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RESEARCH ARTICLE

Long-Term Transportation, by Road and Air, of Devil-Ray (*Mobula mobular*), Meagre (*Argyrosomus regius*), and Ocean Sunfish (*Mola mola*)

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Between September 2006 and April 2007 the authors transported one 0.9 m wingspan *Mobula mobular* from Olhão (South of Portugal) to Valencia (East of Spain), 12 ~1.0 m long *Argyrosomus regius* to Tarragona (Northeast of Spain) and four ~0.4 m long *Mola mola* to Atlanta (GA, USA). These journeys had a total "water to water" duration of 17, 22 and 33 hr, respectively. The first two transports were conducted by road whereas the third involved a combination of road and air travel. Water quality parameters—specifically dissolved oxygen, temperature, pH and ammonia—were monitored continuously throughout the duration of the trips and were maintained at optimum levels through the use of battery-powered filtration and chemical supplements. All animals arrived alive and well at their destinations. This paper reports on the specific transport regime adopted in each case and provides some insight for potential improvements in future similar transports. Zoo Biol 27 : 1–17, 2008.

Keywords: husbandry; aquariology; captive; amquel

INTRODUCTION

Public aquaria have changed quite dramatically in the last decades. Early institutions were known and commonly portrayed as "fish bowls," which was, in fact, the term used in one of the earliest National Geographic articles on the subject

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of marine live animal displays [La Gorce, 1952]. However, this perception has since evolved substantially and modern public aquaria are perceived as organizations actively engaged in educating the public, which amounts to several hundreds of millions, worldwide, every year. Some facilities are even involved on research, with multiple examples given by Smale et al. [2004], while addressing the subject of research conducted on captive elasmobranchs.

Engaging a public that is used to modern technology is no easy task and public aquaria focus increasingly more on acquiring and displaying original and novel animals. In April 1988, the Osaka Aquarium Kayukan (www.kaiyukan.com) brought massive Whale sharks (*Rhincodon typus*) to within centimeters of millions of visitors. In November 2002, the Okinawa Churaumi Aquarium (www.kaiyouhaku.com) opened its doors to the public by hosting an impressive school of Manta rays (*Manta birostris*)[1]. That same month the Oceanário de Lisboa (www.oceanario.pt) became the first European institution to exhibit this species, and in the summer of 2003 was the first, in the world, to display a Devil-ray (*Mobula mobular*). In 2004 the Monterey Bay Aquarium (www.mbayaq.org) broke new ground by successfully displaying a female Ggreat white shark (*Carcharodon carcharias*) for approximately 6 months. After release back to the wild that animal would soon be replaced by a second great white shark, which was, as the first, the subject of multiple behavioral research programs. In November 2005, the Georgia Aquarium (www.georgiaaquarium.org) was inaugurated with its mammoth 25 million liters tank (largest tank in the world) featuring no less than four whale sharks, and currently focuses on adding a school of Ocean Sunfish (*Mola mola*) to their exhibit. These are a few examples of institutions that have gone to significant lengths to present high-profile displays to their patrons, while actively immersing them in a conservation-oriented atmosphere.

Mobulids (Family Mobulidae), such as Devil-rays (i.e. *Mobula* spp.) and Giant Manta rays (i.e. *M. birostris*), certainly qualify as "high-profile" animals, and so do Ocean Sunfish (*M. mola*), which is why modern facilities have attempted to procure and display such species. However, their capture and transport are not as straightforward compared with most ornamental fish species on display today, which is mostly because of their delicate nature and impressive size, especially when fully grown.

M. birostris [Walbaum, 1792] reach a disc width of up to 9 m [Last and Stevens, 1994] and is a very popular species, frequently portrayed in televised documentaries of marine life and often the core business of recreational dive operators. *Mob. mobular* [Bonnaterre, 1788] reaches 5 m in wingspan [McEachran and Seret, 1990] and is a less common Mobulid, although clearly identifiable as one through its cephalic lobes and distinctive diamond-shaped body. "Disc width" is commonly referred to as "wingspan" when Mobulids are concerned, owing to their distinctive airplane-like diamond shape and wing-like locomotion of the pectoral fins.

M. mola [Linnaeus, 1758] reach a maximum length of 3.3 m and can weigh up to 2.3 metric tons [Tortonese, 1990]. The Monterey Bay Aquarium released a captive *M. mola* back to the wild, in 2000 that weighed an astonishing 800 kg and had to be transported to the nearby ocean by air (Powell, personal communication[2]). The slow

[1]In June 2007, this institution announced worldwide the captive birth—after conception and one year gestation in-house—of one such animal, which is also an impressive accomplishment.

[2]Powell, D. 2001. Monterey Bay Aquarium. 886 Cannery Row, Monterey, CA 93940, USA.

delicate movements of Sunfish, coupled with their astounding size and unusual shape, make this a very charismatic species amongt aquarium patrons.

Smith [1992], Correia [2001], Young et al. [2002] and Smith et al. [2004] provide an extensive background (including a thorough literature review of previous work by other authors) of the physiological aspects involved during transport. These include the logistic measures that have to be taken into place to counteract such concerns. The size of the animals to be collected is a primary issue, and it is therefore advisable to collect such animals at a small size, therefore maximizing their chances of survival during capture, transport and acclimation.

However, size is hardly the only concern in a long-term transport. During transport pH will gradually decrease, whereas ammonia will increase, as a result of carbon dioxide buildup and the release of nitrogenous waste and miscellaneous stress-related metabolites, respectively. Both of these tendencies need to be counteracted through the use of filtration and/or chemical supplements. The control of pH can be achieved by the use of buffering agents, such as the tribuffer described by McFarland and Norris [1958], common baking soda (i.e. sodium bicarbonate—$NaHCO_3$) or soda ash (i.e. sodium carbonate—Na_2CO_3). Ammonia (NH_3 and NH_4^+) may be removed with the assistance of quenching agents such as AmQuel® ($HOCH_2SO_3$) (Fritz Industries, Mesquite, TX), which binds to ammonia and transforms it into nontoxic aminomethanesulfonate ($H_2NCH_2SO_3^-$) and water. This substance has been successfully used in the transport of marine species for many years, specifically elasmobranchs [Visser, 1996; Young et al., 2002]. Oxygen dissolved in the water will also decrease during transport as a direct result of respiration. This is easily counteracted by supplying oxygen through the use of an airstone connected to a cylinder of compressed medical-grade oxygen.

The southern coast of Portugal (a region known as Algarve) is a passage way for animals swimming in and out of the Mediterranean Sea, during their migratory patterns. A fishing company, Tunipex S.A., has established a set-net in this location (Fig. 1). The set-net is the only one of its kind in Portuguese waters and has been a source of live marine animals for public aquaria, such as the Oceanário de Lisboa in Lisbon/Portugal; the Aquarium Finisterrae in La Coruña/Spain (www.casaciencias.org/aquarium); L'Oceanogràfic in Valencia/Spain (www.cac.es/oceanografic); Atlantis in Paradise Island/Bahamas (www.atlantis.com); and the Sea Life Centre in Munich/Germany (www.sealifeeurope.com).

Set-nets are a preferred fishing method for public aquaria, as the fish are allowed to swim freely before capture, and no invasive steps are involved in the removal of the ocean per se. The set-net operated off the Algarve shore captures a diverse array of both teleost and elasmobranch species (e.g. *Thunnus thynnus*, *Sarda sarda*, *Isurus oxyrinchus*, *Prionace glauca*, *Cetorhinus maximus* and many others), with the unique advantage of covering a wide range of sizes, from newborns to fully grown. It was therefore no surprise that most of the institutions named above demonstrated an interest on acquiring small Mobulids, Sunfish and other charismatic species, should they enter the set-net.

Meanwhile, research facilities around the World have been focusing on the aquaculture of multiple marine species, to satisfy global demand for protein from marine organisms. As marine resources face mounting difficulties, aquaculture assumes a role that increases in significance (both financial and as produced wet weight) every year [Jennings et al., 2001]. Meagre (*Argyrosomus regius*) [Asso, 1801]

Fig. 1. Location of commercial fishing set-net where *M. mobular*, *A. regius* and *M. mola* were collected. The set-net is 10 km southeast of Olhão. Two fishing boats check and haul the nets daily, departing and returning from Olhão.

is one species that has merited attention from this industry in recent years. It is also one of the species commonly caught by the Tunipex set-net, which is why a Catalonian governmental research facility, IRTA (Institut de Recerca I Tecnologia Agroalimentaries) in Tarragona (Spain) requested some animals from Flying Sharks. Meagre grow quickly and can reach 2.3 m in length and can weigh up to 103 kg [Chao and Trewavas, 1990], which is one of the reasons why they are becoming the focus of many aquaculture facilities (Pousão personal communication[3]).

MATERIALS AND METHODS

The animals were caught by Tunipex on the following dates:

- One *M. mobular*, 0.9 m wingspan, August 2006.
- 12 *A. regius*, ranging from 0.9 to 1.2 m total length, caught during the first 2 weeks of October 2006.
- Four *M. mola*, measuring approximately 0.4 m total length, caught in February and March 2006.

Once caught in the set-net, the animals were removed using nonabrasive vinyl stretchers and transported to land inside the fishing vessel's cargo hold, which was flooded with seawater. The cargo hold measures 4 m long × 3 m wide and was filled 1 m high with water, yielding a volume of 12 m^3. Transport of the *M. mola* to land was performed inside a round 1.6 m diameter polyethylene tank also filled 1 m high with seawater. The trip to shore took approximately 1 hr, during which oxygen was added to the water in the cargo hold and/or polyethylene tank from a compressed

[3]Pousão, P. 2006. IPIMAR. Av. de Brasília, 1449-006 Lisboa, Portugal.

oxygen cylinder and airstone. Dissolved oxygen was maintained above 100% saturation.

Once arrived to shore *M. mobular* and *A. regius* were immediately transferred to one 10 m diameter × 1.8 m high round fiberglass tank. *M. mola* were transferred to one 4 m diameter × 0.8 m high round fiberglass tank. These staging tanks are on a flow-through system and have no temperature control. Introduction was therefore preceded by a quick acclimation period (typically 10–15 min). Filtration of the staging tanks consists of one rapid sand filter, for mechanical filtration and one elevated tower loaded with bioballs for biological filtration. All systems are kept on a semi flow-through regime, with a daily turnover rate of approximately 100%. New water is pumped directly from the nearby shore, as the staging facility is located in Olhão, deep inside the Ria Formosa lagoon complex.

One day after arrival all animals were offered the following foods:

M. mobular was offered small (approximately 5–8 mm carapace length) frozen shrimp (*Palaemonetes varians*) on the surface of the water, using a small plastic yellow scoop (Fig. 2). Food was offered six times daily. Three days after food being offered, the animal would quickly swim toward the yellow scoop as soon as it was placed in the water. Food was then offered three times per day. The animal was estimated to weigh 10 kg (an accurate weight measurement was acquired in Valencia, after arrival, and it was 9.0 kg), and food was offered with a target of 3% body weight per day (i.e. 300 g). However, this feeding technique involves a substantial amount of waste, mostly owing to the fact that *M. mobular*'s mouth is ventral and almost double of the target, therefore 300 g of food was offered daily.

A. regius were fed Mackerel (*Scomber japonicus* and *S. scombrus*) caught fresh every day by Tunipex. Some live Mackerel were also introduced in the staging tank, as Meagre are notorious for rejecting dead food during early stages in captivity.

Fig. 2. Feeding of 0.9 m wingspan *M. mobular* caught on set-net in the south of Portugal. Small shrimp were offered at the surface using a small plastic yellow scoop, toward which the animal would actively swim when placed on the surface of the water. (Photo courtesy of Ray Davis, Georgia Aquarium, USA).

M. mola were offered medium-sized (approximately 25–30 mm carapace length) frozen Tiger prawns (*Penaeus* spp.) three times per day. Prawns were offered at the end of a plastic yellow round target (Fig. 3), toward which the animals would actively swim once placed on the surface of the water. This behavior was learned by the animals within minutes of the first feeding attempts (!).

M. mobular and the 12 *A. regius* were transported to their final destination approximately 3 weeks after their respective arrival to the staging facility. No treatments were performed on these animals. The four *M. mola* had a longer stay and displayed some external parasites shortly after arrival. A visual inspection revealed these were predominantly copepods (Order Copepoda). These were treated by immersion of the animals for 2 hr in Praziquantel baths at 10 mg/l and also by oral daily treatments using Praziquantel at 25 mg/kg of body weight for 3 consecutive days. *M. mola* also displayed external injuries and were treated orally daily with Enrofloxacin at 15 mg/kg for a minimum of 10 consecutive days. At the end of the Praziquantel and Enrofloxacin treatments, the *M. mola* were transferred from the 4 m to a 10 m wide round tank. This transfer was immediately preceded by a Praziquantel bath as described above.

Two days before travelling all animals were fasted, to decrease the amount of nitrogenous waste released during transport. The transport took place during the following dates and consisted the routes described below:

- *M. mobular* was moved by road directly from Olhão to Valencia on September 20, 2006.
- The 12 *A. regius* were moved by road directly from Olhão to Valencia on October 26, 2006.
- The four *M. mola* were moved by road from Olhão to Lisbon on April 4, 2007. They were then moved by air from Lisbon to Vitoria (Spain), then Brussels (Belgium), then New York (USA) and, on 5 April, from New York to Atlanta

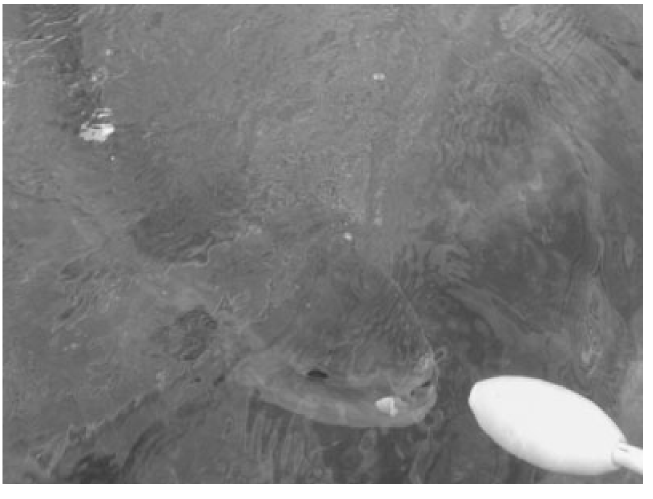

Fig. 3. Feeding of *M. mola* caught on set-net in the south of Portugal. Shrimp were offered at the surface using a plastic yellow target, toward which the animal would actively swim when placed on the surface of the water.

also by air. Freight aircraft were used, ensuring that two attendants were able to continuously monitor the tanks and animals throughout the entire duration of the trip.

The transport tanks for the three missions described above followed a relatively simple concept, previously used and described in detail by Correia [2001] and Young et al. [2002]. This simple method consists of (Fig. 4) the following.

One polyethylene round container with the following dimensions:

- 2.4 m diameter × 1.2 m high for one 9 kg *M. mobular*. The tank was filled 1 m high, yielding a usable volume of 4.5 m^3, which means a bioload of 2.0 kg/m^3.
- 1.6 m diameter × 1.0 m high for two 20 kg *A. regius* each. The six tanks were filled 0.7 m high, yielding a usable volume of 1.4 m^3, which means a bioload of 28.6 kg/m^3.
- 1.4 m diameter × 0.9 m high for one 4 kg *M. mola* each. The four tanks were filled 0.7 m high, yielding a usable volume of 1.1 m^3, which means a bioload of 3.6 kg/m^3. All tanks were filled with the same seawater the animals were being kept in.
- One Jacuzzi® (Jaccuzi Inc., Chino, CA) cartridge filter powered by a 12 V Rule® (ITT Industries, Inc., Gloucester, MA) 2000 GPH bilge pump mounted on the lid; each cartridge consisted of multiple laminated sheets of filter paper with the addition of one bag of activated carbon in the center.
- One fiberglass-reinforced lid was bolted to the polyethylene tank, ensuring that it was sealed and leak proof. This was particularly important while moving tanks by

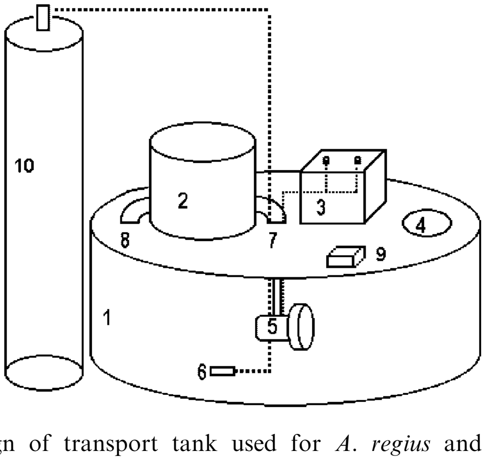

Fig. 4. General design of transport tank used for *A. regius* and *M. mola*. Legend: 1: Polyethylene transport tank (1.6 m diameter × 1.0 m high for *A. regius* and 1.4 m diameter × 0.9 m high for *M. mola*) with 15 mm thick fiberglass-reinforced lid bolted to 30 mm gasket. 2: Filter unit; contains one laminated paper cartridge and one mesh bag with activated carbon. 3: 12 V dry-cell-sealed battery, wired to bilge pump. 4: Porthole, removable. 5: 12 V powered Rule® 2000 GPH bilge pump, pushes water up through filter. 6: Airstone, fed by airline connected to pressurized oxygen cylinder. 7: Filter inlet, i.e. PVC elbow mounted through wooden lid, connected to bilge pump through 2.5 mm reinforced hose. 8: Filter outlet, i.e. PVC elbow mounted through wooden lid, returns filtered water above surface of water inside the tank. 9: Small AA 1.5 V battery-powered aeration unit, attached inside of the lid. The airstone was connected to this unit whenever the use of oxygen from compressed cylinder was not permitted (e.g. inside aircrafts during flight). 10: Pressurized oxygen cylinder, secured to pallet carrying tanks.

air and was the object of one official inspection by the Portuguese Institute of Welding and Quality (www.isq.pt). During such inspection the tank was filled to the top, closed, sealed and pressurized to 0.1 bar. No leaks were detected. After this test, the tank was shaken vigorously. No leaks were detected either. Each lid included a acrylic hatch that allowed for visual inspections of the animals and also their placement inside the tank.

The transport tank used with the *M. mobular* suffered some changes, as there was concern that the presence of the bilge pump in the middle of the tank would constitute an obstacle that would continuously force the animal to navigate around it, which is generally accepted as something elasmobranchs do not handle well. This reasoning was applied to *Hydrolagus colliei* (not an elasmobranch, but still a *Chondrichthyes* and therefore prone to similar difficulties) in 2000 [Correia, 2001] and yielded very satisfactory results (i.e. 100% survival). The changes carried out on the *Mobula* tank included the addition of one separate *filtration* tank, as described below (Fig. 5):

- The tank in which the animal travelled, i.e. the *Mobula* tank, was upgraded to a 2.4 m diameter × 1.2 m high (i.e. approximately 5.4 m^3), rather than using the traditional 1.6 m diameter × 1.0 m high (i.e. approximately 2.0 m^3).
- No filtration was mounted on this tank; all filtration was mounted on a separate 1.6 m diameter × 1.0 m high tank, i.e. the *filtration* tank.

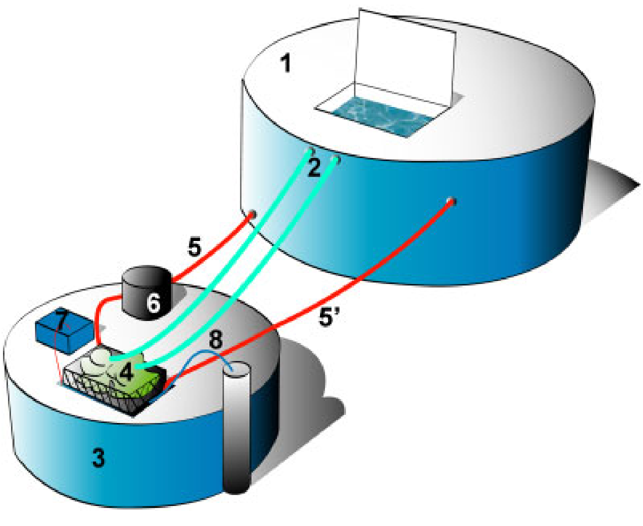

Fig. 5. Tanks used for road transport of *M. mobular* from Olhão (Portugal) to Valencia (Spain). Legend: 1: *Mobula* tank, 2.4 m diameter × 1.2 m high. 2: Surface skimmers, connected through hose to *filtration* tank. 3: *Filtration* tank, 1.6 m diameter × 1.0 m high. 4: Glass wool bed over which water trickling down from *Mobula* tank poured. 5: Outgoing hoses from *Filtration* tank to *Mobula* tank; hoses are connected to one 12 V powered Rule® 2000 GPH bilge pump each. 6: Filter unit; contains one laminated paper cartridge and one mesh bag with activated carbon. A 12 V powered Rule® 2000 GPH bilge pump (immersed inside tank), pushes water up through the filter. 7: A 12 V dry-cell-sealed batteries, wired to bilge pumps. 8: Airline connected to compressed oxygen cylinder (secured outside tank) and to small 12 V powered Rule® 500 GPH bilge pump (immersed inside tank), atomizing oxygen.

- Two 8 cm diameter hoses connected the top of the 2.4 m wide *Mobula* tank to the 1.6 m wide *filtration* tank. The water from the *Mobula* tank therefore trickled down to the *filtration* tank by gravity, effectively creating surface skimming as well.
- Water from the *Mobula* tank poured in the *filtration* tank over a bed of glass wool, for mechanical filtration and removal of particulate matter.
- Water in the 1.6 m wide *filtration* tank was filtered with a Jacuzzi® unit powered by a Rule® 2000 GPH bilge pump, as described in Figure 4.
- Two additional Rule® 2000 GPH bilge pumps returned water from the *filtration* tank back to the 2.4 m *Mobula* tank through two 4 cm wide reinforced hoses, directly connected to the side of the *Mobula* tank. One hose returned water to near the bottom of the *Mobula* tank whereas the other hose returned water approximately half way to the top of the *Mobula* tank.
- One small Rule® 500 GPH bilge pump was also mounted inside the *filtration* tank and oxygen was fed through one airline, directly into its impeller, therefore atomizing the oxygen. This apparatus allowed a continuous oxygen flow of 0.5 l/min to yield a dissolved oxygen saturation rate, in both the *Mobula* and *filtration* tanks, of up to 180%.

All animals were loaded inside their respective transport tanks using nonabrasive vinyl stretchers, whereas handlers used latex gloves to prevent damage of the skin. In transport, animals and equipment were checked approximately every hour. Checks included monitoring the animals, equipment and water quality parameters such as temperature and dissolved oxygen (using a hand-held OxyGuard® Handy Oxygen probe®—OxyGuard Intl., Birkerod, Denmark), pH (using a hand-held OxyGuard® Handy pH® probe) and ammonia (using a Tetra® Ammonia test kit during the first two transports—Tetra Werke, Melle, Germany—and a Palintest® Photometer 7000® photometer—Palintest, Tyne & Wear, UK—on the *M. mola* transport).

Oxygen was supplied at a rate of 2 l/min, but this flow was raised if dissolved oxygen dropped below 100% saturation. During the *M. mola* transport, oxygen or filtration was not permitted on board flying aircraft and air was supplied using small battery-powered aerating units, mounted inside the lids of the tanks.

During the *M. mobular* and *A. regius* transports, ammonia test results higher than 0.25 mg/l were counteracted by doing partial water changes, as spare water was transported specifically for that purpose. During the *M. mola* transport there was only one opportunity to perform a water change while on the ground in New York. On other occasions ammonia test results higher than 0.25 mg/l were counteracted by adding 30 g of AmQuel® to the water. Each dose of AmQuel® also contained a 16 g dose of sodium bicarbonate and 9 g of sodium carbonate, as the use of AmQuel® is known to be associated with a decrease in pH. This "cocktail" of AmQuel®, sodium bicarbonate and sodium carbonate was calculated with the objective of quenching 1 mg/l of ammonia per 1 cubic meter of water, which was the approximate volume carried inside the tanks.

Once arrived at their destination all animals were slowly acclimated to their final destination water, except for *A. regius* that were introduced directly to their new tank. Acclimation took 3 hr for *M. mobular* and 2 hr for *M. mola*. *M. mobular* was fed approximately 4 hr after arrival, but it would not feed until 3 days after arrival.

A. regius began feeding 14 days after arrival, and *M. mola* began feeding immediately (!) after arrival.

RESULTS

All animals arrived alive and well at their respective destinations. Water quality results and detailed itineraries of the three transports are given in Tables 1–3. Detailed pH, ammonia and dissolved oxygen readings during the *M. mola* transport are given in Figures 6 and 7.

The water changes performed with *M. mobular* and *A. regius* successfully kept the pH above 7.90 and reduced ammonia to under 0.25 mg/l (Tables 1 and 2). Similarly, the addition of AmQuel® and sodium bicarbonate to the *M. mola* tanks also maintained the pH above 8.06 and ammonia under 0.15 mg/l (Table 3). Oxygenation or, when oxygenation was not possible, aeration kept the dissolved oxygen above 100% saturation, except for the *M. mola* tanks, which showed values under 100% after 15 hr with no oxygenation and aeration only (i.e. at 18:30 total time) (Figs. 6 and 7). At that point the freight aircraft's crew allowed the use of oxygen, which was carried out under close supervision and in accordance with all IATA rules. Oxygenation was stopped before landing and replaced with aeration from the small battery-powered units.

DISCUSSION

The transport regime used for all the animals moved seemed adequate and yielded positive results, which means that there were no mortalities in transit.

M. mobular was moved in the largest of all tanks (5 m^3) and benefited from two full water changes and one partial water change, which was easily performed by carrying three extra 2.4 m diameter containers loaded with water from the origin. These were made because *Mobula* was perceived as a challenging animal to move and extra care was taken to ensure water quality was at its peak. Indeed, *Chondrichthyes* have a reputation for being difficult animals to move, with many authors reporting on multiple physiological and behavioral needs that need to be addressed, as illustrated by Cliff and Thurman [1984], Andrews and Jones [1990], Murru [1990], Arai [1997] and others. The difficulties faced by these animals, specifically, are linked to a number of mechanisms, such as (1) impaired ram ventilation, which occurs when an elasmobranch cannot pass sufficient water over its gills and effective ventilation and respiration are compromised [Gruber and Keyes, 1981; Hewitt, 1984]; (2) an interrupted swimming pattern and associated decreased muscular pumping activity, resulting in reduced circulation of vascular and lymphatic fluids [Gruber and Keyes, 1981; Lowe, 1996]; (3) elevated energy expenditure from increased turning frequency to avoid corners and interactions with conspecifics [Weihs, 1973; Klay, 1977] and (4) anaerobic metabolism and blood acidosis induced by periods of extended hyperactivity [Murdaugh and Robin, 1967; Albers, 1970; Bennett, 1978].

These four latter issues were addressed by providing (1) the largest possible volume of water, therefore allowing for ample swimming space; [(2) and (3)] removal of any obstacles that would force the *Mobula* to negotiate around and (4) frequent water changes to eliminate all metabolic waste. The 0.9 m *Mobula* swam continuously throughout the duration of the transport and acclimation, indicating

TABLE 1. Water quality parameters during transport by road of a 0.9 m wingspan *Mobula mobular* From Olhão (Portugal) to Valencia (Spain), on September 20–21, 2006

Date	Time at origin	Dissolved oxygen (%)	Temp. (°C)	NH_4^+/NH_3(mg/l)	pH	AmQuel® additions	Filtration (on/off)	Obs.	Location	Transport means	Total time
Sep 20, 2006	23:00	100	23.5	0.00	>8.1	–	1	Loading-baseline parameters	Olhão		0:00
Sep 21, 2006	0:00	157	23.5	0.00	>8.1	–	1			Road	1:00
	2:15	180	23.4			–	1		Near Sevilla	Road	3:15
	3:45	169	23.1			–	1	100% water change		Road	4:45
	6:15	163	23.1	0.00	>8.1	–	1			Road	7:15
	8:25	160	22.6	0.00	7.9–8.1	–	1	100% water change	Near Valdepeñas	Road	9:25
	10:50	180	22.9			–	1			Road	11:50
	12:30	158	22.2	0.00	7.9–8.1	–	1	50% water change		Road	13:30
	13:30						0	Begin acclimation	Valencia	Road	14:30
	16:00						0	Introduction to new tank, local time: 17:00		Road	17:00

Total duration = 17 hr. Filtration indicates on (i.e. "1") or off (i.e. "0").

TABLE 2. Water quality parameters during transport by road of 12 0.9–1.2 m long *Argyrosomus regius* from Olhão (Portugal) to Tarragona (Spain), on October 25–26, 2006

Date	Time at origin	Dissolved oxygen (%)	Temp. (°C)	NH_4^+/NH_3 (mg/l)	pH	AmQuel® additions	Sodium bicarbonate additions (g)	Filtration (on/off)	Obs.	Location	Transport means	Total time
Oct 25, 2006	14:00	100	20.9	0.00	7.90	–		1	Loading-baseline parameters	Olhão		0:00
	17:00	149	21.2			–	100	1			Road	3:00
	20:00	152	21.0	1.5–3.0	7.45	–	100	1			Road	6:00
	23:00	160				–		1			Road	9:00
Oct 26, 2006	1:00	153	20.3			–		1	50% water change		Road	11:00
	2:30	151		0.25–1.50	7.50	–	100	1			Road	12:30
	5:00	144				–		1			Road	15:00
	7:30	176				–	100	1			Road	17:30
	11:00	143				–		0	Begin acclimation	Tarragona	Road	21:00
	12:00					–		0	Introduction to new tank , local time: 13:00		Road	22:00

Total duration = 22 hr. Values given are average of the six tanks. Filtration indicates on (i.e. "1") or off (i.e. "0").

TABLE 3. Water quality parameters during transport by road and air of four 0.4 m long *Mola mola* from Olhão (Portugal) to Atlanta (U.S.A.), on April 4–5, 2007

Date	Time at origin	Oxygen (%)	Temp. (°C)	NH_4^+/NH_3 (mg/l)	pH	AmQuel® additions	Filtration (on/off)	Obs.	Location	Transport means	Total time
Apr 4, 2007	12:30	112	18.6	0.16	8.43	100%	1	Loading-baseline parameters	Olhão		0
	15:00	136	18.2	0.07	8.44	25%	1			Road	2:30
	16:00	165					1			Road	3:30
	17:15	161		0.09	8.39	100%	0		Lisboa	Loading freight aircraft then fly	4:45
	21:30	124	18.0		8.30	50%	0		Vitoria	Changing freight aircrafts then fly	9:00
Apr 5, 2007	1:30						0		Brussels	Changing freight aircrafts then fly	13:00
	3:30	139	17.6	0.15	8.25	100%	0			Airborn	15:00
	7:00	87	17.3		8.20	50%	1			Airborn	18:30
	9:00	182	17.5		8.22		0			Airborn	20:30
	11:30	139	17.1				0		New York	On the ground	23:00
	13:00						1	50% blow-down		Changing to charter aircraft then fly	24:30
	16:00	165	16.4		8.10	100%	1			Airborn	27:30
	19:30	122	16.3		8.06		1	Begin acclimation	Atlanta		31:00
	21:30						0	Introduction to new tank, Local time 16:30			33:00

Total duration = 33 hr. Values given are average of the four tanks. AmQuel® addition values indicate if all tanks received AmQuel® (i.e. "100%") or if only two tanks received it (i.e. "50%") or if only one tank received it (i.e. "25%"). Filtration indicates on (i.e. "1") or off (i.e. "0"). Filtration at 07:00 (18:30 total time) reads "1" but only oxygen was flowing; filters were not running.

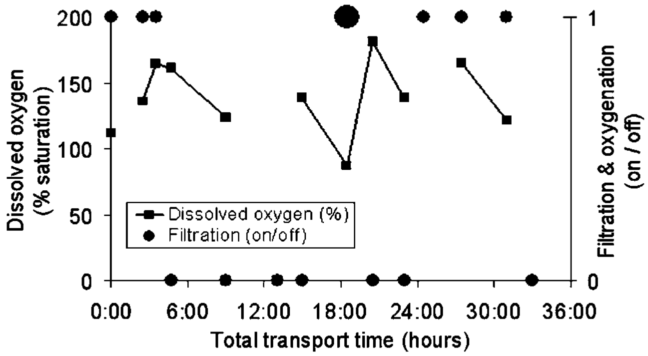

Fig. 6. Water quality parameters during transport by road and air of four 0.4 m long *M. mola* from Olhão (Portugal) to Atlanta (USA), in April 2007. Total duration = 33 hr. Lines and squares indicate dissolved oxygen. Circles indicate filtration and oxygenation: "on" (i.e. "1") or "off" (i.e. "0"). The large circle (at 18:30 total time) corresponds to oxygenation "on" only; filtration was "off". Whenever oxygenation was "off" aeration was turned "on".

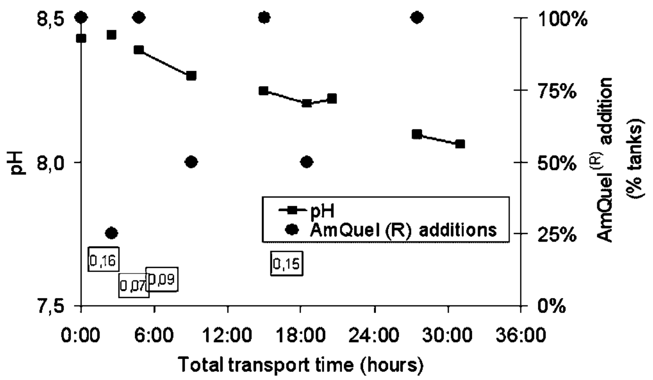

Fig. 7. Water quality parameters during transport by road and air of four 0.4 m long *M. mola* from Olhão (Portugal) to Atlanta (USA), in April 2007. Total duration = 33 hr. Lines and squares indicate pH. Circles indicate addition of AmQuel®: "100%" means all four tanks were dosed with AmQuel® and sodium bicarbonate; "50%" means two tanks were dosed; "25%" means only one tank was dosed. Numbers in boxes are ammonia concentration (mg/l).

the regime adopted was adequate for this species, at this size, during this length of transport.

Once at the destination, in Valencia, the *Mobula* was introduced in a round 6 m diameter × 1 m high pool. The animal looked disoriented at first, frequently swimming against the sides of the tank. Vertical lines were drawn around the wall of the tank the morning after, and this had an immediate and remarkable effect on the *Mobula's* behavior, which quickly began to swim in a stable circular pattern, maintaining a constant distance of approximately 30 cm from the side of the tank. The same food the animal was taking in Olhão was offered shortly after arrival, but it was not until September 24 (i.e. 3 days after arrival) that it began feeding regularly from a yellow plastic scoop, similar to the one used in Olhão.

The *A. regius* transport was done with a substantial lower level of logistics in comparison with *M. mobular*. The main differences were discernible in bioload and amount of blow-down. *A. regius* were packed at 28.6 kg/m^3, vs. the 2.0 kg/m^3 used for *M. mobular*. Only one 50% water change was done in comparison with 2.5 100% water changes on *M. mobular*. Regardless, this regime proved sufficient for the sedentary nature of *A. regius*, which does provide insight into the fundamental physiological differences between teleosts and elasmobranchs.

Having a swim bladder enables teleosts to hover perfectly still in water, with no need to continuously swim to maintain buoyancy. These animals are also capable of breathing while remaining motionless, which also constitutes a significant advantage during transport. It is doubtful that an elasmobranch would tolerate similar conditions, but these seem adequate for a teleost, specifically *A. regius*.

Both pH and ammonia reached values usually considered as not ideal (i.e. 7.45 and 3.0 mg/l, respectively). However, the frequent addition of 100 g of sodium bicarbonate and one 50% water change were sufficient to maintain these parameters below critical levels and none of the animals displayed any external indication of stress.

Ocean Sunfish are an interesting species because, being a teleost, they exhibit all the traits commonly associated with these animals, such as remaining practically motionless in transit. However, they are regarded as delicate creatures and that is the reason why AmQuel® was considered indispensable during the trip, which was scheduled, from the beginning, to last up to 36 hr. In addition, both *M. mobular* and *A. regius* benefited from the fact that travelling by road allows for constant filtration and oxygenation to be in place; on the other hand, travel by air, precludes these two. It was therefore necessary to ensure that pH and ammonia were maintained within an appropriate range during the 15 hr leg where filtration and oxygenation were not available. The addition of AmQuel® coupled with pH-buffering agents was, more than likely, the reason behind the success of this trip, which would have, most likely, been fatal without them.

In conclusion, different types of animals exhibit different tolerances to transport conditions and these need to be addressed with care. Elasmobranchs generically require ample space to swim and optimal water quality, whereas teleosts exhibit a relatively higher degree of tolerance to both these factors. Nevertheless, waste removal, oxygenation and buffering remain as the three most predominant factors that need addressing while moving marine animals.

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