks as well as problems in the mechanical equipment i.e. failure in pumps, aeration and filtration can cause health problems. Inadequate diet and stress can also induce diseases (McVicar and Richards, 1981). The treatment of fish diseases needs the expertise of an ichthyopathologist; the present section will be limited to the source of diseases, hygienic conditions and practices that should be routinely applied in a public aquarium. Early disease detection with the first symptoms can lead to successful therapy, avoiding extensive disease outbreaks and mass deaths. Healthy fishes should show clean bodies and untorn fins (Stokoe, 1966). Swelling of the belly can be a symptom of internal digestive ailment provided that the fish is not pregnant. Loss of color is also a symptom of metabolic and circulatory problems. Skin diseases show symptoms of discoloration, the appearance of ecchymoses, formation of white spots or grey slime. Lack of appetite can also be related to fish health. Fish diseases can be caused by bacteria, fungi, viruses and parasites. Some fish diseases such as fin and tail rotting as well as dermatitis although they have to be cured to avoid a disease outbreak, they can also affect fish appearance; In that case the fishes are not suitable for the display tanks.

Control measures are necessary to avoid diseases. Disinfection of aquaria, piping, pumps and the rest of the equipment should be carried out on a regular basis. Water quality should be checked and disinfection using a UV source or an ozonator should be applied if necessary. Abiotic conditions should also be cared for and a balanced diet should be provided to the specimens. As commercial food can lead to lack of some trace elements or vitamins, fish meals should be combined with fresh food and if possible with live food. Records with the fish diseases in the aquarium should be kept; it is going to save time and effort when problems arise.

Dinsinfection

Disinfection reduces the number of microorganisms to an acceptable level that does not cause health hazards to aquarium fishes. As the outbreak of a disease also depends on the general condition of the aquarium and fish condition, it is not easy to define thresholds values referring to microbial populations; curators experience is very important. Disinfection is applied to holding facilities and equipment as well as on the incoming water; if the system is closed water should be disinfected before reuse (Huguenin and Colt, 1992). The disinfectants used in an aquarium can be (a) chemical compounds and (b) ozone.

Chemical disinfectants: Chemical compounds used as disinfectants include iodine compounds, formalin, ammonium compounds and chlorine. A good disinfectant should be very effective in killing microorganisms and at the same time water soluble as these compounds are very toxic to aquatic life. Iodophors (orgnanic iodine compounds) are costly compounds but very effective. Concentration ranging between 50 and 100 mg l^{-1} for 10-30 min can be very effective. In addition, the change of the coloration of iodophors indicates when this chemical is no longer effective. Chlorine although is a low cost chemical, it can be used under special conditions. The chemistry of chlorine compounds in seawater and freshwater is very complex and results in the formation of a wide range of organic compounds, called disinfection byproducts or DBPs (Golfinopoulos *et al.*, 2003); these compounds have adverse health effects on human beings (Nikolaou *et al.*, 2004). Milder disinfectants such as ethyl alcohol, benzy-4-chlorophenol, phenylophynol and sodium chlorite were found effective in reducing or eliminating populations of *Mycobacterium marinum* in aquaria (Mainous and Smith, 2005).

Ozone treatment: although ozone is widely used for disinfecting drinking water (Loeb, 2009), ozone treatment in an aquarium will be used with causion. Ozone is highly toxic to both human and many species cultured (Wickins and Helm, 1981). In addition, it is corrosive to aquarium equipment and destroys chelating agents such as humic acid. It is also an expensive method for disinfecting aquarium water. Ozonation can be considered for recirculating systems where bacteria populations tend to increase drastically; also ammonia and nitrite should be oxidized. The efficiency of ozonation depends on turbidity, salinity, dissolved substances, microbial populations and planktonic densities.

Ultraviolet light: UV light reduces the reproductive capacity of bacteria and therefore acts as a bacteriostatic method. Similar effects have been observed on fungi. Part of the dissolved organic matter is also oxidized (Wickins and Helm, 1981). The wavelength used varies in the range of 240 to 280 nm and a dose of 30,000 to 35,000 $\mu W\ s^{-1}\ cm^{-2}$ is commonly used (Huguenin and Colt, 1992). The presence of particulate material reduces the efficiency of the UV radiation and therefore filtration of the sea water is recommended before the UV treatment.

AQUARIUM MISSIONS

The mission of a successful aquarium includes visitors recreation, education, research and conservation. All these missions cannot be served in isolation from each other but rather in an interactive mode with mutual benefits. However, in the present review these missions will be viewed in separate sections as the emphasis will be given rather to the core of each activity than the positive outcome from their interaction.

RESEARCH

Research activities are considered as a primary objective in many public aquaria (Hutchins and Smith, 2003). Many reasons have been reported for the growing interest on research in public aquaria: increased interest in conservation and biodiversity issues, the need for applied research to solve management problems, the growing interest to environmental sciences and environmental protection as well as the availability of animal stock for experimenting in the aquarium tanks (Stoinski *et al.*, 1998). The fields of study cover a broad spectrum of scientific disciplines: behavior, nutrition (Corsini and Karydis, 1990; Kalogirou *et al.*, 2007), demography, genetics, reproduction, ichthyopathology, life histories, autoecology (Corsini and Economides, 1999), marine ecology (Karydis and Corsini, 1985) and wildlife management (Hutchins and Thompson, 2008). As public aquaria have extended their scientific programs to environmental issues on coastal ecosystems and coastal water quality are within their interests.

Although the potential for research in aquaria is obvious, there is still questioning concerning research organization models (Lawson *et al.*, 2008). If the staff is dedicated only to research the scientific output can be sound; in addition, there is more time for collaboration with Academic Institutions and for fund raising but may not be integration of research with the aquarium interests. This can lead to limited flow of information and collaboration among the education staff, the aquarium care staff and the research staff. On the other hand, if the integrated approach is accepted mutual benefits are expected. In 2004 a survey was carried out (Lawson *et al*., 2008) among zoo and aquarium professionals focusing on three primary professional communities: conservation scientists, education staff and zoo/ aquarium directors. The results showed that the majority of zoo/ aquarium researchers was focusing on animal management (“animal health and well being”) followed by “creating and maintaining self sustaining populations”. Other fields of scientific interest, conserving wild places and inspiring caring and conservation action were not a priority for the aquarium scientific community. Research in an aquarium shows both advantages and shortcomings: research needs, scientific and technical manpower that comes from the staff managing the aquarium but also needs financial contribution and administrative support. On the other hand, research improves the scientific quality of the personnel involved, makes fund raising easier and promotes collaboration with research centers and universities. This collaboration promotes educational goals for both sides and allows benefits through shared resources (Freistner and Price, 2002). Academic Institutions offer library and laboratory facilities as well as research staff highly qualified in laboratory methodology. Public aquaria offer the animal stock and infrastructure for keeping them for experimentation. Views also have been expressed on the mutual benefits from research collaborations between Zoos and Academic Institutions by Fernandez and Timberlake (2008).

Another issue arising about research carried out in aquaria is research priorities. Most publications on this subject considered as priority in research efforts the scientific fields of behavior, genetics, reproductive biology, re-introduction and environmental enrichment (Hutchins and Thompson, 2008). Statistical analysis was attempted to access the presentation of Zoos and Aquaria in research Journals (Wemmer *et al.,* 1997). The authors analyzed 395 articles published by the Zoo Biology Journal over the last 15 years. On the basis of senior author’s affiliation, Zoos accounted for 43%, Aquaria for 5.5% and Universities for 36% of the articles. Although affiliations between Universities and Aquaria exist, they are not too obvious in the Zoo Biology journal. This finding suggests that there is still a lot of potential for developing research activities based on public aquaria.

EDUCATION

The contribution of aquaria towards environmental education can be either to the level of formal education or towards non-formal education programs mainly to encourage environmentally responsible behavior.

Formal environmental education developes at academic level. Aquaria can accept Ph.D. and Post Doc. students through joint research projects with Academic Institutions. On the other hand it has been reported (Lawson *et al.*, 2008) that many Universities oriented to “modern” disciplines do not offer courses on natural history programs such as mammology, herpetology and animal behavior. Research oriented staff can be actively engaged in University teaching both at undergraduate and graduate level. This has happened between Zoo Atlanta and Georgia State University (Lawson *et al*., 2008). This close collaboration can lead to further fund raising for research and conservation.

The non formal education is central mission to almost all zoos and aquaria. These education projects are targeting to both children and adults; aquarium visitors, school pupils, members of clubs or societies on natural history and conservation are the main classes of visitors. It has been urged that traditional teaching may not be enough to promote Environmentally Responsible Behavior (ERB) alone. On the contrary, it has been found that people familiar with nature exhibited more ERB

(Price *et al.*, 2009). School groups can enjoy guided tours and training sessions. The National Marine Aquarium at Plymouth offers tuition in subjects like species identification, habitats, adaptations and pollution (NMA, 2009). The same Aquarium also offers training to secondary school pupils, more advance material; their learning program includes fields such as climate change, fisheries, coral conservation and pathogens.

Research on the educational value of aquaria carried out at three aquaria in Britain (Evans, 1997) using questionnaires, the Newquay Sea-Life Center (Corwall), the Weymouth sea-life Center (Dorset) and the Pool Aquarium (Dorset), showed that visitors preferred public aquaria to improve their levels of interpretation and to be provided with more information on conservation aspects. The same author reported that the information provided by these aquaria was distorted for two reasons (a) as most of the exhibits were fishes, the information provided to visitors was distorted as far as the range of species and species diversity in the marine environment and (b) the environmental impact from the fishing industry was not mentioned. Non-formal environmental eduation is still an open field and educators can organize courses, seminars or presentations using live specimens, preserved organisms, film projections and computer software on conservation issues. It has been shown that even preserved or dried animal were also effective for understanding the marine environment (Sherwood *et al*., 1989). Although there are many concepts concerning the way that environmental education can be organized in public aquaria there is one point beyond any doubt: the environment is in a critical state. The potential of aquaria should be fully exploited especially if the impact of aquaria on their guests is considered. The aquarium environment inspires the recreational visitor to act in an environmentally responsible manner (Ogden and Heimlich, 2009).

CONSERVATION

There is no doubt as to the importance of public aquaria for protecting marine and freshwater species. Overfishing and water pollution devastate wild populations and aquaria play the role of the "ark" for the survival of many species (Gibbons and Stoskopf, 1983). Fishes are the most endangered species among aquatic organisms and a number of available approaches has been suggested for fish conservation: habitat management, habitat restoration, translocation, captive breeding and cryptopreservation (Maitland, 1995). If habitat management and restoration is not possible, translocation can be attempted i.e. creation of additional independent stocks. Aquaria can provide care, conservation expertise and well trained staff to cope with the conservation approaches mentioned above. However, conservation oriented to propagation projects of captive fishes is facing difficulties (Thoney *et al.*, 2003) due to high taxonomic diversity, a wide variety of reproductive methods as well as lack of knowledge on ecological, behavioral and nutritional needs for some species; knowledge on husbandry and fish pathology is also limited.

VISITORS

Public aquaria attract a large number of domestic and international visitors. There are several factors that keep the public popularity of aquaria high. Many people nowadays live in cities and the natural environment is not within their daily routines and experiences (Wetzel and O'Brien, 1995). Aquatic organisms cannot be observed regularly as aquatic environment is not accessible to people. Individuals, families and social groups are visitors of aquaria. The aquarium exhibits habitat replications, integrated film and video programs enhance the educational value of public aquaria. The animal visitors see within a public aquarium are "ambassadors" of the natural world (Taylor, 1995). This way aquaria shift from recreational centers to informal educational centers. Interaction panels, posters and web facilities can act as interactive interfaces and promote both interest and learning (Lin, 2007). A study was conducted at the National Aquarium in Baltimore (NAIB) to access visitor's experience to conservation (Adelman *et al.*, 2000). The study provided evidence that visitor's attitude was affected in the short term. Enthusiasm and emotional commitment to conservation returned to the original levels. These results indicate that a more integrated policy is needed for the visitors to be conservation oriented and participate in conservation actions. On the other hand, Monderay Bay Aquarium (MBA), tried to assess visitor's interests towards conservation as MBA major mission was to inspire visitors to the conservation of the oceans (Yalowitz, 2004). It was found that most visitors responded positively to conservation. If we take into account that large aquaria handle millions of visitors per year, it is obvious how crucial they can be in conservation and non-formal education.

PUBLIC AQUARIA: FUTURE PROSPECTS

Over the last three decades public aquaria are blossoming all over the world. New aquaria are built with modern concept and design; many old aquaria have been renovated. Four reasons have been reported that make construction and operation of aquaria feasible (Wetzel and O'Brien, 1995): (a) Construction and operation costs can be accurately accessed (b) they have limited requirements for space and therefore they can be built in urban areas with many potential visitors and academic opportunities (c) they are still popular as recreation centers and (d) they can enliven declining waterfront areas and (e) widening of the missions of the aquaria to include recreation, education, conservation, research and social benefits. These missions also help funding of the aquaria through research, conservation and educational projects, promote collaboration between aquaria and Academic Institutions and improve staff quality. Book publications and film productions on aquatic and marine life enhance the relationships between visitors and aquaria; the contribution of aquaria to change people's attitudes towards nature can be the target for this century.

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