

## Chapter 39

### Research on Elasmobranchs in Public Aquariums

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*Abstract:* Public aquariums have contributed to knowledge on elasmobranchs in various fields including diet, age and growth, bioenergetics, physiology, pathology, behavior, captive care, and population dynamics. Benefits of conducting research in public aquariums include: clear water, large tanks, species variety, and knowledge of husbandry. Limitations include: artificial habitats, possible modification of environmental cues (e.g., photoperiods, etc.), and insufficient replicates for adequate hypothesis testing. Although research in aquariums is continuing to increase, it appears to be restricted to relatively few institutions. We actively encourage aquariums to participate in elasmobranch research. We recommend cooperation between aquarists and colleagues at academic organizations to maximize the value of their respective skills. The ultimate aim of each study should be to publish results in peer-reviewed journals or books, ensuring rigorous research practices and knowledge dissemination. Research activities will be of immediate benefit to the aquariums involved and ultimately aid in the conservation of elasmobranchs.

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Research and public aquariums may appear not to have a lot of common ground, or areas of common interest, but in this section of the manual we intend to show that research can be and has been achieved in public aquariums, and that there is great benefit in harnessing this potential. We will discuss the benefits and limitations of research conducted in aquariums, and give many examples of successful studies undertaken in various fields. We will sketch the process required to develop and steer research projects through an aquarium administration, and discuss the importance of publishing results.

What is research? According to Webster's New World Dictionary (Nerfeld, 1990) research is defined as:

"...careful, systematic study and investigation in some field of knowledge..."

Basic (or pure) research may be defined as investigating phenomena without specific applications in mind, whereas applied research is intended to gain knowledge or understanding to meet a specific need. Researchers investigate questions (ideas or hypotheses) by testing them to see if they stand up to experimental analyses. Essentially the hypothesis is tested to see if it can be supported or rejected. This process requires multiple repetitions, or replicates, to obtain sufficient information and scientific robustness. Statistical analyses of the data investigate whether the results may be explained by chance alone. The hypothesis may then be modified and tested again. Experimental or observational settings need to be carefully described so that others can replicate the study and achieve consistent results.

Current research on elasmobranchs worldwide is both basic and applied, and in reality the separation into basic and applied may be an artificial division. Most elasmobranch research to date has occurred in academic institutions, affiliated field stations, or in government laboratories. With the proliferation of public aquariums worldwide there is considerable potential for the industry to play a much greater role in research involving elasmobranchs and other aquarium animals.

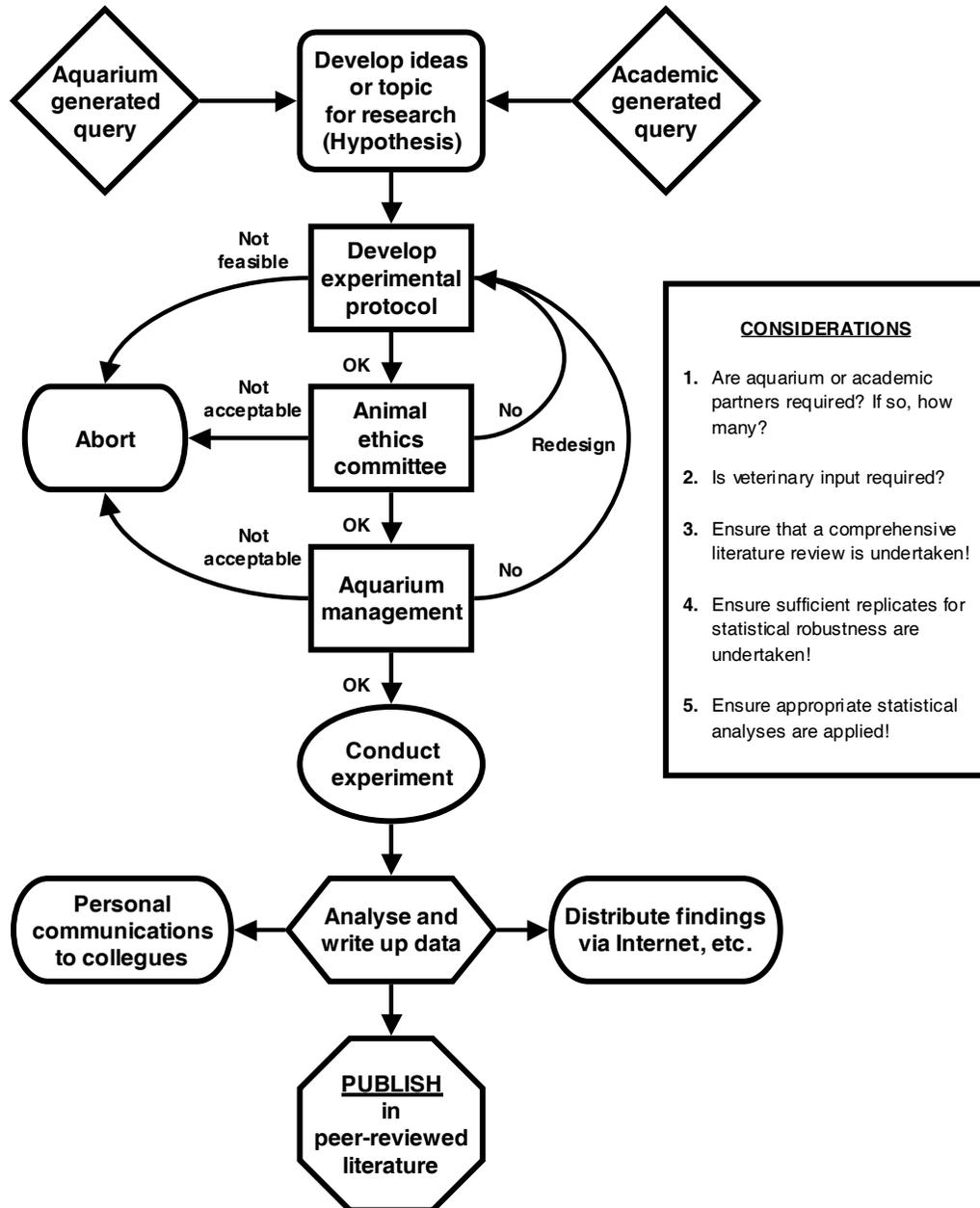
Applied investigations into improving captive husbandry or meeting the biological needs of specimens on exhibit dominate research generated within public aquariums. This work directly benefits both the institution and wild populations, because the goal is to improve animal health and thereby reduce the number of specimens taken from the wild. Examples of applied research includes studies of nutritional requirements (refer to Chapter 14), hematological studies (refer to Chapters 20 and 23), growth studies (refer to Chapter 15), and species-specific exhibit design (e.g., Chapter 32).

Basic research that addresses a research question or tests a hypothesis, following strict protocols, is relatively rare in aquariums. The availability of experimental control groups, for statistical robustness, is particularly challenging when working with large elasmobranchs. Furthermore, costs in time, space, and personnel have generally restricted the amount of research projects undertaken. However, molecular and cellular studies have often benefited from access to captive specimens, particularly for taxonomic and stock identification purposes. For such studies, one sample is often sufficient.

Cooperation between academic institutions and public aquariums has great potential, as both partners benefit from the relationship. There are already examples of applied and basic research being combined to improve captive care, while also answering a key biological question. Such investigations have been carried out on both bioenergetics (Schmid and Murru, 1994; Henningsen, 1996) and endocrinology (Crow et al., 1998). Partnerships between aquariums and academia have yielded

valuable physiology studies (Rasmussen and Murru, 1992; Crow et al., 1998; Henningsen et al., 1999; Henningsen et al., 2000). Such cooperative efforts are ideal as the focus of trained researchers and the unique skills of aquarium staff form effective partnerships in resolving specific research goals.

A model of the process required to develop a research project and steer it through institutional administration is outlined in Figure 39.1.



**Figure 39.1.** A flow diagram illustrating a model for undertaking research in public aquaria. The process may best be seen as an endless loop because the testing of a research hypothesis inevitably results in future research questions that need to be developed and tested.

## **ADVANTAGES AND LIMITATIONS OF AQUARIUMS**

There are both advantages and limitations to research on captive elasmobranchs. Among the advantages are: an availability of specimens belonging to several species, access to captive history (i.e., husbandry and medical records), and knowledge of environmental parameters (e.g., photoperiod, temperature, water chemistry, etc.).

Among the limitations of research on captive elasmobranchs are: small sample sizes, minimal comparability with wild conspecifics, and minimal comparability with conspecifics under different conditions at other institutions. Ideally, information derived from captive elasmobranchs should be verified with data derived from wild conspecifics. For example, steroid titers of captive carcharhinid sharks determined by Rasmussen and Murru (1992) were compared to wild sharks, at comparable stages of maturation and reproductive cycle, and were shown to be similar. Without such comparisons it is possible that results observed are an artifact of the aquarium regimen. All of these limitations should be considered, and accounted for, when constructing a research project.

In captivity the temperature and photoperiod may be modified because aquariums are frequently isolated from the external environment. This isolation limits environmental cues influencing sharks and rays, and may influence their physiology. Older and less sophisticated aquariums can have difficulties keeping seasonal temperature fluctuations within acceptable extremes. This risk may limit the number of species that can be maintained and may also influence the physiology of sharks if extreme temperatures become stressful. The physical limitations of an exhibit may further limit the natural responses of animals, being unable to swim distances possible in the wild and unable to interact at normal distances with conspecifics or other species. These restrictions may constrain social behaviors such as mating and schooling, and artificially influence observations in aquariums.

Research can be expensive, and although many aquariums have funds for investigation allocated in their budgets, they are generally fairly limited. Aquariums generally become involved in research projects that are consistent with their mission statement and will shy away from those that may detract from that statement. Nevertheless,

aquariums may undertake excellent and economic research projects, as we will show in the examples below.

## **ANIMAL WELFARE CONSIDERATIONS**

Prior to the initiation of research, an appropriate animal ethics committee should review the proposal to ensure that it is conducted according to internationally-accepted standards of animal welfare. Research must comply with all federal, state, and local laws, and regulations for the humane treatment, care, and use of animals, as well as those covering endangered species. In the USA, institutional animal care and use committees (IACUC) must be established to oversee and evaluate each institution's animal program, as well as the approval of all research involving animals.

## **AREAS OF RESEARCH**

### **Diet and Nutrition**

Research on improving the diet of captive elasmobranchs has been necessitated by the unavailability of natural prey. Usually a narrow selection of frozen fish and invertebrates (normally used for human consumption) is available and experience has shown that elasmobranchs remain healthier if vitamin and mineral supplements are added to their food (Murru, 1990). The introduction of an elasmobranch species not previously kept in aquariums represents a prime candidate for research—accompanied by a literature review, communication with peers, and almost certainly, trial-and-error. Field studies of natural prey (e.g., Randall, 1967; Smale and Compagno, 1997; Smale and Goosen, 1999) should guide the choice of food to be offered. Rigorous and detailed record keeping is essential to allow ultimate knowledge transfer within and between institutions.

### **Growth and development**

Public aquariums offer an opportunity to study the growth and early life stages of unusual elasmobranch species. Such studies may be undertaken as part of standard animal record keeping, although information on feeding rations and temperature ranges should also be maintained. Results should be compared with

results from wild elasmobranchs to assess the influences (if any) of the test environment and feeding regimes. This is undoubtedly one of the areas where aquariology has contributed the most toward elasmobranch research. Species for which growth has been studied in captivity include: nurse sharks, *Ginglymostoma cirratum* (Carrier and Luer, 1990), bull sharks, *Carcharhinus leucas*, sandbar sharks, *Carcharhinus plumbeus*, sand tiger sharks, *Carcharias taurus* (Schmid et al., 1990), broadnose sevengill sharks, *Notorynchus cepedianus* (Van Dykhuizen and Mollet, 1992), and epaulette sharks, *Hemiscyllium ocellatum* (West and Carter, 1990), among others. Coupling length and weight data with nutrition information yields a powerful tool for the assessment of husbandry techniques, allowing an assessment of the adequacy of a given feeding regime.

### Bioenergetics

Bioenergetic studies require closed circuits, allowing energy budgets to be calculated under the assumption that the difference between input and output in a system equals growth. It is paramount to conduct such studies under controlled, closed environments and aquariums are ideal for such studies. Many species have been studied in aquariums, including the spiny butterfly ray, *Gymnura altavela* (Henningsen, 1996) and the bull shark (Schmid and Murru, 1994).

Studies of food rations, food retention times, and food passage rates, for ecological studies, have been carried out on lemon sharks, *Negaprion brevirostris*, in laboratory aquariums (Wetherbee et al., 1987; Wetherbee and Gruber, 1990). Such experiments are essential for energetic studies, but are normally restricted to juveniles because of size constraints. Extensions of energetic studies, to include larger individuals, have been achieved in public aquariums. Pole feeding, in combination with detailed record keeping, have provided estimates of daily ration for the broadnose sevengill shark (Van Dykhuizen and Mollet, 1992).

### Physiology

Despite the logistical difficulties involved in monitoring biochemical and physiological parameters of large captive elasmobranchs, more and more public aquariums have come to realize the benefits of conducting regular surveys as a preventive rather than corrective measure. Naturally, the procedure of catching and

restraining a specimen can bias the results, especially where hormone and serum electrolyte levels are concerned. However, systematic recording of blood parameters (refer to Chapters 20 and 23 of this manual) allows tracking of physiological changes over extended periods of time, provides a valuable tool in identifying and diagnosing potentially pathological situations, and allows comparison of equivalent parameters between institutions. Examples of species studied include: lemon sharks (Murru et al., 1989; Pike et al., 1989; Stoskopf, 1993), sandbar sharks, nurse sharks, and tiger sharks, *Galeocerdo cuvier* (Stoskopf, 1993).

Captive animals are excellent subjects for long-term serum hormone studies (Rasmussen and Crow, 1993). Changes in steroid hormone titers may be monitored over periods of months to better understand fluxes in living animals. The constraints of the aquarium situation need to be considered, and care needs to be taken to minimize confounding effects (e.g., circadian rhythms, etc.) that may influence levels in the blood (Rasmussen and Crow, 1993). Although it is important to minimize stress when collecting samples, this artifact may be studied to quantify the effects of long-term stress on captive elasmobranchs.

Tooth-shedding rate, which would be hard to study in the wild, is relatively easy to monitor in captivity. Traditionally, sand tiger sharks have been the focus in this field (Overstrom, 1991; Correia, 1999). Correlation of tooth-shedding rate with environmental variables (e.g. temperature, food intake, etc.) may provide insight into the animal's physiology as well as its adaptability to captivity.

### Pathology

Pathology is the study of disease. Despite its obvious negative connotation, the occurrence of disease in captive elasmobranchs necessitates a cure, thereby creating an opportunity for research. Skin scrapes, tissue smears, biopsies, and other procedures often lead to the identification of pathogens and their respective treatments. Stoskopf (1993) provides a review of such cases. Other references include Grimes et al. (1984), Grimes et al. (1986), Noga (1996), and Subra (1998).

The study of elasmobranchs in aquariums has led to the identification of several new species of parasites and also the processes by which they may be eradicated (refer to Chapter 24 of this

manual). A typical example is the description of *Paralebion elongatus* in captive whitetip reef sharks (*Triaenodon obesus*), by Benz et al. (1992).

Histopathological studies of tissues obtained during necropsies can aid in identifying the cause of death of captive elasmobranchs and also provide good research opportunities. Recently Crow et al. (2001) determined, by histological assessment, that elasmobranch and human goiters have a similar pattern of development and etiology. Such studies not only advance the knowledge of human disease, but also facilitate the diagnosis of elasmobranch diseases by other institutions.

### Behavior

Clear water and specimen containment allow the observation of behaviors that would otherwise not be possible in the turbid, natural habitat of many elasmobranchs. For example, mating, gestation, and birth can all be recorded, yielding useful information (refer to Chapter 17 of this manual). Examples of such studies include those describing the captive breeding of whitetip reef sharks (Garner and Mackness, 1998a) and the blotched fantail ray, *Taeniura meyeni* (Garner and Mackness (1998b). Uchida et al. (1990) reported details of reproduction in seven species of sharks and seven species of rays held at the Okinawa Expo Aquarium (Okinawa, Japan). Their work expanded knowledge about elasmobranch reproduction. However, successful breeding (which they defined as newborn or hatched pups maintained until they reach maturity and breed themselves) was achieved at the Okinawa Expo Aquarium in only one species, the whitetip reef shark. This suggests that facilities, even in the best public aquariums, are not always suitable for elasmobranch reproduction and the completion of elasmobranch life cycles. As Pratt and Carrier (2001) note in their extensive review of elasmobranch reproduction, the restrictions of aquariums may limit understanding of mating patterns and interpretations may be inaccurate if they are not verified by detailed studies in the wild. Naturally, this is often difficult to achieve. Regardless, there is little doubt that aquariums have advanced our knowledge of reproduction in elasmobranchs, as is evidenced by numerous studies that have produced new information on reproductive behavior (Klimley, 1980; Gordon 1993; Pratt and Carrier, 2001).

Other examples of behavioral studies in captive elasmobranchs include those of Myrberg and

Gruber (1974) and Seligson and Weber (1990). The systematic logging of specific behaviors, with the inclusion of pictures or drawings, provides good insight into long-term behavioral changes, when correlated with time, and other variables such as feeding, lighting, introduction of conspecifics, etc. By including data fields on daily record sheets, it is possible to encourage husbandry staff to monitor animal behavior regularly. Although behavior is not always easily described, separation into discreet categories can often provide an adequate compromise. Such categories might include resting, swimming, feeding, mating, etc. The use of video photography may help in recording behaviors that are difficult to describe, and may facilitate communication and comparison between different observers.

### Population dynamics

Many elasmobranch population studies have been undertaken by government agencies, such as the National Marine Fisheries Service (Merson and Pratt, 2001), and academic institutions, such as the Virginia Institute of Marine Science (Musick et al., 1993). Since many aquariums collect elasmobranchs from the same locations each year, they can contribute to such studies by keeping accurate field records.

### Transport

Public aquariums have been transporting elasmobranchs for decades. Knowledge in this area has increased considerably in recent years (refer to Chapter 8 of this manual), particularly with species traditionally regarded as difficult to transport. Long-duration elasmobranch transport (i.e., >24 hours) has driven aquarium staff to better understand and control elasmobranch physiology and biochemistry, a key factor for transport success. References in this area are numerous and species studied include the sand tiger shark (Smith, 1992), scalloped hammerhead shark, *Sphyrna lewini* (Arai 1997; Young et al., 2002), sandbar shark (Andrews and Jones, 1990; Jones and Andrews, 1990), spiny dogfish, *Squalus acanthias* (Jones et al., 1983), and spotted ratfish, *Hydrolagus colliei* (Correia, 2001).

### Dissemination of results

Dissemination of research undertaken in aquariums is vital. Basic ethics dictate that

research results should be shared wherever possible. Inter-institutional dissemination can be as simple as distributing information via e-mail, web sites, or even telephoning colleagues facing similar husbandry challenges. To allow comparisons between studies or localities, the specifics of the study environment need to be clearly described. Ultimately, new and significant findings should be published in books and peer-reviewed journals to maximize global information transfer, and to maintain the highest standards of research. If the decision to publish results is made before the study is initiated, it will help focus research activities and promote experiments with rigorous hypotheses.

### Future work

Aquarium studies have contributed significantly to our knowledge of elasmobranchs. However, there are numerous areas suggestive of further research. These include: parasitology, for example the study of un-described parasitic organisms to which elasmobranchs play host (refer to Chapter 24 of this manual); captive breeding, in particular species whose populations are threatened in the wild (refer to Chapter 17 of this manual); and DNA analysis of animals from known sources. Such DNA studies may be achieved with minimal damage to individual specimens and yet would yield important insight into population dynamics, conservation strategies, and associated management plans (refer to Chapter 18 of this manual).

### CONCLUSIONS

Historically, research was considered to be outside the focus of public aquariums. Ten years ago it was stated by McCormick-Ray (1993) that:

“...what aquariums generally lack is a coherent approach to the science of aquariology. That is, they lack a research focus that would advance captive animal biology and technology and contribute to existing husbandry, conservation, and educational concerns...”

This chapter seeks to demonstrate that advances have been made to address this criticism.

A recent survey of North American zoos and aquariums reports an increased focus on research (Stoinski et al., 1998). However, it may be more accurate to say that research has been

undertaken by a few specific institutions, and is the direct result of the dedication, individual skills, and interests of a handful of employees, as well as their proximity to research professionals outside the aquarium industry. Despite this situation, there appears to be a growing trend of support for scientific investigation in aquariums. Many benefits accrue to institutions that undertake research, and aquarium administrators should be apprised of these rewards and encouraged to support research efforts. Aquariums should initiate research projects and remain receptive to initiatives from outside the institution. A research department should be created and funded so that basic husbandry investigations and field studies are encouraged, structured, supported, undertaken, and ultimately disseminated.

One of the best ways to optimize research potential at a public aquarium is to form partnerships with colleagues in academic institutions. Such partnerships, between animal husbandry experts and trained scientists, will build on the strengths of both parties (e.g., husbandry skills, knowledge of research practices, etc.) and ensure that studies are robust, focused, and of an appropriate academic standard. Communication between aquariums and academic associations that specialize in elasmobranchs is encouraged. These associations include, among others, the IUCN SSG (International Union for the Conservation of Nature and Natural Resources, Species Survival Commission, Shark Specialist Group), AES (American Elasmobranch Society), and the EEA (European Elasmobranch Association).

Research results can be rapidly disseminated using electronic communication, but it is vital that investigations are set up rigorously to allow publication in high quality, peer-reviewed journals. Resultant studies will improve both the husbandry and conservation of elasmobranchs.

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