Predicting long-term survival of riverine Irrawaddy dolphins (*Orcaella brevirostris*) in East Kalimantan using population viability analysis

Saving two to three individuals of a mean number of 5 dead dolphins per year may prevent the extinction of the *pesut* in the Mahakam River with a maximum probability of 76% and 97%, respectively.
Chapter 12

ABSTRACT

Population viability analysis was applied to a small, isolated population of Irrawaddy dolphins, *Orcaella brevirostris*, in the Mahakam River in East Kalimantan, Indonesia. Simulations of population survival were performed using the individual-based VORTEX program for initial population sizes of \( N = 55 \) and \( N = 76 \). Besides, the impact of inbreeding, harvesting, catastrophes, varying carrying capacities, reductions in mortality and supplementation involving translocation of an isolated sub-population to the main population were modelled. Without any conservation action, the population only has a 1% to 4% chance of survival to the next century. The key to survival lies in mortality reductions: preventing the deaths of 2 individuals of a total of 5 dead dolphins per year may help to set this population back on the road to recovery and prevent the dolphins from extinction with a 50% to 75% probability, whereas saving 3 individuals yearly causes a survival probability of near 100%. Since 80% of deaths occur through gillnet-entanglement, conservation efforts should primarily focus on finding ways to prevent death through entanglement. Gillnet restrictions in certain confluence areas, increased frequency of checking nets, compensating fishermen for damaged nets in the process of releasing entangled dolphins may all make a significant contribution to the survival of Indonesia’s only freshwater dolphin population.

RINGKASAN

Analisa kelangsungan hidup populasi lumba-lumba Irrawaddy dilakukan dalam suatu kelompok kecil, terasing di Sungai Mahakam, Kalimantan Timur, Indonesia. Simulasi tentang kelangsungan hidup populasi telah dilakukan dengan menggunakan program VORTEX didasarkan pada individu dengan mengetahui ukuran populasi dari \( N=55 \) sampai \( N=76 \). Disamping itu, akibat dari perkawinan antar individu sedarah (inces), penangkapan, kerusakan parah pada lingkungan, kapasitas habitat yang berbeda-beda, penurunan tingkat kematian dan pembuatan model termasuk penambahan individu dengan pemindahan sub-populasi yang terasing ke dalam populasi utama. Tanpa adanya usaha pelestarian, populasi hanya mempunyai 1 % ke 4 % kemungkinan untuk dapat bertahan sampai abad mendatang. Kunci untuk mempertahankan hidup terletak pada pengurangan jumlah kematian : mencegah kematian dari 2 atau 3 individu setiap tahunnya akan membantu mengatur kembali populasi ke arah pemulihan dan mencegah lumba-lumba dari kepunahan dengan tingkat kemungkinan 50%-70 %, dimana penyelamatan 3 individu per tahun dapat membuat kemungkinan bertahan hidup mendekati 100%  Dikarenakan 80% kematian terjadi disebabkan oleh rengge atau jala, usaha pelestarian sebaiknya dititikberatkan pada pencarian cara agar mencegah kematian akibat terperangkap. Larangan pemakaian jala dibeburapa daerah tertentu, peningkatan frekuensi pemeriksaan jala, memberikan ganti rugi kepada nelayan yang mana mengalami kerugian akibat proses pembubusan lumba-lumba yang
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terperangkap kemungkinan dapat memberikan kontribusi yang nyata terhadap kelangsungan hidup satu-satunya populasi lumba-lumba air tawar Indonesia.

INTRODUCTION

Population viability analysis (Gilpin & Soulé, 1986; Schaffer, 1981, 1987) is widely used to provide estimates of the likelihood of extinction usually by either estimating the time to extinction, or the probability of extinction within a given period, typically 100 years. Although extinction is commonly believed to be inevitable for small, isolated populations due to demographic stochasticity, inbreeding depression, and catastrophic environmental and epizootic events (Soulé & Wilcox, 1980; Gilpin & Soulé, 1986; Lynch, 1996), this is not the expectation either from either the theory (Mills & Smouse, 1994; Frankham, 1995), or the empirical evidence. Many species have persisted for long periods at low population sizes (Haig et al., 1993) or have flourished from small founder populations (Van Aarde, 1979). However, greater problems may arise when a large population is suddenly reduced because most likely genetic and demographic processes interact so that as populations decline it becomes increasingly harder to bring about recovery (Gilpin & Soulé, 1986; Lynch et al., 1995).

The Irrawaddy dolphin is a “facultative” river dolphin species of which separate coastal and freshwater populations exist. The freshwater dolphin population in the Mahakam is one of three riverine populations of Irrawaddy dolphins, which also occur in the Mekong River in Vietnam, Laos, Cambodia, and the Ayeyarwady River in Myanmar (Stacey & Arnold, 1999). The Irrawaddy dolphin population in the Mahakam is the only one to be listed as ”critically endangered” on the IUCN Red List based on preliminary results of this study (Kreb, 2002), although preliminary research in the two other rivers indicate a similar critical situation as in the Mahakam (Smith et al., 2003). Irrawaddy dolphins are also patchily distributed in small populations in shallow, primarily estuarine, tropical and subtropical marine waters of the Indo-Pacific from northeastern India east to Malampaya Sound, Philippines (Dolar, et al., 2002) and south to northeastern Australia (Stacey & Arnold, 1999).

In order to take the right conservation measures for this population, which upper limit of size estimation only reached 76 individuals based on mark-recapture analysis of photo-identified individuals (Kreb, in press a), population viability analysis seems to be the way to proceed. Through this type of analysis one is forced to reflect on demographic parameters, identify gaps in the knowledge, consider how further data can be collected and understand the consequences of changes in parameter values, e.g. harvesting or changes in mortality rates (Akcakaya & Burgman, 1995). So, in order to study the effects of deterministic forces as well as demographic, environmental, and genetic stochastic (or random) events on the dynamics of a small, isolated population of Irrawaddy dolphins, *Orcaella brevirostris* in the Mahakam River in East Kalimantan, Indonesia, a population viability analysis was conducted (PVA) using the individual-based simulation program VORTEX (Lacey et al., 2003)
METHOD & ANALYSIS

Basics of the VORTEX model

Data on population dynamics of the freshwater Irrawaddy dolphin population were collected during 718 hours of observation in 13 different survey periods of dolphins in the Mahakam River between early 1999 and mid 2002. A detailed description of survey procedures related to abundance and population dynamics, are described in Kreb (2002; *in press* a; *in press* b). For the population viability analysis (PVA) version 9.21 of the VORTEX program was used (Lacey *et al.*, 2003). In VORTEX several scenarios can be set with their own population characteristics (see life table settings and scenarios), which can be simulated (I simulated each scenario 500 times) over a certain time period (I choose 100 years) to obtain information on the probability of extinction, mean deterministic and stochastic growth rates across all years of the simulation, mean population size (of the 500 simulations or "populations") of the surviving population at the end of the simulated time period, mean genetic diversity remaining in the extant populations, mean number of founder alleles remaining within extant populations, and the mean time of extinction. Vortex models demographic stochasticity by determining the occurrence of probabilistic events such as reproduction, sex determination, and death with a pseudo-random number generator.

Life table settings of the Mahakam population

Prior to running the Vortex simulations, I set the life table variables and definitions to comply with my population data set (see below) and for two different initial population sizes $N = 76$ (scenario 1) and $N = 55$ (scenario 2). The same settings of these scenarios are used for all other scenarios in which some changes were made in one of the variable values or definitions to look for the effects of these specific parameters on the probability of population survival while keeping the other variables constant (see scenarios). The abundance estimates above were chosen as the best and maximum estimated population sizes, respectively, based on the results of a Petersen’s mark-recapture analysis of photo-identified dorsal fins (Kreb, *in press* a). Estimates based on this analysis had the highest precision. These estimates excluded an isolated group of six dolphins, which is trapped between two rapid streams. The effects of translocation of this group of six individual dolphins on the population’s survival probability are also investigated in the VORTEX simulation (see below: Scenarios: Supplementation).

I entered the following values for each life-table variable and set the following definitions for basic scenarios 1 & 2:

*Scenario settings:* 1) number of iterations = 500 times, 2) simulation time = 100 years, 3) extinction definition = only one sex remains.
Species description and catastrophes: 1) no inbreeding depression, 2) set environmental concordance of reproduction and survival, representing the annual variation in the probabilities of reproduction and survival that arise from random variation in environmental conditions. The model is constrained such that that good years for reproduction are also good years for survival, which makes sense in the Mahakam River where fish abundance not only fluctuates seasonally but also annually, 3) no catastrophes;

Reproductive system: 1) polygamous reproduction system, which is based on this study (see chapter 9), 2) reproductive age for females and males is 9 years and 12 years, respectively. This is based on the fact that near adult size was reached in 6 years (Marsh et al., 1989), so that adult size and adult reproductive capabilities are hypothesized to occur at the age of 8 and giving birth at age nine at the earliest. Males are assumed to be physically mature at the same age (capable of producing sperm) but are only socially mature (capable of effectively competing for females) some years later (Connor et al., 2000), 3) maximum age of reproduction (defined in Vortex as reproductive until death) = 30 years of age based on Irrawaddy dolphins from northeastern Australia (Marsh et al., 1989), 4) maximum number of progeny in one “litter” is one, 5) sex ratio at birth = 50 % for cetaceans (Berta & Sumich, 1999), 6) no density dependent reproduction. Since it was found that males rove between different female core areas, it does not seem likely that difficulties in finding mates at low densities would apply.

Reproductive rates: 1) % adult females breeding in any year = 50 %, since Irrawaddy dolphins are fully weaned at two years of age (Marsh et al., 1989) and pregnancy may occur during the second year of lactation, resulting in births by one female with 2 years of interval minimally, 2) environmental variation in breeding (SD in yearly breeding) = 0 because of lack of data due to short-term character of study in which only information of newborns for two years is available, during which in both years a similar number of newborns was observed, 3) females breeding have a 100% chance to produce a maximum of 1 offspring after each pregnancy.

Mortality rates: 1) For \( N = 76 \): age 0-1 = 16% age1-2 = 0%; age 2-8 = 3% per yearly age class; age 9-30 = 12%. 2) For \( N = 55 \): age 0-1 = 16% age1-2 = 0%; age 2-8 = 5% per yearly age class; age 9-30 = 17%. For each class the standard deviation of rates were defined as 37%. Males and females were assumed to have equal rates since data on sex-specific deaths were incomplete. To calculate mortality rates, the average number of dead individuals per age class were divided by the number of individuals alive in each age class. Mortality was estimated from own observations and semi-structured interviews conducted during a preliminary survey in 1997 and during the surveys from February 1999 until August 2002. Mortality was traced back as far as 1995 and covered 7 years. Incomplete or untrustworthy accounts with missing locality, date, and traceable eyewitnesses were disregarded (14% of \( n = 44 \)). Only for neonates and calves (0-1 years of age), mortality rates were obtained from a life-table of an in-depth study of bottlenose dolphins, *Tursiops truncatus* (Stolen & Barlow, 2003) because only once in 7 years a still-birth of a neonate was reported, which is very likely
an under-estimate. Death of neonates may be more likely to remain undetected as their cause of death may be related to disease or birth complications, whereas death of calves (1-2 years of age) have a higher chance to be detected as their main cause of death may also just like juveniles and adults involve gillnet entanglement. Therefore, since no calves (1-2 years) have been reported, the number of deaths in this age class is assumed to be zero within this model.

The number of individuals alive in each age class was based on the average yearly composition of 15% newborns and calves (0-1 years), 10% calves (1-2 years), 25% juveniles (2-8 years) and 50% adults (9-30 years) found during three different extensive monitoring surveys, which covered the entire dolphin distribution area (see also population dynamics in Kreb, in press b). The average number of newborns during each of these surveys was only one individual, but since the total number of newborns (0-2 months of age) per year was recorded to be 6, this last total number was used for age class 0 to 1 years of age, when calculating the percentage of population composition. This population composition in percentage was maintained and multiplied with different initial population sizes. The standard deviation was calculated based on the mean of the total number of individuals, which minimally died yearly. Because the standard deviation was unknown for the mortality rates obtained from literature, a mean standard deviation of yearly rates was calculated combined for different age classes.

**Mate monopolization:** 50% of males are assumed in breeding pole based on polygamous breeding system (see also chapter 9). The actual % of breeding males are unknown.

**Initial population size:** for \( N = 76 \): specified age distribution in each yearly age class: age 0-1 = 6; age 1-2 = 4; age 2-6 = 2; age 6-26 = 1; age 26-30 = 0. For \( N = 55 \): age 0-1 = 4; age 1-2 = 3; age 2-3 = 2; age 3-22 = 1; age 22-30 = 0.

The age distribution was based on the percentage population composition for different age classes (described earlier for the mortality rates) multiplied with initial population size and divided with the number of years in each age class. Since only complete values were used in the analysis, in some of the last years of the adult age class a zero value was entered so that the initial population size was not exceeded.

**Carrying capacity:** \( K = 200 \); SD in \( K \) due to environmental variation = 20. In the VORTEX model if \( N \) exceeds \( K \), additional mortality is imposed across all age and sex classes in order to reduce the population back to its upper limit. A carrying capacity of 200 was chosen as it this was assumed to be applicable due to the limited remaining suitable habitat with sufficiently abundant fish resources. If dolphins are forced to move to secondary habitat (which they probably have to when \( N = 200 \)), this may result in decreased fecundity or survival resulting in a reduction in population numbers.
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Scenarios

Scenarios 1 and 2 represent future population survival of populations with initial population sizes of \(N = 55\) and \(N = 76\) with mean mortality rates of 5 individuals per year (mean number derived from Kreb, in press b). I investigated the impacts on population survival if mortality rates can be reduced yearly with one, two, or three individuals per year. Scenarios 3, 5, and 7 had initial population sizes of \(N = 76\) but annual mortality was reduced with one, two and three individuals, respectively. Likewise, scenarios 4, 6, and 8 had initial population sizes of \(N = 55\) and reduced annual mortality with one, two and three individuals, respectively. To test these scenarios with mortality reductions the values in the parameter mortality rates were changed as follows: mortality reductions of one, two or three individuals expressed in percentages of mean mortality of five individuals per year are 20%, 40% and 60%, respectively. These percentages were inversely multiplied with the mortality rates and standard deviation per age class of scenarios 1 and 2 in order to obtain the reduced mortality rates.

Default scenarios 1 and 2 also formed the basis for other alternative scenarios (which were not numbered but used descriptive terms mentioned further in the text) in which some changes were made in parameter values or definitions to look for the effects of these specific parameters on the probability of population survival while keeping the other variables constant. In this way, the effects of changes in inbreeding depression, catastrophic events, harvesting and supplementation were investigated. To investigate the impacts of inbreeding depression, the option inbreeding depression within the Species description and catastrophes was ticked and lethal equivalent were set to be 3.14 (the median of 40 mammalian populations surveyed by Ralls et al. 1988) with 50% of that due to lethal alleles. To investigate the impacts of catastrophes, two types of catastrophes that may realistically occur within the river dolphin population are simulated: The first is a catastrophe caused by pollution that may cause a reduction of 50% in breeding during catastrophic years and have no direct impact on survival. The second catastrophe is caused by sudden and extreme drought, which may cause entrapment in shallow areas and death of one group of mean group size \((n = 4)\) and also causes a decrease in direct population survival with 5% and 7% of \(N = 76\) and \(N = 55\), respectively. To investigate the impacts of habitat improvements, i.e. increasing the carrying capacity \(K\) on population survival for \(N = 76\) and \(N = 55\), different values for \(K\) were simulated between 250 and 500 individuals with increments of 50 individuals and with SDs = 10% of \(K\).

To investigate the impacts of harvest or live-captures on the population survival, section Harvest within VORTEX was ticked and the following harvest values were entered for \(N = 76\ & 55\), and for 1, 2, and 3 individuals reductions in mortality rates: harvest = 7 adult females and 2 adult males totalling 9 individuals as requested for live captures by local authorities. I also investigated the effects of a possible supplementation involving translocation of an isolated group of 6 dolphins (4 females and 2 males), which are trapped between two rapids since 1998 and which cannot
exchange with the main population. The effects of supplementation were analysed for 
\(N = 76 & 55\), and for 1 and 2 individuals reductions in mortality rates. The harvest 
values entered were: supplementation = 4 females and 2 males. In other scenarios I 
also simulated supplementation when taking place at later time events, after 10, 20, 30, 
40 or 50 years from now.

**RESULTS**

The outcomes produced by population viability analysis of scenarios with initial 
population sizes of \(N = 55\) or \(N = 76\) and with reductions of mortality of 0 to 3 
individuals per year for 100 years are presented in Table 1. Scenarios 1 and 2 with 
stable mean mortality rates of 5 individuals per year have a very high probability of 
extinction \((PE)\), i.e. 94% and 99% respectively, and the mean time to extinction is 
within two or three decades. Reductions in mortality of one individual per year are not 
sufficient as the probabilities of extinction are still 83% and 97% for initial population 
 sizes \(N = 76\) and \(N = 55\), respectively (scenarios 3 and 4). The probability of 
extinction decreases drastically with 70% and 51% for initial population sizes \(N = 76\) 
and \(N = 55\), respectively, and arrives at 24% and 48% after yearly reduction of 
mortality with 2 individuals (scenarios 5 and 6). Mortality reductions of 3 individuals 
per year result in a near 100% probability (96% and 97%) of survival for the next 100 
years (scenarios 7 and 8). Additionally, stochastic growth rates become positive only 
when mortality has been reduced with 2 individuals. Only for scenario 2 with initial 
population size \(N = 55\) and with no mortality reductions was the population in 
deterministic decline. Likewise, mean population sizes after 100 years only exceed 
their initial sizes when mortality has been reduced with 2 or 3 individuals yearly, i.e., 
scenarios 5 to 8 (Figure 1). Final genetic diversity and number of founder alleles 
remaining in the population increased steadily overall with increased reductions of 
mortality rates. The simulations of scenarios 1 to 8 show a high, final degree of genetic 
variation and indicates that the extent to which the population is inbred according to 
these models is low.

Simulations of alternative scenarios based on scenarios 1 and 2 but with assumed 
inbreeding depressions (which do not have scenario names) showed nearly similar 
probabilities of extinction as those without assumed inbreeding depressions with only 
2% or no differences in probabilities for \(N = 76\) and \(N = 55\), respectively. The 
impacts of habitat improvements as expressed in an increase in carrying capacity \(K\) 
with sustained population sizes between 200 and 500 individuals, did not have any 
impact on population survival probability for initial \(N = 76\) and \(N = 55\), respectively. 
Catastrophes in the form of one-time events have a far greater impact on the 
probability of extinction when they affect direct survival instead of rate of 
reproduction. To study the impact of catastrophes simulations were run of the 
scenarios in which mortality was reduced with 2 individuals and with probabilities of 
extinction of 0.24 and 0.48 of \(N = 55\) and 76 respectively, since probability of
Table 1. Population viability analysis outcomes for different initial population sizes and reductions in mortality as expressed in numbers of individuals.

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<td>REDUCE MORTAL (N)</td>
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extinction of the default scenarios 1 and 2, but also 3 and 4 were already too high to analyse the impacts of catastrophes. When the severity of the catastrophe was set at 5% reduction of population survival during one year (of 100 years in total), the probability of extinction increased with 50% and 36% for \(N = 76\) and \(N = 55\), respectively compared to a situation with no catastrophes. On the other hand, when severity of a catastrophe was set to reduce breeding by 50% in any given year, the probability of extinction was increased only with 6% and 5% for \(N = 76\) and \(N = 55\) compared to a situation without catastrophes.

The impacts on harvesting the population with the minimum number of animals (n = 9) requested by local authorities for live-display in an oceanarium (see chapter 6, threats) were applied to default scenarios 1 to 8. Three out of 8 default scenarios (scenarios 5, 7 and 8) had > 50% probability of survival when harvesting occurred. If no harvesting takes place, 4 out of 8 scenarios (scenarios 5 to 8) have >50% probability of survival. Also, survival probability of all scenarios was reduced with 5% on average (range = 1% - 15%). Moreover, in the small initial population size of \(N = 55\), genetic diversity decreased from 0.850 prior to recruitment to 0.0 after harvesting. A 4% reduction of gene diversity occurred at initial population size of \(N = 76\).

When investigating the impacts of supplementing the population (using default scenarios 1 to 6, because 7 and 8 already cause a 100% survival) with an isolated group of 6 individual dolphins, which is trapped between two rapid streams, it appears that translocation in this case does not make a significant contribution to the population’s survival: only 1% positive difference in survival probability was achieved (range = 1% - 3%). Small, positive increases in survival probabilities were found when this one-time supplementation event occurred at a later time period; a 13% increase of survival probability occurred when supplementation took place after 50 years.
Figure 1. Graph presenting mean population sizes through time for several scenarios corresponding with table 1. Mean population sizes are based on 500 simulations per scenario. Scenarios 1 to 4 have between 83% and 99% probability of extinction. In scenarios 1 and 2 no reductions in mortality occur, whereas in scenarios 3 and 4 mortality is reduced with one individual per year. In scenarios 5 and 6, and 7 and 8 mortality is reduced with 2 and 3 individuals yearly and with 3% and 48% probabilities of extinction within 100 years.

DISCUSSION

Population viability analysis has proven very useful in this case-study in determining conservation actions just as it has in other case-studies (Lindenmayer et al., 1993; Green et al. 1996). For example, by studying the impacts of harvesting and supplementation of the population, it is now clear that no live-captures should be allowed. In this study, results of a one-time harvesting event was already drastic in terms of decreased genetic variation and marked decline in survival probability, whereas it is very likely that captures will be repeated in the future to substitute
individuals that have died in captivity. The impacts of repeated captures will undoubtedly cause higher extinction probabilities. Also, the main key to survival is not relocation of an isolated sub-population to the main river dolphin population, but rather involves reducing direct mortality to a minimum of 2 to 3 individuals per year. The huge impact of these seemingly insignificant numbers (3% to 5% of total $N = 55$ and 76) were also found by Fujiwara and Casswell (2001) for North Atlantic right whales, *Eubalaena glacialis*, in that prevention of the deaths of 2 to 3 adult females yearly could save the population from extinction. Since 80% of deaths in this study were found to occur through gillnet entanglement (Kreb, *in press* b), it is essential to focus conservation efforts on ways to prevent these entanglements. In the years after the study had finished in 2002, meetings of fishermen were organized in several villages in primary dolphin habitat by a local NGO, RASI Conservation Foundation in cooperation with the Wildlife Conservation Department of East Kalimantan Province and the Fisheries Department, to provide information on more sustainable fishing techniques, to demonstrate theoretically how to release entangled dolphins, to ask for fishermen’s support to release entangled dolphins, and to refund their nets if damaged while in the process of releasing a dolphin. Also, in one major dolphin area where 60% of the population is thought to occur (see chapter 6), daily patrol is conducted by a locally employed fisherman to check for dangerously placed nets and to relocate these. Through frequent patrols, entangled dolphins may also be sooner detected and prevented from drowning. However, the best option would be to restrict use of gillnets inside important dolphin areas, such as some confluence areas, which are daily frequented by dolphins (Kreb, *in press* b).

Finally, some caution ought to be taken when drawing conclusions based on the simulations conducted because short-term or small data sets may produce very different results, i.e., extinction probabilities compared with a long-term data set (Brook & Kikkawa, 1998). Also, we found that inbreeding depression did not have a great impact on the population. However, in VORTEX inbreeding depression is defined as a reduction in the survival of offspring during the first year of life and likely underestimates its effect since it may also depress other components of fitness such as adult survival, fecundity, and/or success in competition for mates (Miller & Lacy, 2003). Nevertheless, although parameter values may not reflect actual values, the results of this simulation may help since they hint at the direction where an effort at conservation is most required and indicate which events determine the viability of the population.

REFERENCES


Kreb, D. (*in press b*) Conservation management of small core areas: key to survival of a critically endangered population of riverine Irrawaddy dolphins in Borneo. *Oryx*.


