Post-harvest mortality in the marine aquarium trade: A case study of an Indonesian export facility[1]

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Introduction

The use of destructive harvesting methods, the collection of unsuitable species, poor handling and husbandry practices, and the potential for overexploitation have raised concerns about the marine aquarium trade over the last decade (Barber and Pratt 1997; Johannes and Riepen 1995; Jones 1997; Sadovy 2002; Wood 2001). Most of these concerns are directly or indirectly related to high post-harvest mortality. The reduction of post-harvest mortality therefore plays a central role in the management of the trade. Because tropical fish are transported great distances to overseas destinations, and because many people are involved in their processing, there are a number of possible causes of post-harvest mortality. The reasons may be summarised as follows:

- Physical damage and use of cyanide during the catch, resulting in a higher risk of bacterial and parasitic infections and delayed mortalities (Hanawa et al. 1998).
- Poor handling, leading to stress and, thus, to a decreased resistance to continually present pathogens and diseases (Rottmann et al. 1992; Grutter and Pankhurst 2000).
- Inferior water quality during transport and in the tanks.
- Collection of species or juveniles that are almost impossible to maintain in aquaria.

There is a strong interest, motivated by sound economic and conservational reasons, in avoiding post-harvest mortalities. Every dying fish means a financial loss and a waste of fishing effort, as the fish needs to be replaced to fill the orders, thereby placing extra pressure on natural resources.

Although considerable action has already been taken to fight these problems, the management of the marine aquarium trade faces a lack of reliable data on post-harvest mortality (Holthus 1999; MAC 2001). Because of differences resulting from variations in product treatment around the world, it is nearly impossible to generalize globally about the level of post-harvest mortality that is typical in the trade.

Indonesia, a centre of global coral reef biodiversity, is a focus of the marine aquarium trade and the world's largest exporter of reef ornamentals. In order to provide information on the cause of post-harvest mortality, and to identify possible solutions to reduce mortality rates, post-harvest mortalities of marine ornamental fish were assessed in several deliveries made to and processed in an export facility in Indonesia over a six-month period.

Methods

The study was carried out in a single export enterprise that consists of numerous branch stations all over Indonesia, with three on Bali. Fish from middlemen and fishermen arrive at the branch stations, where they are unpacked, acclimatized and repacked. At the Goris branch station in northwestern Bali where this study was carried out, one fish supplier is a middleman located on Madura, who transports the fish by boat, landing at a nearby beach. This middleman buys fish from local fishermen on Madura who spend several days to weeks capturing the fish. Thus, the fish can be from regions such as Sulawesi or even the Philippines, and they may spend several days stored in plastic bags on board fishermen's boats, often exposed to direct sunlight, without sufficient oxygen and with only partial water changes. Before being transported to the Goris branch station, the fish spend at least one day at the middleman's facility on Madura. After the export company places an order, the fish are packed and brought to the branch station. During the deliveries observed in this study, transport time from Madura to the Goris branch station varied from 11 to 14 hours.

Other sources of fish for the Goris branch station are local middlemen and fishermen. In these cases, transport times are significantly shorter (1.5–2 hours) than for the Madura-based middleman. In the single observed delivery made by a local middleman, the middleman did not store the fish for several days before transporting them to the branch station, as was typical for the Madura-based middleman. The local middleman repacked the fish with a partial water exchange and refilled the oxygen before making the delivery by truck to

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the branch station. Only dead fish were culled before transport to the exporter. Local fishermen transport their catch by moped to the branch station. In their deliveries, dead and injured fish are included. On arrival, the staff of the branch station controls the quality of the fish, and dead and injured fish are culled.

Injured fish are returned to the fishermen, or in the case of Madura, they are stored in separate tanks at the branch station in the hope of recovery. After acclimatization and repacking, the fish are transported by truck (3–4 hours) to the company's central station in Denpasar. Here the fish are acclimatized once again and kept in holding tanks until export — via Thailand and Singapore — to Europe and the United States.

In the course of this work, we observed the fishes' condition at each stage of processing, starting from the point at which they entered the branch station, up to the point they were exported from the central station. We followed and observed six deliveries of fish that were made to the Goris branch station and subsequently sent on to the central export station. Normally one delivery investigation took about 10 days, most of it consisting of the time the fish spent in the stock system at the central station (see Table 1). The six deliveries included a total of 2576 fish of 120 species — all finfish.

In this article, the six deliveries are named after the origin of the fish, followed by the transport time, in hours (h), from the place of origin to the branch station. They are listed below in the order they occurred.

Information was collected on numbers of fish dead on arrival (DOA), dead after arrival (DAA), and injured, as well as on the types of equipment used in the facilities, water quality (based on standardised tests) and handling, with the objective of examining possible stress factors causing mortality. DOA refers to every fish arriving dead or dying at the point the bags were opened at the branch station, whereas DAA refers to fish that die during the two acclimatisation periods and the stay in the holding, or stock, system until the point of packing for export. The term "losses" is used to refer to the sum of DOA, DAA, and fish injured to the point of being unmarketable. Observations of mortality and injury were recorded at the species level and apparent reasons for mortality were noted. The three most abundant species in terms of delivered numbers in total were *Chrysiptera parasema*, *Chelmon rostratus* and *Amphiprion clarkia*. Most abundant in terms of frequency during the six deliveries were *Chelmon rostratus* and *Zebrasoma veliferum*.

As additional background information, the management of the export company reported that it believes about 80% of the delivered fish are caught using cyanide, even though this is prohibited by law in Indonesia.

Results

Equipment and handling methods in the export facility

It was observed that the equipment and handling methods used in the facility were quite advanced. Possible negative effects of the equipment and the

Delivery	Origin
"Madura 13 h"	from company intern middleman on Madura
"Madura 14 h"	from company intern middleman on Madura
"Middleman 1.5 h"	from local middleman with fish from South Sulawesi
"Fisherman 2 h"	from local fisherman in Goris
"Madura 11 h"	from company intern middleman on Madura
"Madura 12h"	from company intern middleman on Madura

Table 1. The different processing stages at the export company and the timing for each of the six observed deliveries

Delivery	Branch Station					Central Station			
	Arrival	Un-packing	Acclimat-isation	Packing	Depar-ture	Arrival	Un-packing	Acclimat-isation	Days in stock system
Madura 11h	12.20	13.40	14.00–10.30	10.30	3.00	6.15	16.16	16.30–8.00	7
Madura 12h	11.00	11.15	11.30–17.30	17.30	3.30	6.30	8.30	8.45–13.00	7
Madura 13h	10.10	10.15	10.15–16.00	16.00	3.00	6.00	17.40	17.50–14.30	9
Madura 14h	11.40	14.00	14.00–13.00	13.00	3.00	7.30	8.45	8.50–13.40	7
Middleman 1.5h	9.30	11.15	11.15–10.30	10.30	3.30	7.00	10.50	11.00–14.30	8
Fisherman 2h	9.00	11.15	11.30–17.10	17.00	4.00	8.00	15.00	15.00–11.00	12

fish handling methods with respect to mortalities are noted in the following discussion.

Post-harvest mortalities

Total losses varied from 24–51%, by number, among the six deliveries, with mortality rates running between 10–40%. Injured fish made up a considerable part of the losses (Fig. 1).

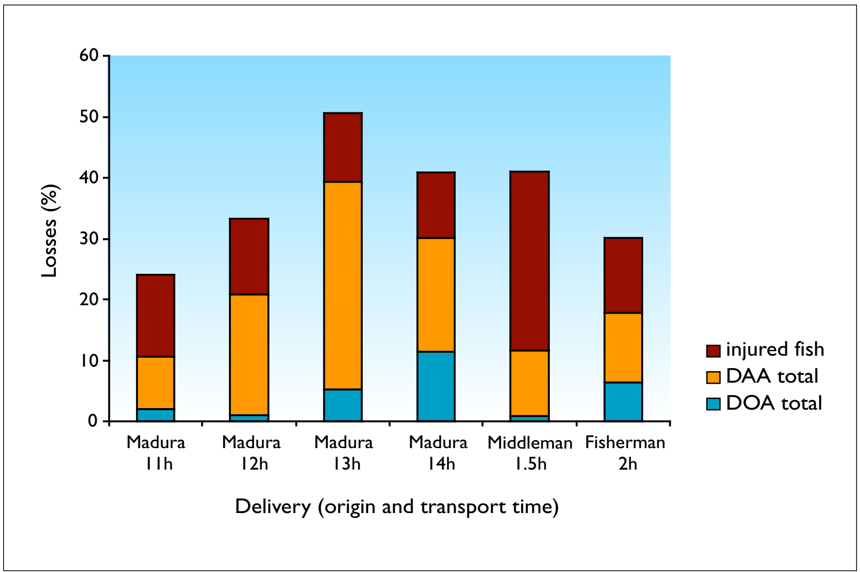

Figure 1. Losses of fish in each of the six deliveries, in percentage of the number of fish delivered to the branch station.[4]

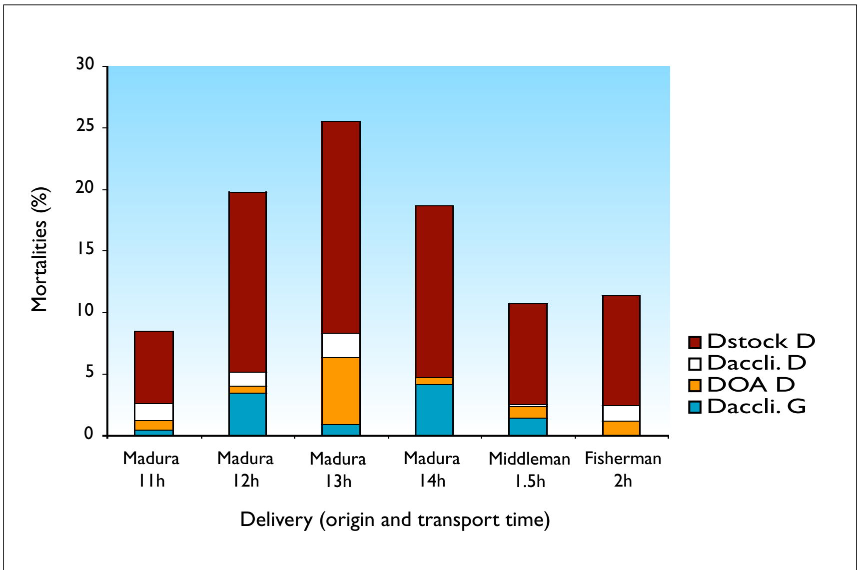

Figure 2. Mortalities at four processing steps after arrival (DAA), in percentage of the number of fish delivered to the branch station.

Considering only the four deliveries from the middleman on Madura, a statistically significant correlation between transport time and DOA was found (r = 0.84). When taking all six deliveries into account, the correlation coefficient, r, dropped to a value of 0.43, which was not statistically significant. This indicates that transport time was not the only factor influencing DOA. Treatment and handling of fish in the period from catch to arrival at the branch station played an important role too. In all Madura deliveries, treatment and handling were presumed to be similar, which is reflected in the strong influence of transport time alone on DOA. The relatively high number (given the short transport time) of DOA in the middleman and fisherman deliveries can be explained by the influence of even more stressful treatment and handling.

Most of the losses in four of the six deliveries were DAA (Fig. 1). DAA amounted to 68% of the total losses in the case of the Madura 13h delivery. The causes of mortality are reviewed by first examining the processing steps during which fish died. Figure 2 breaks down the DAA into four different processing steps. Mortalities occurred during the first acclimatisation in the Goris branch station (Daccli G), on arrival after transport to the central station in Denpasar (DOAD), during the acclimatisation in the central station Denpasar (Daccli D), and finally, during the stay in the stock system at the central station (Dstock D), which made up the largest part of DAA. Table 2 indicates the main causes of mortality in the stock system. Diseases caused by bacteria and parasites were the most prevalent causes.

A connection between cause of mortality and time of death was observed. The longer the duration of stay in the stock system, the stronger the influence of disease-causing bacteria and para-

4. Please note that in the Madura 13h delivery, mortalities occurring during packing at the branch station are excluded from Figure 2 while included in DAA in Figure 1.

sites. This explains the peaks of mortality that were frequently observed to occur after five to six days.

Mortality rates proved to be highly species dependent, but the species composition and numbers of fish varied widely among the deliveries, so it was difficult to rigorously identify differences in mortality rates among species. Generally, it was obvious that species not only differed in their mortality rates, but also in the processing steps at which mortality tended to occur. By application of a Chi Square test a significant correlation among species between processing step and mortality was found (Pearson chi square: 192.054; $p<0.001$). Some species died mainly during transport (*Chrysiptera parasema, Cromileptes altivelis, Ecsenius bicolor, Euxiphipops sexstriatus, Siganus vulpinus, Symphorichthys spilurus*). Others survived transport and died in the holding system (*Amphiprion sandaracinos, A. clarkii, Doryramphus dactyliophorus, Labroides bicolor, Labroides rubrolabiatus, Premnas biaculeatus, Pterois antennata*). A significant difference between these two treatments in the numbers of deaths they caused was found (Pearson chi square: 87,519; $p<0.001$). Fish of the subfamily *Amphiprioninae* started dying after four days in the stock system, caused by a *Brooklynella hostilis* infection that spread rapidly to almost all individuals in the subfamily. The cause of mortality in the majority of fish from other species was bacterial infection.

Table 2. **Causes of mortality in the stock system (percent of total).**[5]

Delivery	Disease parasites	Disease bacteria	Other
Madura 11h	27.3	68.2	4.5
Madura 12h	30.8	57.7	11.5
Madura 13h	27.3	22.7	50.0
Madura 14h	16.7	50.0	33.3
Middleman 1.5h	24.3	10.8	64.9
Fisherman 2h	72.7	13.6	13.6

Water quality

Water quality parameters are presented in the same sequence as they were measured for each delivery. Differences in water quality among tanks or transport bags for a given delivery are reflected in the range of measurements presented, which are, in all cases, the lowest and highest values measured. Tables 3 through 8 present the values measured for each delivery as the deliveries moved through the

Table 3. **Water quality parameters in the transport bags at the Goris branch station (random sample of ten bags of each of the three most abundant species in each delivery).**

Delivery	Salinity (‰)	Dissolved oxygen (mg L^{-1})	pH	Temperature (°C)	Ammonium (mg L^{-1})	Ammonia (mg L^{-1})	Nitrite (mg L^{-1})
Madura 11h	32.3–32.7	12.1–14.7	6.95 –7.25	29.2–29.4	4.0–8.0	0.05	0.15–0.25
Madura 12h	32.8–33.3	10.4–13.8	6.93–7.28	28.9–29.2	4.0–7.0	0.03–0.08	0.10–0.25
Madura 13h	33.3–36.5	6.98–8.60	7.13–7.42	29.1–29.3	1.0–10.0	0.01–0.19	0.10–1.00
Madura 14h	34.5–34.7	8.31–13.49	6.71–6.75	30.6–30.7	10–>10.0	0.04–0.05	0.05–0.15
Middleman 1.5h	34.1–34.3	16.01–18.61	7.01–7.36	26.3–26.9	2.5–4.0	0.02–0.04	0.00
Fisherman 2h	32.3–33.3	13.0–14.17	6.91–7.13	29.0–29.5	6.0–7.0	0.04–0.10	0.05–0.25

Table 4. **Water quality parameters in the two acclimatisation tanks at the Goris branch station**

Delivery	Salinity (‰)	Dissolved oxygen (mg L^{-1})	pH	Temperature (°C)	Ammonium (mg L^{-1})	Ammonia (mg L^{-1})	Nitrite (mg L^{-1})
Madura 11h	33.3	6.28–6.34	7.84	27.9	0.25	0.050	0.00
Madura 12h	34.3	6.08–6.20	7.16	27.6	0.00	0.010	0.01
Madura 13h	33.9	6.09–6.30	7.84	27.8	0–0.1	0.010	0.01
Madura 14h	36.2	6.26–6.32	8.13	27.6	0.25	0.050	0.02
Middleman 1.5h	36.4	6.42–6.47	8.02	26.0	0.20	0.050	0.01
Fisherman 2h	37.6	6.85	6.91	29.3	0.20	0.025	0.00

5. The "other" category indicates unidentified causes, which probably include poisoning by cyanide during the catch and its after-effects, or poisoning by copper, which is used for parasite prevention in the stock system.

facility, starting from the time they arrived in transport bags at the Goris branch station (Table 3) up to the point they were in the stock system in the Denpasar central station (Table 8).

In the transport bags at the branch station (Table 3), the deliveries showed great differences in the water quality parameters. Salinity and temperature in the transport bags of one delivery varied slightly by species, whereas dissolved oxygen, pH, ammonium and nitrite values showed larger variations by species.

In the acclimatisation tanks at the branch station (Table 4), all parameters, apart from dissolved oxygen, had the same values in the two tanks. Dissolved oxygen differed between the two tanks, depending on number of fish and species. Values of pH depended on the time of measurement as the pH changes during the process of acclimatisation (gradually increasing with time).

In the packing water at the branch station (Table 5), salinity differed only slightly among the deliveries; the lower salinities in the deliveries "Madura 11h" and "Madura 12h" were a consequence of a change in handling practices. These were the last two deliveries that were investigated, and they were done so after the management of the facility made a change in its water treatment instructions to its staff. Temperatures were strongly correlated with the climate in the vicinity, as packing water was taken out of an underground reservoir and put in plastic boxes before packing. The especially low pH value in the "Madura 13h" delivery is notable. Ammonium and nitrite were not detected in any of the deliveries.

In the transport bags arriving at the central station (Table 6), salinity and temperature showed similar values among species of one delivery. Dissolved oxygen, pH, ammonium and nitrite values differed considerably by species.

In the acclimatisation tanks at the central station (Table 7), salinity was quite similar among the deliveries; only the "Madura 13h" and "Fisherman 2h" deliveries had different values. In general salinity was low. Dissolved oxygen and pH values are dependent on the time of measurement, as oxygen is supplied during acclimatisation, so dissolved oxygen and pH can be expected to increase over time.

In the stock system at the central station (Table 8), salinity, temperature, pH, ammonium and nitrite were measured repeatedly over the length of the stay there, and at any given time, all these parameters had similar values at the point of the measurement in all six tanks that were used for holding the fish in a given delivery. Ammonium and nitrite were only measured once a week, but all other parameters were measured daily during the length of stay. Variations in the values were found from day to day

Table 5. **Packing water quality parameters at the Goris branch station.**

Delivery	Salinity (‰)	Dissolved oxygen (mg L^{-1})	pH	Temperature (°C)	Ammonium (mg L^{-1})	Ammonia (mg L^{-1})	Nitrite (mg L^{-1})
Madura 11h	29.2	6.07	8.46	27.5	0	0	0
Madura 12h	29.2	6.14	8.42	27.3	0	0	0
Madura 13h	34.2	6.28	8.05	28.6	0	0	0
Madura 14h	34.1	6.24	8.26	30.1	0	0	0
Middleman 1.5h	34.3	6.59	8.35	26.7	0	0	0
Fisherman 2h	33.8	6.55	8.28	27.9	0	0	0

Table 6. **Water quality parameters in the transport bags at the central station.**

Delivery	Salinity (‰)	Dissolved oxygen (mg L^{-1})	pH	Temperature (°C)	Ammonium (mg L^{-1})	Ammonia (mg L^{-1})	Nitrite (mg L^{-1})
Madura 11h	29.1–29.2	9.32–11.25	7.09–7.44	26.7–27.1	0–0.2	0	0–0.01
Madura 12h	29.0–29.2	9.30–11.40	7.06–7.56	26.9–27.4	0–0.1	0	0–0.01
Madura 13h	34.1–34.7	11.41–13.04	7.51–7.64	27.7–27.9	0–0.5	0–0.01	0
Madura 14h	34.4	11.40–14.40	6.34–7.24	28.7–28.9	0–4.0	0–0.03	0–0.05
Middleman 1.5h	34.0–34.3	13.72–15.42	7.05–7.43	27.6–27.7	0.25–0.9	0–0.01	0–0.025
Fisherman 2h	no data	no data	no data	no data	no data	no data	no data

Table 7. Water quality parameters in the acclimatisation tanks at the central station.

Delivery	Salinity (‰)	Dissolved oxygen (mg L^{-1})	pH	Temperature (°C)	Ammonium (mg L^{-1})	Ammonia (mg L^{-1})	Nitrite (mg L^{-1})
Madura 11h	25.3	5.57–6.19	8.28	25.5	0.2	0.02	0.02
Madura 12h	25.2	5.80–6.23	8.24	25.7	0.1	0.01	0.01
Madura 13h	28.2	5.73–6.31	8.16	27.5	0–0.2	0–0.02	0–0.02
Madura 14h	25.5	5.74–6.09	8.02	29.7	0	0	0
Middleman 1.5h	25.2	5.80–6.47	8.14	27.8	0.25	0.02	0.05
Fisherman 2h	26.1	6.50–6.62	8.27	26.8	0.1–0.2	0.01–0.02	1–0.025

Table 8. Water quality parameters in the stock system at the central station. Ranges present the lowest and highest values measured in all six holding tanks over the length of stay.

Delivery	Salinity (‰)	Dissolved oxygen (mg L^{-1})	pH	Temperature (°C)	Ammonium (mg L^{-1})	Ammonia (mg L^{-1})	Nitrite (mg L^{-1})
Madura 11h	26.1–26.5	5.42–6.77	8.30–8.44	26.6–28.3	0	0	0
Madura 12h	26.2–26.7	5.78–6.68	8.29–8.42	26.5–28.2	0	0	0
Madura 13h	27.4–28.1	5.98–6.57	8.15–8.27	27.0–29.0	0	0	0
Madura 14h	26.8–27.9	6.05–6.41	8.25–8.44	26.8–28.1	0	0	0
Middleman 1.5h	26.3–26.7	5.72–6.55	8.36–8.44	27.1–28.2	0	0	0
Fisherman 2h	26.0–26.2	5.94–6.49	8.41–8.47	27.1–28.4	0	0	0

and also among the deliveries. The largest differences, reflected in the ranges shown in Table 7, were 1.1 parts per thousand (‰) for salinity, 1.35 mg L^{-1} for dissolved oxygen, 0.19 for pH and 2.0°C for temperature. Temperatures changed by as much as 0.6°C during the course of a day. Concentrations of dissolved oxygen varied from tank to tank, from day to day and also among the deliveries. The values depended on the tank contents (number and species of fish) and on temperature.

Discussion

Some initial comments

The main objectives of this study were to estimate post-harvest mortality rates at different steps of processing, and examine the causes of the mortalities at the export facility. It was hypothesized that stress caused by treatment and handling was the fundamental cause of mortality. Stress was defined by Barton and Iwama (1991) as a state of reduced fitness. A stress-producing factor (stressor) leads to a change in the biological state of an organism, which can, especially if the stressor is chronic, strain the organism's adaptability, and ultimately result in its death. Different stressors and the resulting stress responses together have strong cumulative impacts on the fish, even though the single influences may be weak. Mortalities arise at each step of processing. They are related not only to the direct stressors acting at each step, but also to the stressors that affected the fish up to that point. Mortalities also depend on the resistance of the individual fish to stress.

Losses and mortalities in general

Looking at Figure 1, it is apparent that total losses differed considerably among deliveries, varying from 24–51%. Total mortalities (DOA and DAA together) ranged from 11–40%. This range is lower than the 30–40% mortality rates given by Vallejo (1997) for holding facilities in the Philippines, especially considering that four out of the six figures are within a range of 11–21%.

A closer look at the contributions of each of the three categories of losses (DOA, DAA and injured fish) shows that injured fish were a considerable part of the total losses (25–76% of the total, Fig. 1). The treatment of fish during transport to the branch station was observed to be rough (e.g. in the case of the deliveries from Madura, the bags were thrown on the beach where they lay unprotected in the sun). Mechanical influences while packing and transport can also injure fish. Although not specifically studied here, it seems clear that the handling and treatment of fish by workers in the export facility were more advanced than by the middlemen. Differences in the quality of treatment between the branch station and central station were observed as well. In the central station, handling was under the constant control of facility managers and guidelines were followed by the employees. In contrast, the quality of handling in the branch station seemed to fluctuate depending on the time and attitudes of the employees.

Dead on arrival

The percentage of DOA, which was influenced by the quality of the packing water, holding conditions before transport, handling during packing, and the duration of transport, ranged from 0.8–11%. The low value of 0.8% in the "Middleman 1.5h" delivery can be explained by the short transport time together with the fact that dead fish were culled from the delivery by the middlemen prior to their transport to the branch station. The high value of 11% in the "Madura 14h" delivery can be explained by the order of the Madura deliveries. "Madura 14h" was the second delivery observed. The authors' observations of the high numbers of DOA and generally poor condition of the surviving fish were passed on to the management, which resulted in the management passing instructions regarding quality control, handling and packing to the middleman on Madura. In the next observed deliveries by this middleman, the condition of fish on arrival was better and the number of DOA dropped considerably.

The negative influence of a long transport period can be compensated by better treatment and handling of the fish. But the catching method also has to be considered.

This leads us to an examination of the water quality in the transport bags arriving at the branch station (Table 3). The measured parameters can be compared to optimum and acceptable ranges for coral reef fish in aquaria given by Baensch and Debelius (1997) (the ranges given as "acceptable" refer to short periods only; they indicate conditions that are not acutely toxic):

- Salinity: 30.3–32.7‰ at 25°C
- Dissolved oxygen: 6–7 mg L^{-1}
- pH: 8.1–8.3 (optimum); 7.9–8.5 (acceptable)
- Temperature: 25°C (optimum); 22–28°C (acceptable)
- Ammonium: 0 mg L^{-1} (optimum); 0.01–0.05 mg L^{-1} (acceptable)
- Ammonia: 0 mg L^{-1} (optimum); up to 0.01 mg L^{-1} (acceptable)
- Nitrite: 0 mg L^{-1} (optimum); up to 0.05 mg L^{-1} (acceptable)

When comparing the parameters measured in the transport bags arriving at the branch station to these ranges, most of them did not fit into the acceptable ranges.

The dissolved oxygen values exceeded the acceptable range. The high concentrations can be explained by the use of pure oxygen for filling the transport bags, which can result in supersaturation up to 277%. Supersaturation can be harmful to fish and lead to gas bubble disease (Bassleer 2000), although this was not observed in this study. Oxygen concentration, together with pH, ammonium, ammonia and nitrite, is also a species-dependent parameter. The pH in all the transport bags in all the deliveries was lower than the acceptable range. In the transport bags water is polluted by faeces and exhaled carbon dioxide, so the pH can drop to undesirable levels over time. But since this is a long-term process the fish can adapt to the pollution and low pH level and can cope with it. Actually the low pH acts like a life insurance for the fish, as at this level most of the end products of protein metabolism are present in the form of ammonium, which is less toxic to fish than ammonia, to which ammonium is converted at higher pH levels. But at the measured pH levels, ammonium — and therefore also ammonia — concentrations are high and outside the acceptable ranges. The survival of the fish in the observed deliveries can be explained by the short period of influence of these high concentrations. But the relatively high ammonia concentrations were probably a factor that influenced the number of DOA. The same is true for nitrite. Another effect of ammonia is that at low levels it acts as a strong irritant, leading to skin and gill hyperplasia. Gill hyperplasia results in respiratory problems and creates ideal conditions for opportunistic bacteria and parasites to proliferate (FishDoc 2003). Mortalities related to these problems can also occur later in the chain of processing.

Dead after arrival

Most losses were DAA. The percentages of DAA among the deliveries varied from 8.5–34%. The total DAA was broken down into four different mortality rates related to different processing and treatment steps during the stay in the export facility (Fig. 2).

Death during acclimatisation in the branch station

Mortality rates ranged from 0–4% during this step (Fig. 2). Among the water quality parameters measured in the acclimatisation tanks, ammonium and ammonia appear to be plausible causal factors. Both parameters depend on the species composition and stocking density in the tanks. If tanks are overstocked, ammonium and consequently ammonia accumulate in the tanks and influence the number of deaths during acclimatisation. The especially high mortality rate during acclimatisation of the "Madura 12h" delivery probably cannot be explained by water quality or treatment alone. The authors believe that the number of deaths during the acclimatisation process is largely influenced by the treatment the fish receive during transport and unpacking prior to the acclimatisation process.

Dead on arrival at the central station

Mortality rates at this stage ranged from 0.4–5.5% (Fig. 2). The latter value was observed in the "Madura 13h" delivery and was the result of problems during packing at the Goris branch station. The packing process was stopped when packed fish were dying. The fish were then unpacked and transferred to the acclimatisation system until later, when packing resumed.

In all deliveries but "Madura 13h", the mortality rate was no greater than 1.2%, a relatively small percentage. Although no correlation between the duration of stay in the bags and the number of deaths was found, this seemed to be the commanding negative influence on survival at this stage. Obviously, handling during packing played a role too, as it appeared to have led to the high mortality rate in the "Madura 13h" delivery. Generally we assumed that the stress caused by transport and treatment before arrival at the central station influenced survival at the subsequent stages of processing. Iversen et al. (1998) found that stress from catch and transport of Atlantic salmon resulted in longer times needed to recover — more than 48 hours in some cases. Carmichael (1984) found even longer recovery periods — 96 hours — for *Micropterus salmoides* (largemouth bass, a freshwater species), where the corticosteroid level was elevated in response to the influence of stressors. Although those investigations were made on temperate species, the observations seem to be similar to the stress responses found in coral reef fish. For example, Grutter and Pankhurst (2000) found elevated plasma cortisol levels in *Hemigymnus melapterus* (blackedge thicklip wrasse) as a response to capture and handling. The levels decreased only after 2.5 months of observation in the laboratory, but they still did not reach the levels measured in freshly captured fish. This kind of stress response suggests that wild fish may never acclimate completely to life in captivity.

Death during acclimatisation in the central station

Among the six deliveries, only 0–2% died during the acclimatisation process at the Denpasar central station, substantially less than the mortality rate incurred during the same process at the Goris branch station (Fig. 2). The reasons for the difference were the better equipment, arrangement of tanks and organization of work, and stricter control of handling in the central station. Although water quality in the acclimatisation tanks at the central station was poorer than the water quality found in the tanks at the branch station, the better handling of fish (including unpacking with caution and separating the fish by species to avoid interspecies competition before introducing them to the tanks) seemed to have resulted in lower mortality rates at this stage. It must also be kept in mind that at this point in the processing, the weakest fish had already died.

Death in the stock system at the central station

Most of the DAA died during their stay in the stock system (49–79% of total DAA). Mortalities at this stage accounted for 6–17% of total mortalities (Fig. 2). The highest rate, 17%, occurred in the "Madura 13h" delivery. This may be explained by the especially stressful processing of this delivery, as described above.

All the water quality parameters in the holding tanks, with the exception of salinity, were observed to lie generally with the acceptable ranges cited above. The same was true with respect to the acceptable ranges given in the Export Facilities Supplementary Guidance by the Marine Aquarium Council (2001), which has been written to assist exporters seeking to be certified:

- pH: 7.8–8.5
- free ammonia: up to 0.001 mg L^{-1}
- nitrite: up to 0.125 mg L^{-1}

Salinity was intentionally lowered in the stock system to a level of 26–27‰ for the purpose of parasite prevention — a common treatment recommended by aquarium experts (Bassleer 2000; Baensch and Debelius 1997). This treatment is a stress-causing factor, but since the period of the stay in the stock system is normally a week or less, it should not be a death-causing factor. Rather, its positive influence should outweigh its negative one.

Among the various causes of death observed in the stock system, it was found that bacterial and parasitic infections dominated (Table 2), and that their influence increased with the duration of the stay. Death by diseases caused by bacteria and parasites can be explained by the suppressed immune response of fish caused by chronically elevated cortisol levels induced by handling stress (Grutter and Pankhurst 2000). Fish that are already weakened by the influence of stressors and the resulting stress response cannot resist bacterial and parasitic infections (Barton and Iwama 1991). Even the daily freshwater baths typically given to fish in stock systems cannot prevent the spread of these diseases, but rather, may contribute as an additional stressor to the elevated cortisol levels. In general, it appears that no single factor, including water quality, was the primary death-causing factor for any of the species kept in the stock system. Rather, there were several stress-causing factors that resulted in cumulative adverse effects on the fish, ultimately overwhelming the resistance of the fish to diseases and death (Barton and Iwama 1991).

Conclusions and recommendations

It seems reasonable to conclude that the mortality rates observed in this study, ranging from 10–40%, were unacceptably high. These losses occurred despite the advanced equipment and handling used in the export facility. The high variability in mortalities and injuries among the six observed deliveries indicates that the quality of treatment and handling was quite variable, and suggests that improving consistency in treatment and handling could yield positive results. The large differences in the mortality rates of the first two deliveries from Madura compared to those that followed — after new handling instructions were given to the supplier — indicate that improved handling methods can reduce post-harvest mortality significantly. Clearly, stricter quality control for treatment (including water quality) and handling at the different stages of processing in the branch stations is necessary. The authors provided detailed recommendations to the company's management on possible improvements that could be made at each of the different processing stages.

Although the export company cannot directly control handling during fishing and transport to branch stations by outsiders, training suppliers would undoubtedly result in improvements and is greatly needed. Also urgently needed is a change in the way fish are captured, that is, a move from cyanide-caught to net-caught fish. Rubec et al. (2000) cite an importer of marine fish in the US who experienced a difference of 20% in mortality rates of cyanide-caught fish (greater than 30%) and net-caught fish (less than 10%) from the Philippines. This anecdote points to the reduced resistance to stress of cyanide-caught fish and shows that post-harvest mortality can be significantly lowered just by the use of proper catching methods. Fish that are exposed to cyanide during capture are even more susceptible to stress and show a reduced adaptability (Hanawa 1998). Diseases caused by bacteria and parasites play an important role, especially in the stock system. The findings in this study indicate that even slight improvements in treatment, water quality and handling would be acceptable.

Mortalities observed in this study proved to be highly species dependent. During all six deliveries, 120 species of fish were examined in total. Unfortunately none of the species occurred in all six deliveries and only two species were found in five of the six deliveries. Seven species occurred in four deliveries and twenty species occurred in three deliveries. Deliveries differed substantially in their species composition. The number of individual fish among deliveries also varied greatly, which complicated statistical analysis of species-dependent mortality. In any case, further research is urgently needed in order to identify species not suitable for handling and treatment in the chain of custody. It was observed in this study that the export company did not meet, for a large number of species, the standard for certification established by the Marine Aquarium Council on DOA and DAA (up to 1% each). It was noticed in the course of the study that species were being traded that are known by hobbyists to be difficult to maintain because they have specialised food requirements that are not readily available for home aquaria (e.g. coral polyps). This is consistent with the statement by Sadovy (2002) that 40% of traded species may not be suitable for the average aquarist.

Obviously, further incentives must be put in place in order to reduce mortality. This might be accomplished through the certification scheme being established by the Marine Aquarium Council (certified fish still make up only a small part of the trade). But in any case it will only succeed if buyers insist on better quality products, even if it comes at a higher price. For a business, the certification process requires significant investment, both in equipment and for the certification itself. The prospective benefits to the business of better sales and higher prices for certified products may or may not be sufficient to convince exporters to reduce mortality rates.

In developing countries such as Indonesia, a more detailed guide to assist businesses seeking certification is needed. It should include a step-by-step approach for all treatment and handling procedures, giving detailed instructions on how to meet the standards (such a guide is, in fact, already under development by the Marine Aquarium Council in Indonesia). A certification standard that has a slightly increased DOA and DAA allowance (5%) for a certain transitional period might be the right approach to win over companies for certification, at least in regions where fishing with cyanide is still common and difficult to control.

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