UNIVERSITY OF PADUA

DEPARTMENT OF INDUSTRIAL ENGINEERING

Master Thesis in Environmental Engineering

BOTTLENOSE DOLPHINS IN THE NORTHERN ADRIATIC SEA:

A LONG-TERM ASSESSMENT OF THE POPULATION DYNAMICS

Supervisor: Luca Palmeri

Co-supervisor: Alberto Barausse

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And the man that has anything bountifully laughable about him,
be sure there is more in that man than you perhaps think for.

(Moby Dick or The Whale, Herman Melville)

Abstract

The northern Adriatic Sea is one of the most eutrophic and overfished basins in the Mediterranean sea. Bottlenose dolphins are among the few predators regularly present in the area. Their population is established to be in a vulnerable condition, threatened by habitat degradation, food depletion and unintentional catches by fisheries. The aim of this study is to determine which was the population of bottlenose dolphins present in the 1930s, considering that in these years culling campaigns were allowed and hundreds of dolphins were killed. This information is vital to define targets for conservation, such as stock rebuilding. The first part of the model consist of a Stochastic Stock Reduction Analysis represented by a logistic growth model reduction. This is structured on three parameters: the net growth rate, the carrying capacity and the time series of catches. Carrying capacity was assumed to be constant or, alternatively, I have modeled its changes over time based on the biomass variation of sardine, anchovy and hake, which all together compose the 53% of the dolphin diet. The time series of catches were consider to follow the data of the culling campaign until the 1960s, and for the next years to be linearly decreasing until a minimum value of 22 dolphins killed in the current years. The second part of the study used Bayesian methods based on the likelihood function. Starting from the observation of the current number of dolphins the methodology establishes which were the key parameters which reproduce the current population, and show the most plausible trajectory of population abundance over the past decades. The results of the analysis present different scenarios and the past bottlenose population (at carrying capacity) is established to be in a relatively narrow range of 4400 to 9000 individuals. Even if there are uncertainties in the model estimation, it is certain that fishing mortality has played the major role in the long-term decrease of this population in the northern Adriatic sea.

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Introduction

Monitoring cetacean populations is important for understanding the ecological changes occurring over time, including also the shifts in species composition of marine communities. Dolphins, as top predators of the marine food web, represent excellent biological indicators of the status of the environment they inhabit (Notarbartolo di Sciara, 2010). They live an average of 30 years so they are important bioaccumulators of manmade polluting substances (organochlorine compounds and heavy metals) that can affect reproduction and health (Bearzi et al., 2008). Given their size and relatively slow growth rate and late age at maturity, these cetaceans are vulnerable to fishing pressure and deliberate or accidental captures. Therefore, evaluating the status of the dolphin populations is extremely important and the decrease of a dolphin population represents a signal of a potentially excessive human pressure that should be carefully assessed. This study is focused on a long-term assessment of the population dynamic of bottlenose dolphins in the northern Adriatic sea. Starting from the 1930s culling campaigns burden on these mammals (Crnkovic, 1958). They were seen as vermins who damage fishermen during their operations. The government of Italy and Ex-Yugoslavia enhanced their killing with money awards so until the 1960s hundreds of dolphins were legally killed in the Adriatic. This is the first reason of their over-exploitation, considering that two species of dolphins (common and bottlenose) were reported to inhabit the Adriatic in these years but only bottlenose dolphins are still occurring. Only relatively recently, when the opinion towards them change and international agreements take place, dolphins became fully protected (Bearzi et al., 2004). Nowadays the main threats are prey depletion, by-catches in fishing gears and environmental pollution (Bearzi et al., 2008). Interactions between dolphins and fisheries are inevitable. As a characteristic of this species to be clearly opportunistic, they were frequently seen following vessels and trying to take advantage of the fishing activity, with the result that they risk to remain entrapped in the nets (Crnkovic, 1958). But also fisheries can impact indirectly on dolphins. Overfishing indeed influences the availability and distribution of their prey in the region and even if bottlenose dolphins are considered a catholic species their diet would be anyway impoverished (Bearzi et al., 2004).

This is also correlated with the changes in the northern Adriatic ecosystem. This semi-enclosed basin is characterized by an annual and seasonal variability of hydrological and biological variables and its local ecosystem is especially sensitive to seasonal and long-term variations of both climate and anthropogenic nutrient loads. It is considered the most exploited and eutrophic basin of the Mediterranean Sea, dominated by low trophic levels and a depletion of the top predators (Barausse et al., 2009). Therefore, taking in account these considerations in this study I try to estimate the population trajectories for the exploited bottlenose dolphins by means a Bayesian Stochastic Stock Reduction Analysis. The modeling approach is based on a simple production model which is the logistic growth model driven by the removal information based on historical catch time series (Stock Reduction Analysis). The SRA generates a single population trajectory conditional on the net production (r_{max}), the carrying capacity (K) and the independent process errors (w_t) (Christensen, 2006). In order to developed a model that best represent the state of the population, the carrying capacity was either considered constant, or calculated year by year using an innovative approach based on the dolphin diet. European hake(Merluccius merluccius) is established to be the main prey (0.44 of the total diet) followed by other demersal fishes and pelagics. So according with the data available I choose to keep the attention only on hake, anchovy and sardine, considering that they account for the 53% of the diet (Piroddi et al., 2010) . For each group were calculated first of all the total biomass and production, then the amount caught by fisheries and consumed by other species. Such amount was subtracted from the total produced biomass to, finally obtained, the biomass of the species available to the dolphins. The carrying capacity was then calculated by divided the available biomass by the dolphin consumption rate (Bearzi et al., 2010). Considering that the model is also based on the historical catch times series, I calculated it starting from the data available for the 1930s and 1960s (Bearzi et al., 2004). Because no reports regard killings or by-catches are available for all the years, after the 1960s I developed a linear temporal series which linked the minimum amount of the current by-catches with an average amount for the years after the culling campaign. Three possible scenarios were analyzed considering to double and triplicate the minimum catches. The second part and core of the study is to implement this data adopting a Bayesian point of view, considering at least one observed abundance level at a definite time. In this way with an inverse approach, using the likelihood function, it is possible to outline the hypothesis (the abundance level) which is consistent with the data (net production and carrying capacity) (Hilborn et al., 1997). Finally with an importance sampling procedure I can obtain a posterior probability density for the parameters of interest.

The results show that, although finding a clear, unique value for the bottlenose dolphin population in the 1930s is not possible, the number of individuals at that time was most probably in a range between 4400 to 9000. This uncertainty reflects that of the input data. First of all the time series of catches underestimates the real situation, considering that the records are partial or absent at all and still nowadays there is no a clear picture of the impact of the unintentional catches. So it is quite sure that more than 4000 mammals inhabited this region. Moreover the other two parameters of net growth rate and carrying capacity are inversely related and when the former decreases the latter increases. This brings to the consequence that if the bottlenose dolphin reproduce slowly, the carrying capacity in 1930 rises. The carrying capacity itself modeled following the diet of the bottlenose dolphin, has surely been influenced by other several factors (i.e. environmental processes). So an improvement of the determination of the input data can be a help for a better estimation of the population.

This study represents a first approach to the difficult issue of the population estimation of these mammals in the northern Adriatic. First of all uncertainties are at the base of the input data: the composition of the dolphin diet which varies not only in time but also in space, the dynamic biomass of pelagic and demersal fishes and also the fishing catches over the years. Indeed, it is difficult to follow in a correct way the variation of these parameters, thanks to the lack of observation data. Moreover the model used is simple one, for example it does not consider the impact of environmental pollution on the population. So improvements can be done in this field too. However, even if this is a simple and tentative study, its novel approach has contributed substantially to the important goal of demonstrating that the human impact on the dolphin population in the northern Adriatic sea has, as already hypothesized in the literature, kept in danger these mammals and depleted them by 40% to 70% in almost 90 years.

The Mediterranean Sea Bottlenose dolphin

The common bottlenose dolphin is one of the best-known specie of cetaceans, studied in numerous location around the world. Yet in the Mediterranean Sea relatively little is known about bottlenose dolphins, as modern cetacean field studies started only in the late 1980s.From a regional Red List workshop in March 2006 a first assessment of the status of the bottlenose dolphins in the region was done. According to the International Union of Conservation of Nature (IUCN) Red List criteria, the participants agreed that the Mediterranean “subpopulation” of bottlenose dolphins qualified as ‘Vulnerable’. For the bottlenose dolphin the criteria at the base for its Vulnerable category is: an observed, estimated, inferred or suspected population size reduction of ≥30% over the last 10 years or three generations, whichever is the longer, where the reduction or its causes may not have ceased or may not be understood or not be reversible (A2) (http://www.iucnredlist.org). Basically three are the main causes (Reeves et al. 2006):

- A2d: actual or potential levels of exploitation. In the northern portions of the Mediterranean basin, there is a well-known history of intentional killing, including extensive extermination campaigns conducted between 1930 to 1960 and there has been (and continues to be) substantial incidental mortality in fishing gear.
- A2c: a decline in area of occupancy, extent of occurrence and/or quality of habitat. There is a strong evidence that overfishing of dolphin prey has resulted in a form of habitat loss and degradation.
- A2e: the effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites. High levels of contamination by pollutants and disturbance by marine traffic, may be contributing to the decrease of the population.

Considering that the bottlenose dolphins occur mainly in coastal waters, they are regularly exposed to a wide variety of human activities. The main treats in recent times include:

1. Overfishing and environmental degradation caused a reduce availability of prey. This leads to a severe change in the ecosystem, causing a decline of many fish stocks such as demersal stocks which are the key bottlenose

dolphin prey. Nutritional stress may be a factor in the low density of bottlenose dolphins in several Mediterranean area.

2. Incidental mortality in fishing gear. In some Mediterranean areas occur frequently that bottlenose dolphins incidentally died in fishing gear (particularly trammel and set gillnets, but also drift gillnets). Bycatch in trawl nets appears to be relatively uncommon in most areas. However in the past years frequently happen that bottlenose dolphins were shot, harpooned or harassed by the coastal fisheries although because they were regarded as vermin and systematically persecuted (Crnkovic, 1958). Nowadays this approach is less frequent and along the Mediterranean coasts the attitudes towards dolphins vary greatly according to cultural, religious or other factors.
3. Toxic effects of xenobiotic chemicals. Contaminant levels, particularly of organochlorine compounds found in the Mediterranean waters are a concern due to their potential effects on reproduction and health. Compound such as PCBs have been associated with reproductive disorders and immune-system suppression in bottlenose dolphins from other populations.

In addition to these three main threats other potential pressures at local scale can influenced the already vulnerable bottlenose dolphin population: mass mortality, direct disturbance from boating activities, noise and climate changes. A mass mortality can be a consequence of the compromised immune-system induced by exposure to xenobiotics and/or by stress from poor nutrition so the risk of disease outbreaks in bottlenose dolphins in the Mediterranean may be considerable. Moreover a great expansion of recreational boat traffic and shipping has been observed in the recent decades but the potential for resultant behavioral disruption and habitat loss has been investigated only to a limited extent. For example in coastal waters of Croatia it was reported a permanent or temporary avoidance of bottlenose dolphins according with seasonal increase in boat traffic. Finally climate changes, i.e. global warming, have the potential to affect a range of biological processes and cause significant shifts in marine and other biota. Through direct actions on prey abundance and distribution, the effects of climate change act indirectly on cetaceans and they have become apparent in several non-Mediterranean areas and similar effects may be occurring in Mediterranean waters (http://www.iucnredlist.org).

Population distribution

Bottlenose dolphins are widely distributed throughout the Mediterranean Sea. They are not uniformly distributed , however, and in coastal waters they are characterized by patchy spatial patterns. Gaps with low densities that may be either natural or the result of anthropogenic effects. Total population size is unknown but may be in the low 10,000 based on observed densities in areas that have been surveyed (Reeves et al. 2006).

Bottlenose dolphins in the Mediterranean are commonly regarded as coastal/inshore animals. However, they are regularly found in deep waters near the continental slope in the Alboran and Balearic seas and in continental-shelf offshore waters of the Adriatic Sea and Tunisian plateau.

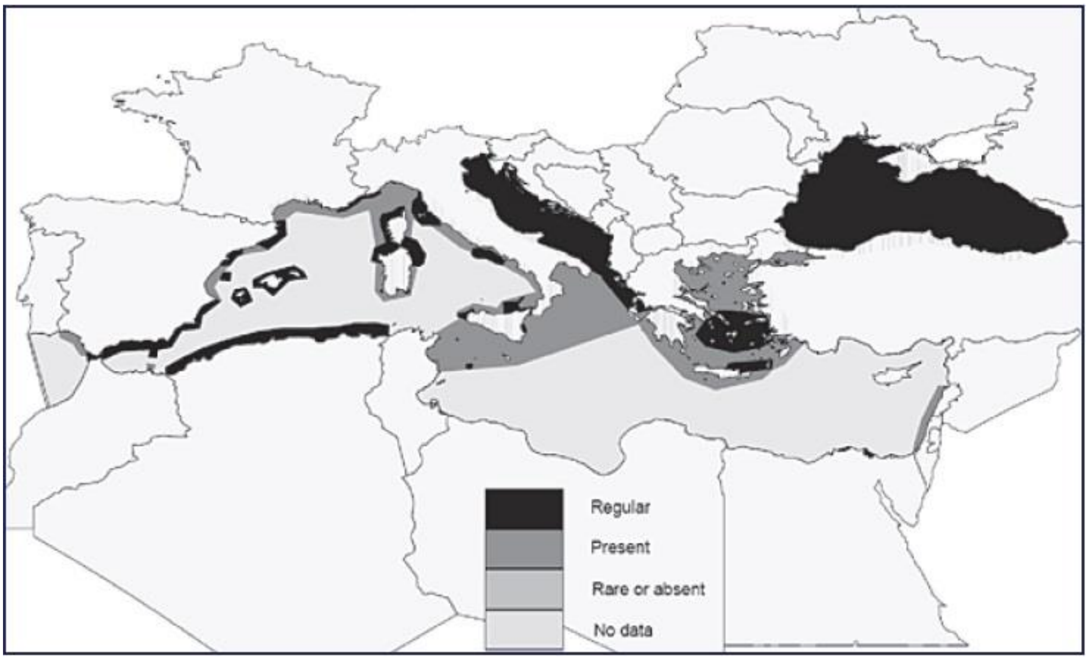

Figure 1. Distribution of the Mediterranean dolphin population according to the data of the IUCN. Dark color represents high density of dolphins (From Reeves et al. 2006).

Taking in consideration this distribution structure, it is possible to represent the single unit of the Mediterranean population as composed by separate subpopulations inhabiting smaller areas. In some areas, such as the Adriatic Sea, the species has declined dramatically over the past 50 years and would therefore qualify as Endangered if assessed on their own (an observed, estimated, inferred or suspected population size reduction of ≥50% over the last 10 years of three generations). Other geographically isolated bottlenose dolphin subpopulations are known to live within relatively small semi-closed basins such as the Amvrakikos Gulf in western Greece (400 km^2), where they exhibit specialized behavior and feeding habits and face a high risk of local extinction.

The mean size of bottlenose dolphin pods varies according to location, from typically small numbers in coastal waters (7 individuals) to larger numbers in pelagic waters (35 individuals). Their diet is mixed with a preference for demersal prey, but anyway they can adapt on the most abundant prey available, that is why they are considered as catholic or opportunistic feeders. As a consequence they sometimes forage around fish-farm cages or take fish from gillnets, leading to an high risk of remaining trapped in the nets. In coastal waters they can spend up to 5% of their time following trawlers. Association with other cetacean species is uncommon, except in the Alboran Sea (Reeves et al. 2006).

International legislation

Cetaceans are protected internationally under several multilateral agreements and conventions. Each of them that are presented below are not binding but voluntary, so if any Party does not follow the agreements, it is not subject to sanctions or pressures of any kind. This means that even if there is a large consensus, the effectiveness of these agreements is lower than expected. Below the main conventions on bottlenose dolphins are listed:

- Convention on Migratory Species (CMS or Bonn Convention, 1979): the bottlenose dolphins are listed in the Appendix II concerning migratory species which have an unfavorable conservation status and which require international agreements for their conservations and management (http://www.cms.int).
- Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention, 1979): lists the bottlenose dolphins as a Strictly Protected Fauna Species (Appendix II) and state that each Contacting Party has to establish areas that protect its habitat and prohibitions intended to ensure 'special protection'. The Bern Convention is the origin of the Bird Directive (79/409/EEC) and Habitat Directive (92/43/EEC) promulgated by the European Union (http://www.coe.int).

- Convention for the Protection of the Mediterranean Sea Against Pollution (Barcelona Convention, 1976): it provides a framework under which specific Protocols, addressing issues of direct relevance to bottlenose dolphins, may be implemented. Three are the main protocols: the Offshore protocol regulates the protection of the Mediterranean sea against pollution resulting from exploration and exploitation of the continental shelf and the seabed and its subsoil, the LBS protocol protects the Mediterranean sea against pollution from Land-Based Sources and Activities, the Special Protected Area (SPA) and Biodiversity protocol obligates parties to draw up a list of "specially protected areas" in their waters, further duties flow once a SPA has been established (http://www.unepmap.org).
- The Agreement of the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS, 1996). It requires the States to implement a detailed conservation plan for cetaceans, based first on respect of legislation banning the deliberate catching of cetaceans in fishing zones by their flag vessels or those subject to their jurisdiction, on measures for minimizing incidental capture and, finally, on the creation of protected areas (http://www.accobams.org).
- The Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES, 1975). This agreement between governments has the aim to ensure that international trade in specimens of wild animals and plants does not threaten their survival. Because the trade in wild animals and plants crosses borders between countries, the CITES was conceived in the spirit of regulate the international cooperation to safeguard certain species from over-exploitation. The bottlenose dolphins are cited in the Appendix II which include all species which although not necessarily now threatened with extinction may become so unless trade in specimen of such species is subject to particularly strict regulation in order to avoid utilization incompatible with their survival and so they may be brought under effective control (http://www.cites.org).

Moreover the following regulations that, unlike the previous are mandatory, have particular relevance in the European Union:

- Habitats Directive or European Commission Directive on the Conservation of Natural Habitats and wild Fauna and flora (Council Directive 92/43EEC, 21 May 1992): it has the aim of protecting the biodiversity by means the conservation of the natural habitats, wild flora and fauna of the European territory of the member States. The Directive leans on the Natura 2000 network (appendix I and II) and the system of protection of species (appendix IV and V). The Tursiops truncatus are listed in both Appendix II and Appendix IV concerning the former the Animal and Plant species of community interest whose conservation requires the designation of special areas of conservation and the latter Animal and Plant species of community interest in need of strict protection (http://eur-lex.europa.eu).
- Marine Strategy Framework Directive (Directive 2008/56/CE of the European Parliament and of the Council of 17 June 2008): it regards to the whole pressures that the human activities exercise on the marine resources. It establishes a framework within which Member State shall take the necessary measures to achieve or maintain good environmental status in the marine environment by the year 2020 (http://rod.eionet.europa.eu).

Protected areas in the Mediterranean Sea

Various kinds of marine protected areas exist or have been proposed throughout the Mediterranean. Although not always specifically intended for bottlenose dolphins, the following measures could contribute to their conservation (Reeves et al. 2006):

- Pelagos Sanctuary, a 90.000 km^2 cetacean sanctuary in the Corsican-Ligurian Basin, created in 1999 by Italy, France and the Monaco Principality. Twenty-two other MPAs of variable size have been established in Italy, and 29 more are planned. If appropriately managed and coordinated, this network of MPAs may contribute to bottlenose dolphin conservation.
- In 1999, the Spanish Ministry for the Environment classified the bottlenose dolphin in its National Endangered Species Act as 'vulnerable' in the Mediterranean. The following year, a program was initiated to identify and promote cetacean-oriented MPAs in the Spanish Mediterranean. A EU-funded LIFE project (2002-2005) has developed the management schemes for cetacean conservation.

- In Croatia, a Dolphin Reserve around the island of Cres and Losinj (north-eastern Adriatic Sea) was established in 2006 by the State Secretary of the Ministry of Culture of the Republic of Croatia. It is an area of 526 km^2 protected by the Croatian Law and designated as a "Special Zoological Reserve for bottlenose dolphins (*Tursiops truncatus*)".
- The eastern Ionian area around the island of Kalamos, where bottlenose dolphins reside, was included by Greece in the Natura 2000 network (Site of Community Importance) under the "Habitats" Directive. The area has been identified by ACCOBAMS (2002) as one where pilot conservation and management actions should be implemented immediately to preserve cetacean habitat.
- In the waters around Ischia, south-eastern Tyrrhenian Sea, the creation of a marine reserve dedicated to cetaceans was proposed recently by Italy, which, if finalized, may lead to migration of obvious threats such as boat disturbance and illegal fishing.

Materials and methods

The study area

The Adriatic Sea is a semi-enclosed sub basin of the Mediterranean Sea of about 138,000 km^2 landlocked by Italy and the Balkan Peninsula.

In the 2007 the General Fisheries Commission for the Mediterranean (GFCM) recognizing the need to compile data, monitor fisheries and assess fisheries resources in a georeferenced manner, established that the Mediterranean Sea has to be divided in 30 Geographical Sub-Areas (GSAs) which led to divide the Adriatic Sea into two areas: GSA 17 (the northern and central basin) and GSA 18 (the southern basin) (resolution GFCM/31/2007/2) (http://www.gfcm.org). The GSA 17 covers the entire area of the northern and central Adriatic, till the invisible line that connects the Gargano Promontory with the city of Kotor for a total surface of 92,660 km^2. This basin is shallow with a depth that increases from north to south and which generally does not go below a depth of 100m except for the Pomo Pit which reaches 260 m. The water temperatures varies from 7 °C in winter and 28 °C in summer (http://www.federcoopesca.it/ - GSA 17 Mar Adriatico Centro-Settentrionale, Piano di gestione).

The area involved in this study covers just the northern part of the GSA 17, from Trieste to an imaginary line linking the Croatian city of Zadar with the Italian city of Ancona, for about 32,000 km^2. The mean water temperature is about 14.5 °C, with a maximum depth of 210 km and minimum depth of 29 m. This shallow basin is characterized by high freshwater inflows mostly coming from the intensely populated, industrialized and cultivated northern Italian plains which make the northern Adriatic naturally productive and vulnerable to nutrient enrichment (Barausse et al., 2009)

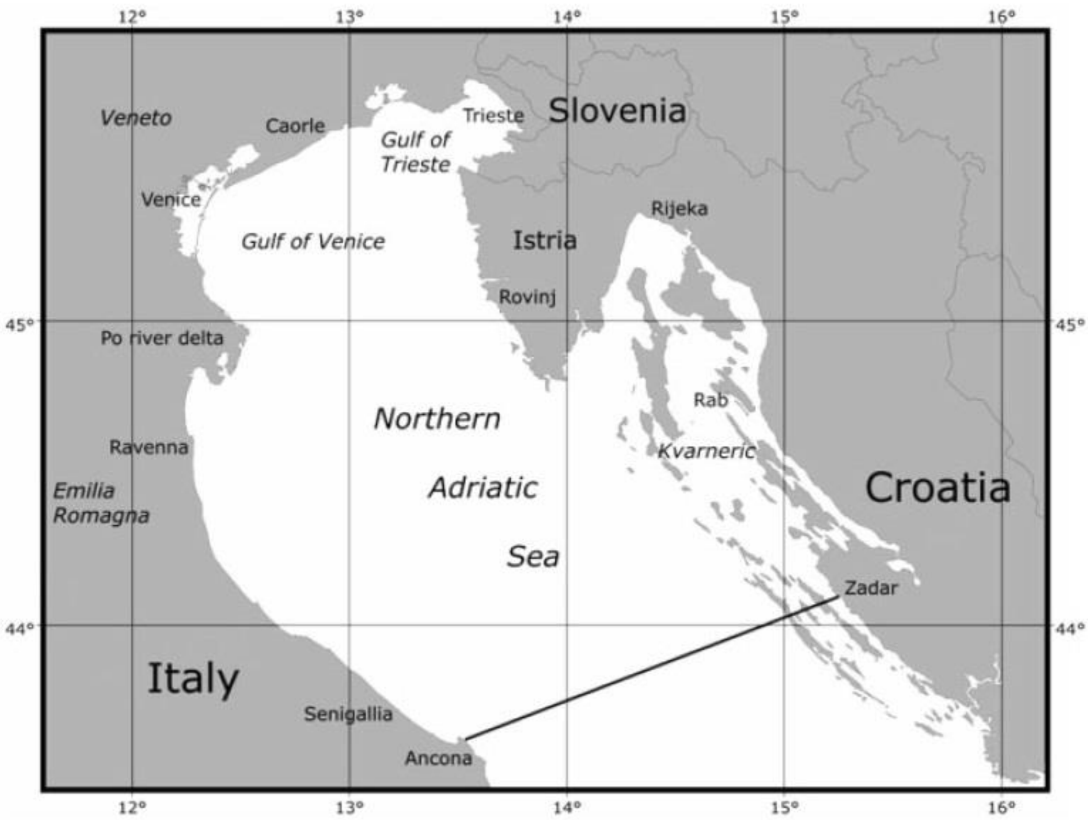

Figure 2. Map of the area involved in the study, considering an imagery line that connect Ancona (Italy) with Zadar (Croatia). The area is about 32.000 km^2 (From Bearzi et al., 2004).

The northern Adriatic ecosystem

The northern Adriatic sea is considered the most exploited basin of the Mediterranean Sea and subjected to several anthropogenic pressures (pollution and destruction of habits), as well as to a large amount of environmental variability (global changes in temperature and ocean acidification). The hydrographic and physical characteristics display marked spatial, interseasonal and interannual changes. Factors such as: eutrophication, the shallow depth and land locked shape, make the Northern Adriatic Sea eutrophic. Nutrient loadings are mainly discharged by north Italian rivers, whose total inflow is about one-fifth of the total river discharge into the Mediterranean Sea, which creates also spatial heterogeneities between the two coasts (Barausse et al., 2011).

Nowadays the trophic structure of the Northern Adriatic Sea (NAS) is dominated by the low trophic levels, which production is not completely exploited in the network. The ecosystem appears highly productive, mainly in the pelagic compartment, in line with its eutrophic status. It seems that the responsible for this lack of top-down control in the ecosystem is the overexploitation, considering that the top-predators appear to be depleted. Pelagic primary productivity, due to the flow of the un-preyed phytoplankton production to detritus, sustains both the pelagic and the benthic-demersal compartments. The predominance of small, fast-growing and resilient organisms like plankton, small pelagic fish and squids which are better fit to survive under a high fishing pressure and bottom anoxic conditions, appears as a potential consequence of the exploitation and eutrophication, which are a symptom of anthropogenic stress. The NAS is depicted in a fishing state, meaning that it has been so long and intensely fished that it is in a depressed state and the depleted higher trophic levels are not reactive even to fishing (Barausse et al., 2009).

Cetacean species in the northern Adriatic Sea

Most of the recorded cetacean species in the northern Adriatic Sea are incidental in the region and only two species, the common bottlenose dolphin, *Tursiops truncatus* and the short-beaked common dolphin, *Delphinus delphis* can be regarded as regular since historical times. The other species reported also include: the fin whale *Balenoptera physalus*, the sperm whale *Physeter macrocephalus,* the long-finned pilot whale *Globicephala melas*, Risso's dolphin *Grampus griseus* and the striped dolphin *Stenella coeruleoalba*. This last one is the commonest pelagic cetacean throughout the Mediterranean but it has always been rare in the northern Adriatic (Bearzi et al., 2004).

In a preliminary assessment of cetacean status in the northern Adriatic in the late 1980s, it was noted that the short-beaked common dolphin which was considered regular in that area, had almost completely disappeared. The presence of common dolphins until the 1970s is well documented. Trois (1894) reported that common dolphin specimens were often put for sale at the Venice fish market after being caught in the inner channels of the Venice lagoon. Today, the occurrence of any cetacean in the lagoon is an exceptional event. The bottlenose dolphin is the only cetacean species regularly reported in the area at the present time (Bearzi et al., 2004).

Legislation in the area

Croatian legislation

One year after the declaration of independence form the Yugoslavia, 1991, the Croatian Parliament adopted the Declaration on Environmental Protection (Official Gazette No. 34/92) in the Republic of Croatia. It states the initial terms for the establishment of an efficient and sustainable management of the natural resources and nature protection. It was with the Environment Protection Act (82/1994), that the preservation of the quality of living and inanimate nature and the rational use of nature and its resources became the main priorities. In 1995 all the marine mammals became protected under the Croatian law (Official Gazette No. 31/95) (http://www.blue-world.org).

The main national laws and rules pertinent to cetaceans are the Law on Nature Protection (NN 70/05 and NN 139/08); Regulations on the types of habitat types, maps of habitats, endangered and rare habitat types and the measures for the maintenance of habitat types (NN 7/06); and Regulations on the transboundary movement and trade in protected species (NN 72/09) (http://www.blue-world.org).

The International Convention and Agreements to which the country is Party are: Convention on Biological Diversity and related protocols (Rio de Janeiro 1992) entered into force the 7th October 1996; the CITIES entered in force the 12th June 2000; the Bonn Convention entered into force the 1st October 2000; the Bern Convention entered into force the 1st November 2000; the Barcelona Convention on and related protocols on the protection of the sea from pollution from land and the Mediterranean Action Plan entered into forced the 12th April 2002; and the ACCOBAMS entered into force 1stJune 2001 (ACCOBAMS, 2007a).

From the 1st of July 2013 the Croatia became a Member Stateof the European Union, so as a consequence it has to implement the Habitat and Birds Directive. About one-third of the state is ready to be included in the Natura 2000 Network (Benvenuta Croazia – il 28° Stato Membro dell'UE, Notiziario natura e biodiversità NATURA 2000, 2013).

Italian legislation

Until the late of the 1970s, in Italy it was legal to kill dolphins, and they were even object of economic compensations. This situation changed in the 80s, thanks to the Italian Ministry and the public opinion when in the 1979 the Italian Government prohibited the unauthorized dolphin killings (Bearzi et al., 2004).

Table 1. The national Italian legislation concerning the conservation of the cetacean species.

Title of text	Date when promulgated	Authorities responsible for application
Disciplina della cattura dei cetacei, delle testuggini e degli storioni	D.M. 03/05/1989	Ministry of Agriculture, Food and Forestry (MiPAAF)
Norme per la protezione della fauna selvatica omeoterma e per il prelievo venatorio	Law n. 157 11/02/1992	State ForestryDepartment
European Council Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (Council Directive 92/43/EEC)	21/05/1992	Ministry of Environment, Land and Sea Protection
Regolamento recante attuazione della direttiva 92/43/CEE (Direttiva Habitat) relativa alla conservazione degli habitat naturali e seminaturali, non ché della flora e fauna selvatiche	D.P.R. n. 357 08/09/1997 modified with D.P.R. n. 120 12/03/2003	State Forestry Department
Ratifica ed esecuzione dell'Accordo relativo alla creazione nel Mediterraneo di un santuario per i mammiferi marini.	Law n. 391 11/10/2011	Ministry of Environment, Land and Sea Protection
Regolamento recante disposizioni in materia di mantenimento in cattività di esemplari appartenenti alla specie *Tursiops truncatus*, in applicazione dell'articolo 17, comma 6 della legge 23 marzo 2001, n. 93	D.M. n. 469 06/12/2001	State Forestry Department and CITES
Decreto Ministero dell'Ambiente e della tutela del Territorio e del mare 3 settembre 2002 "Linee Guida per la Gestione dei siti natura 2000 in attuazione della direttiva 92/43/CEE"	D.M. 03/09/2002; G.U. n. 224 24/09/2002	Ministry of Environment, Land and Sea Protection
European Council Regulation n.812/2004 laying down measures concerning incidental catches of cetaceans in fisheries and amending Regulation (EC) No 88/98	26/04/2004	Ministry of Agriculture, Food and Forestry

Moreover Italy is a Party to the previous multilateral international agreements and conventions of the Cetaceans protection. It is also Party to the trilateral agreement that establishes the Mediterranean Sanctuary for Marine Mammals (Pelagos Sanctuary). By ratifying ACCOBAMS in the 1995, the Italian Government has committed itself to meet all conservation objectives of this International Agreement, including its general conservation objectives to "take co-ordinated measures to achieve and maintain a favorable conservation status for cetaceans" and to "prohibit and take necessary measures to eliminate, where this is not already done, any deliberate taking of cetaceans. The Bern Convention entered into force in the 1982, the Bonn Convention in the 1983, the Barcelona protocols the 1999, CITES in the 1979 (ACCOBAMS, 2007b).

Slovenia legislation

Only in 1991 Slovenia declared its independence from Yugoslavia. It is from this date that the ministry of Environment and Physical Planning and the Ministry of Agriculture, Forestry and Food started to take care of cetaceans.. The main important act is the Nature Conservation Act (Official Gazette of RS No 56/99) which regulates the nature protection in Slovenia. According to its provisions, animals and plants are under special state protection and extermination of any species or reducing their populations, reducing or intentionally damaging habitats or worsen their living conditions is prohibited. It is mandatory to notify the captive keeping of large mammals, birds and reptiles of all species listed in the ratified international treaties, including cetaceans. Moreover other rules concern: Order on the living conditions for and care of wild animals kept in captivity (Official Gazette of RS No 90/01), Rules on the assessment of risk to nature and on the authorization (Official Gazette of RS No 43/02), Decree on the rescue center for animals of wild species(Official Gazette of RS No 98/02) and Rules on the marking of animals of wild species kept in captivity (Official Gazette of RS No 58/04).

Considering an international level, Slovenia became part of the European Union in the 2004 but anyway before this date it implemented several important decrease, above all the Habitat and Bird directive. This was transported in the *Decree on Protected Wild Animal Species (Official Gazette of RS No 46/04).* It protects wild animal species listed in corresponding Annexes and it lays down protection regimes and measures to maintain their favorable conservation status. All cetacean species are under strict protection of the Decree. Moreover Slovenia joined the relevant international convention and agreements: Bonn convention entered into forced 1 February 1999; Bern convention in 1 January 2000; CITIES in 23 April 2000; accession to the Barcelona protocol concerning Specially protected area and biological diversity in the Mediterranean in the 15 of March 1994, ACCOBAMS entered into force the 1st of December 2006 (ACCOBAMS, 2007c).

The bottlenose dolphin

Figure 3. Bottelnose dolphins playing in the Adriatic sea (From http://www.blue-world.org/).

Bottlenose dolphins belong to the order of the Cetacea, suborder Odontoceti, family Delphinidae, genus Tursiops. Tursiops is derived from the Latin word *Tursio* for "dolphin" and the Greek suffix *–ops* for "appearance", in other word "dolphinlike". Currently two species are recognized: the common bottlenose dolphin, *Tursiops truncatus*, and the Indo-Pacific bottlenose dolphin, *Tursiops aduncus.* In general the bottlenose dolphins are 2 to 3.9 m and their average weight is 150 to 200 kg. they are characterized by a short, well-defined snout or beak which is about 8 cm long and apparently resembles the top of an old-fashioned gin bottle. Its fusiform shape is quite energy-efficient for swimming, it can reach maximum speeds of 29 to 35 kph. They have a well-developed, acute sense of hearing. They rely heavily on sound production and reception to navigate, communicate, hunt and avoid predators in dark or limited vision waters. A special ability is the echolocation, which allow them to locate and discriminate objects by projecting high-frequency sound waves and listening for echoes as the sound waves reflect off objects (http://www.seaworld.org).

Growth and behavior

They live in a variety of habitats, form coastal waters to the open ocean and they migrate according to variations in water temperature, movements of food fish and feeding habits. Usually they swim in groups of 2 to 15 individuals, feeding, socializing, travelling and resting. Most bottlenose dolphins probably live 30 years as average (Bearzi, 1995), a female dolphin can potentially bear a calf every two years, but calving intervals generally average three years. The gestation period is about 12 months. In the first few days after birth, calves stay close to the mother who attentively directs the calf's movements. Moreover a mother dolphin may whistle to her calf almost continuously for several days after giving birth. This acoustic imprinting helps the calf learn to identify its mother. As young as one month old a dolphin develops its signature whistle (http://www.seaworld.org).

Distribution in the area

Information on the present status of bottlenose dolphins in the northern Adriatic is rather limited. In the Gulf of Venice, opportunistic sightings data were collected between 1988 and 2002. Of a total of 58 confirmed sightings, the bottlenose dolphin was the only species observed (Bearzi et al., 2004). Moreover in the 2001 and 2002 a cetacean survey was conducted in the area between Marina di Ravenna and Cesenatico at maximum 30 km from the coast. Sightings of bottlenose dolphins reported a mean group size of 14.2 in the 2001 and 8.3 individuals in the 2002 (Triossi et al.).

A first long-term study on the ecology of bottlenose dolphins in the Adriatic Sea started in 1987 by the Tethys Research Institute and is now being implemented in the Kvarneric, Croatia, by the Blue World Institute of Marine Research and Conservation. The study focuses on a community of about 100-130 bottlenose dolphins showing a high degree of year-round site fidelity in a coastal area of approximately 800 km^2. (Genov et al., 2009). From the surveys conducted from 1987 to 1994 a mean size group of 7.4 was reported by Bearzi et al. (1997). Despite the occasional occurrence of groups composed of over 30 dolphins, most groups (90.3%)

included less than 15 individuals. The frequent observations of groups composed of 3-6 individuals indicate that this dolphin community was typically spread into small units. In the Kvarneric, where food resources are reportedly scattered and increasingly scares the small mean group size of dolphins engaged in feeding-related activities, may indicate that small groups can gain the highest rate of food intake (Bearzi et al., 1997).

A similar study was initiated in Slovenian waters in 2002 by Morigenos – Martine Mammal Research and Conservation Society. Land-based and boat-based surveys were focused on a local population of bottlenose dolphins in Slovenian and adjacent waters (Croatian and Italian) between 2002 and 2008 (Genov et al., 2009). A total of 120 sightings were recorded and 101 well marked dolphins photo-identified. Re-sighting rates within and between years showed a relatively high rate of site fidelity for some individuals. The group size range from 1 to 43. Annual mark-recapture density estimates of 0.069 dolphins/km^2 seem to be good baseline information for conservation management (Genov et al., 2008).

Results from a recent study in the northern Adriatic sea complements existing knowledge on bottlenose dolphins. Sightings reports and visual surveys, covering an area of 9.500 km^2 observed a total of 97 confirmed sightings recorded in the study area across 20 years (1988-2007). Encountered rates obtained between 2001 and 2006 during visual cetacean survey, ranged between 0.42 and 1.67 groups per 100 km of navigation with no variation with consistent methodology (Bearzi et al., 2009).

Bottlenose dolphin diet

Feeding habits, seem to shape the behavior of these dolphins, whose diet has been described as catholic or opportunistic. Reported prey items include demersal species such as European hake *Merluccius meluccius,* European Conger *Conger conger,* red mullet *Mullus barbatus,* striped red mullet *Mullus surmuletus.* As most studies have relied on stomach contents from stranded animals, inferences may be subjected to bias. Diet and foraging behavior appear to vary widely depending on area, season or trophic area occupied by the local dolphins (Bearzi et al., 2008).

Miokovic (1999) reported the stomach content of a bottlenose dolphin caught in a fishing net in the area near the town of Sibenik in December 1995. There were identified 3 species of fish: conger eel, *Conger conger*, hake, *Merluccius merluccius* and Pandora, *Pagellus erythrinus*. Comparing the present findings with those of other authors it seems that hake and species form the families Congridae, Sparidae and Gadidae represent the most important part of the diet of bottlenose dolphins that is demersal fishes (Miokovic et al. 1999).

Another analysis of the stomach of bottlenose dolphins was conducted by Stewart (2004) on 11 animals form the Cres-Losinj population. The majority of identified fish prey species (53.85%) are demersal, 30.77% bentho-pelagic and 15.38% pelagic. Species found included conge eel (*Conger conger*), European hake (*Merluccius merluccius*), Pandora (*Pagellus erythrinus*), horse mackerel (*Trachurus trachurus*) and red mullet (*Mullus barbatus*). In disagreement with other Mediterranean diet analysis, the pelagic species horse mackerelwas the most abundant, hence important prey. It strongly differs from past research in the Mediterranean region which all found a dietary preference for European hake, a benthic specie. Stewart himself suggested that if hake was indeed the most important prey for the Adriatic population prior to 1995 fishers may have since increased their exploitation of hake, narrowing the dolphin realized niche, and causing dolphins to switch resources (Stewart, 2004).

Interaction with fishery

Interactions between cetaceans and fisheries in the Mediterranean Sea are probably as old as the first human attempts to catch fish with a net. In the early 1587 a Papal Decree was issued “anathematizing the vermin” in response to concerns in France about the interference of dolphins in fisheries. Reports of the 18th century describe fishermen try to keep dolphins away from their nets, by means loud noises, dynamite, weapons, modifications of fishing techniques and schedules, and large-mesh nets surrounding the fishing net to protect them from dolphin incursions. Several governments (i.e. Italy, Slovenia and Croatia) supported for at least one century, direct killings and offered bounties for dolphins catches represented the first human attempts to solve the problem of net depredation. Together with deliberate killings, incidental catches of cetaceans in fishing gear also increased with the worldwide development of fisheries (Bearzi, 2002).

Impacts of fishery on dolphins

Fisheries can affect cetaceans both directly and indirectly. Effects on animals may include:

- Injury or mortality from culling campaigns;
- Bycatch in fishing gear;
- Overfishing causing a reduction of food prey availability or changes in food prey composition/distribution;
- Habitat loss or degradation;
- Unintentional disturbance by fishery-related operations;
- Short- to long- modification in cetacean behavior leading to emigration, dispersion or reduced reproductive rates as a consequence of direct or indirect interactions with fisheries.

Direct killings

The first record of a monetary reward being offered for a killed dolphin in the northern Adriatic Sea dates back to 1872. Maritime officials in Trieste and Rijeka tried to mitigate conflict with fisheries by promoting culling campaigns (Crnkovic, 1958). The government of Yugoslavia paid two types of bounty: one for dolphins catch accidentally and another deliberately killed. A partial record of animals caught at this time reports that 335 dolphins were caught and killed between 1933 and 1935. There are no records to indicate species, scale or duration of the campaign. In the 1949 the Ministry of Fishery of the People’s Republic of Croatia offered rewards for each animal killed: 500 dinars for a dolphin over the meter size and 250 dinars for less than a meter. In the 1955 the rewards increased to 5000 dinars, independently of the size Crnkovic (1958). In this period 239 dolphins were killed, of these 153 only in the district of Rijeka between 1956 and 1957. A more accurate description of the campaign reported 788 dolphins killed between 1955 and 1960. Again there are not references on the species involved but it is possible to infer from the literature that common dolphins and bottlenose dolphins where the two regular cetacean species in these waters. The culling campaign was supposed to last until 1965, but in 1959 bounties were dropped from 5000 dinars to 3000 dinars. Monetary inflation after 1960 likely contributed to making the 3000 dinars bounty less and less appealing. There is no record of rewards after the 1960, however this doesn’t indicate that deliberate killings were stopped (Bearzi, 2004). Fishermen were usual to carry guns on board and dolphins were frequently shot. Moreover special weapons were realized in order to exterminate dolphins like dedicated boats, harpoons and special nets (Crnkovic, 1958).

Also in Italy in the 1930s the government promoted dolphin killings campaigns. The Italian Ministry of the National Economy issued a ministerial decree in the 1928 in favor of the conflict with dolphins. Considering the necessity to encourage and intensify the battle against dolphins in order to mitigate the damages that they inferred to fishermen the Italian government established that: L. 50 will be given to any Italian that killed or catch a dolphin or L. 100 if it is a pregnant female. (GazzettaUfficiale 26 gennaio 1929, n°22). Even if no records are reported for the numbers of dolphins landed, a total of L. 40000 were budgeted for that fiscal year so great numbers were expected. The cumulative impact of culling off the Italian coasts of the Adriatic remains poorly documented. Killing dolphins for human consumption or sport was also a relatively common practice in Italy until a few decades ago (Bearzi, 2004).

In the 1950s, dolphins in the eastern portion of the Adriatic sea were said to be thousands. It was only in the 1979 that the Italian Government prohibited unauthorized dolphin killings and just in the 1995 that dolphins became protected under the Croatian law. Nowadays the available evidence suggests that the number of bottlenose dolphins in the entire Adriatic is unlikely to exceed few hundred (Bearzi, 2004).

By-catches (unintentional takes)

Due to their opportunistic behavior and predominantly coastal occurrence, bottlenose dolphins in the Mediterranean are at risk of entanglement in many types of fishing gears. In the Slovenian waters it was recorded that the 48.9% of all summer sightings involved interaction of dolphins with bottom trawlers or pelagic pair trawlers. (National report of Slovenia). Not all forms of fishing gear have the same impact and the threat represented by a given type of fishing gear may depend on how that gear is used. Important threats come from the bottom gillnets, pelagic driftnets and trawl nets.

Bottom gillnets have been known to cause incidental entrapment and death of thousands of cetaceans worldwide. This fishing gear is used in coastal waters up to

200 m deep (the maximum depth of the Adriatic sea), and usually targets demersal and bentho-pelagic prey. By-caught cetaceans are usually removed from the nets dead or alive. The proportion of life/dead bycatch is unknown and remarkably few studies have been conducted to evaluate mortality trends in bottom gillnet fisheries. The 1994 International Water Center (IWC) report estimated “likely annual ranges of marine mammal mortality” of 50-200 common bottlenose dolphins in the Mediterranean region (Bearzi, 2002).

Other possible threats for the dolphins are the trawl nets. Their target are demersal and bentho-pelagic stocks, as well as mid-water species. It has been suggested that cetaceans by-caught in trawl nets are probably aware of the net and the boat’s activity. They have learned to follow bottom trawlers to take advantage of fish caught by the net, stirred up by the net, attracted by the net, or discarded from the nets after trawling. Mid-water trawling seems to represent the main threat, because it may target species that represent typical components of cetacean diet. Based on available data, bycatch in trawling nets appears to be relatively uncommon occurrence in most Mediterranean areas but no further study are conducted in this field (Bearzi, 2002).

A study conducted by Fortuna in 2010, tries to establish the bycatch rate of cetaceans and other species during Italian pair trawl fishing operations in the Adriatic Sea. Considering only the northern Adriatic area the numbers of hauls observed were 2899 and two bottlenose dolphins were recorded as dead bycatch, yielding an observed mortality rate of 0.0006 individuals per haul (the bycatch rate was 0.001 individuals per haul). Anyway this estimate is considered unreliable due to the high coefficient of variation (CV = 68-69%). So in order to obtain an annual estimate with an acceptable coefficient variation, with simple simulations of increased observer coverage, it can be assumed an annual captured of 22 dolphins for the northern Adriatic Sea alone, as predicted by these observations (Fortuna, 2010).

Prey overfishing

During the last 50 years, overfishing practices have so impoverished the marine environment that present and future generations of cetaceans are in trouble. Excessive fishing pressure and the decline in fish stock and loss of marine biodiversity is a growing concern. Some of the Adriatic fish stocks that have been either ‘overexploited’ or ‘fully exploited’ include important bottlenose prey such as European hake, striped red mullet and European pilchard (Bearzi, 2008). Reconstructing fish community changes over the past centuries is difficult because information before the second half of the 20th century is quite circumstantial and qualitative. In recent studies changes in a marine community in the northern Adriatic Sea were explored over a period of 65 years considering fishing pressures and environmental variations as driving forces for these changes. It was observed a shift in the community from large, late maturing species to more fecund, smaller and earlier-maturing species (Barausse et al., 2011) . Wide fluctuation were recorded for the European anchovy from the late 1970s (average 1978-1980: 53000 t) until their collapsed in 1987 (3700 t with unchanged fishing effort). Similar fluctuation were reported for other species such as European pilchard and Atlantic horse mackerel *Trachurus trachurus* between 1981 and 1986. Moreover, catches of demersal fish in the Adriatic have declined dramatically over recent decades. A catch reduction in the northern Adriatic mainly concerning demersal fish species was recorded in 1982-1987, when catch per effort declined by one half (Bearzi, 2004).

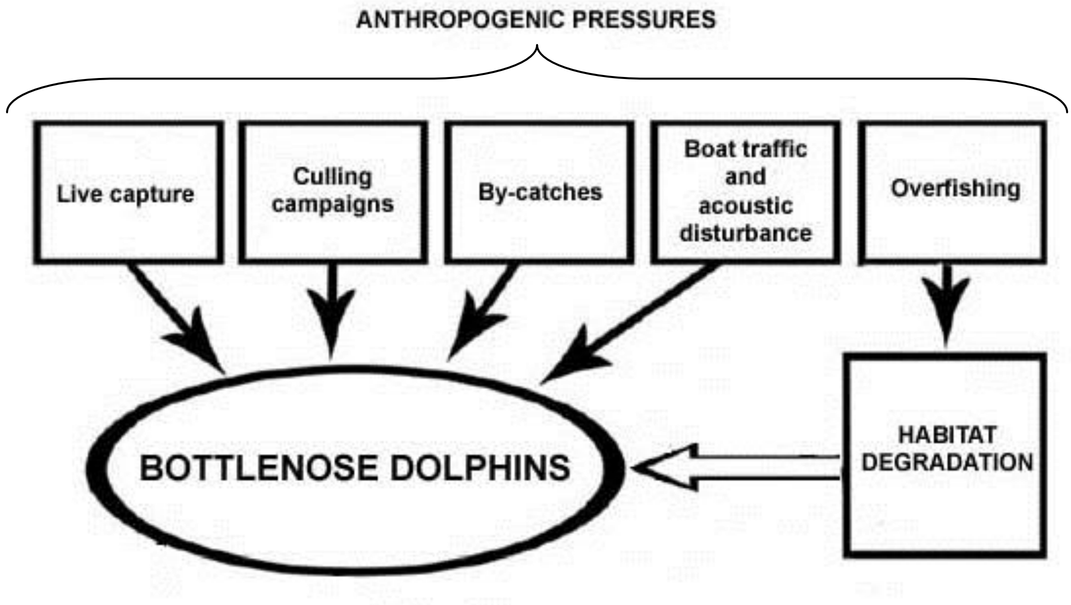

Figure 4. Main environmental and human pressures that threaten the cetacean conservation.

Impact on fisheries

Dolphins are often claimed to compete with fisheries, including through removal of substantial biomass. No robust scientific investigation confirms that present-day dolphin populations reduce fishery catches by removing biomass that would otherwise be available to fisherman. Ecosystem damage resulting from overfishing and habitat degradation in the Mediterranean sea has likely exacerbated the perception that dolphins reduce fishery yields (Bearzi et al 2010). Reports of bottlenose dolphins either removing or damaging the catch, damaging fishing gear and disturbing fishing activities comes from several Mediterranean areas, but the available information is largely unpublished and sometimes difficult to evaluate. This was already reported by Crnkovic (1958) who describes dolphins cause huge damages to the fishery's nets and as a consequence to the economic value of the catch. Moreover he presented dolphins as parasites who follow trawlers and waiting for the discarded fish.

Interactions are noticed also between dolphins and aquaculture. It appears to happen very frequent that bottlenose dolphins visits aquaculture facilities probably due to the rapid expansion of fishing farming in coastal waters and the opportunistic behavior shown by the dolphins possibly as a result of the decreasing food. Observation made in a single study have included dolphins catching farmed fish that had escaped from the cages, targeting fish that had escaped from nets during transfer operations from one cage to another, and even consuming dead, discarded fish (Bearzi, 2008).

Habitat degradation

Toxic contamination can affect reproduction and health. High levels of noxious polychlorinated biphenyls were found in tissues of bottlenose dolphins sampled in northern portions of the basin as well as in some of the dolphin's key prey. Heavy nutrient input from rivers (especially the Po river discharges) exceeds the basin's natural assimilation capacity and considering the Adriatic as highly sensitive to the environmental changes this has a significant impact. Occasional eutrophication phenomena became more frequent during the second part of the 20th century. Starting in the 1970s, algal blooms and the production of mucilage in large portions of the northern Adriatic have become a growing concern because of the frequency, intensity and geographic extension of such phenomena, much greater than in any other parts of the Mediterranean (Bearzi, 2004). Moreover, compounds such as PCBs and PAHs have been associated with reproductive disorders, immune-system suppression and neoplasia. Eventually it is important to take the climate changes into account as a potential impact on the biological processes. A steady increase in sea-surface temperatures has been observed in the Mediterranean deep and surface water. This acts directly and indirectly on the habitat of these mammals, for example resulting in significant changes in the distribution of fish species representing key prey for the bottlenose dolphins (Fortuna, 2010).

The model

The approach used to estimate the exploited bottlenose dolphin in the northern Adriatic Sea is based on a previous study by Line Bang Christensen, 2006. In this report Christensen has reconstructed population trajectories for documented exploited marine mammal species and stocks at the scale of ocean basins. Employing a Bayesian approach to stochastic stock reduction analysis, she constructs probability distributions over historical stock size. This method allows to use historical catch time series to estimate a distribution over population parameters, the intrinsic growth rate and carrying capacity, that give rise to extant populations.

Starting from this work and modifying some procedure in the estimation of the parameters, the Christensen's model is applied in this study for reconstruct the abundance of bottlenose dolphins in the northern Adriatic Sea.

The production model is one of the simplest population models; it is a logistic growth model that assumes no errors in reported catch:

$$N_{t+1} = N_t + r_{max} N_t \left(1 - \frac{N_t}{K}\right) - C_t \qquad (1)$$

Where N is numbers, r_{max} is the maximum intrinsic rate of net population growth, K is the carrying capacity, C is the observed catch and t is the subscript for time. This production model is density-dependent, in other words growth depends on population size. The relationship between the population size and its carrying capacity is quite simple. If we take the derivative of the yearly population change, $N_{t+1} - N_t$, with respect to N_t, then set it to zero to find the inflection point we obtain that the population size (N_{msy}) that maximizes production is equal to:

$$N_{msy} = \frac{K}{2} \qquad (2)$$

This means that when the production is maximized, the population size N_{msy} is half their carrying capacity.

Bayesian stochastic stock reduction analysis

Stock reduction analysis (SRA) was first suggested by Kimura and Tagart (1982) and Kimura et al. (1984) as a simple method for using historical catch data in conjunction with estimates of relative stock reduction due to fishing to reconstruct possible trajectories of stock decline. The idea is to construct a population dynamics model that consists of leading parameters (such as r_{max} and K) that describe the underlying production and carrying capacity and subtract known removals from population over time. Given initial estimates of these leading parameters, the SRA approach then simulates changes in abundance by subtracting estimates of mortality and adding estimates of new recruits, where the new recruits are a function of the current stock size and the leading parameters (Waters et al., 2006).

In this study it is implemented a production model based on the logistic growth (leading parameters are r_{max} and K) and driven by removal information:

$$N_{t+1} = N_t + r_{max} N_t \left(1 - \frac{N_t}{K}\right) e^{w_t} - C_t \qquad (3)$$

$$N_1 = K_0 \qquad (4)$$

Where N_t is the number of mammals in the population time t, r_{max} is net production, K is pre-exploitation numbers or carrying capacity, N_1 is assumed to be K at the oneset of catches, C_t is the catch, in numbers, at time t, and w_t are independent process errors at time t. SRA generates a single population trajectory conditional on the leading parameters and a random anomaly sequence w_t.The Bayesian stochastic SRA (SSRA) proceeds in determining the probability of a stock being at the observed abundance level(s) at time(s) t, given the observed removal information and the assumption that the stock followed a stationary production relationship with mean r_{max} and mean carrying capacity K, with realistic variation in these parameters. The SSRA procedure is the following:

- First are assumed values for r_{max} and w_t from prior normal distributions and the same for K_0 estimated by the biomass variation of the dolphin diet;
- Generating several thousand trajectories of N_t's by randomly drawing from the prior distributions of r_{max}, K and w_t values considering also process and observed errors;
- Simulating the N_t sequence conditional on the observed catches (C_t);
- For each simulated N_t sequence calculating the likelihood of having obtained the observed abundance (y_t). The likelihood of obtaining the observed abundances, y_t, was calculated as:

$$L(y_t \mid r_{max}, K, w_t) = n\left[\log(\sigma_y) + \frac{1}{2}\log(2\pi)\right] + \sum_{i=1}^{n} \frac{z_t^2}{2\sigma_y^2} \qquad (5)$$

  Where n is the number of abundance observations, σ_y is the standard deviation in the abundance estimate, the observation error and z_t is the lognormal residual:

$$z_t = \log(N_t) - \log(y_t) \qquad (6)$$

- Resampling each of the trajectories with sample probability proportional to its likelihood, giving us a posterior probability density for the parameters of interest.
- Lastly the marginal distributions of the most likely estimate (the median) is calculated along with the 95% credible interval of the distribution values for K. This was done using the quantile function in R
- Finally it is calculated how much the population has been depleted:

$$depletion = \frac{K_0 - N_{2013}}{K_0} * 100\% \qquad (7)$$

The likelihood/Bayesian statistic is well suited for the analysis of the contest between competing hypothesis and data. The essence of likelihood/Bayesian analysis is the calculation of the chance of the data given a particular hypothesis, and (for Bayesian method) from that, "posterior distributions" that describe the probability assigned to each possible hypothesis after data are collected.

All the steps above are programmed using the statistical programming language R (www.r-project.org) and the code can be found in Appendix III.

About the errors accounted in the model, I make a difference between process errors (τ_w) and observation errors (σ_y). The former stands for the uncertainty in the parameters (r_{max} and K) involved in the model, the latter is a value of the uncertainties linked to the estimation of the observed abundance (y). A total error κ was assumed and distributed between process and observed errors:

$$\tau_w = \sqrt{1-p} * \sqrt{\kappa} \qquad (8)$$

$$\sigma_y = \sqrt{p} * \sqrt{\kappa} \qquad (9)$$

Where p is the proportion of the error allocated to each error term depending on the uncertainties associated with the observed abundance. In this study it was estimated as in the model of Christensen following the table below.

Table 2. Proportion (p) of the observed error (σ) respect to the total error (κ) and their meaning.

Proportion of κ	Meaning
0.3	Dedicated marine mammal survey with known survey area (map or clearly defined area) and information about uncertainties CV, SD)
0.4	Dedicated marine mammal survey, without definite area description or map and information about uncertainties (CV, SD)
0.4	Survey without area description or time period, but giving range (i.e., min to max estimate)
0.5	Very general estimate, no specific time period or area, no uncertainties (mostly secondary references)
0.5	Outdated general estimates, guesstimates or inferred from other species and unknown

The input data

Growth rate

The model is based on the maximum intrinsic rate of growth, which correspond to the difference between the maximum growth rate and the mortality. Due to the fact that the environmental conditions influenced their reproduction, in literature a varied ranges of life span, age sexual maturity and frequency of birth is presented (http://www.marinemammalscience.org/). In our study I consider that the average life span of a dolphin is of 30 years and the sexual maturity for females and males is reached at 12 years, almost the maximum. The gestation period lasts 12 months. In order to determine an average value I calculate, with the following equation (10), the net growth rate considering that a female can have a calf each three, four or five years. The minimum time between two pregnancy is two years, but this rarely happen.

$$(net\ growth\ rate)\ r_{max} = \left(\frac{30-12}{t}\right) * \frac{1}{30} - \frac{1}{30} \qquad (10)$$

where t=3,4 or 5.

Table 3. Frequency of birth and the correspondent growth rate calculated using the equation (10).

Frequency of birth (years)	Growth rate
3	0.166
4	0.116
5	0.086

Carrying capacity

The carrying capacity in the context of a logistic growth model, is defined as the population density at an upper asymptotic level of population growth. It is influenced by many factors which basically represent the environment where the species lives. A basic relationship is the following:

$$\frac{Resource\ avalable}{Resource\ required} = Number\ supported \qquad (11)$$

Considering that it is difficult to evaluate all the processes that constitute the carrying capacity, I decide to calculate it on the base of trophic considerations only, i.e., based on the available prey in the environment and the required amount of food necessary in the dolphin diet.

So in this study in which the carrying capacity is a key parameter, I decide to determine the maximum amount of dolphins that the area can sustain each year, according with the variations of the biomass of bottlenose most likely preys. As it was said in the previous chapters, the bottlenose dolphins are catholic feeders and so it is not possible to determine a specific diet for them, considering also the few information in this field developed in the northern Adriatic sea. I choose to adopt a diet presented by Piroddi et al. (2010), that even if it is related to a different area of study (the north-east Ionian sea) it is in agreement with the current knowledge based on the studies conducted by Miokovic and Stewart (Miokovic et al., 1999) (Stewart S.E., 2004) on the stomach of stranded bottlenose dolphins in which there are recorded that demersal fishes are the most likely preys of the bottlenose diet in the northern Adriatic sea.

Table 4. Bottlenose dolphin diet (Piroddi et al., 2010).

Most likely bottlenose diet (from Piroddi et al. (2010))	
Sardine	0.02
Anchovy	0.07
Other pelagics	0.05
Hake	0.44
Other demersal	0.39
Cephalopod	0.03

According to this data and also to the available information in literature, I choose that our carrying capacity will be influenced by the biomass fluctuation of only three species: sardine, anchovy and hake; meanwhile the remaining part (47%) will remain constant. The overall equation for the carrying capacity is:

$$K = K_0\big(0.47 + 0.53a(t)\big) \qquad (12)$$

Where K is the carrying capacity (number of individuals), K_0 is the carrying capacity at time t=0 and a is a dimensionless parameter which depends on the variation of biomass of sardine, anchovy and hake; a is equal to 1 at time t=0. This represent a carrying capacity composed by two terms, one constant and the other variable with time (t). K_0 ,which corresponds to the carrying capacity at the first year of observation 1930, it is calculated as:

$$K_0 = \frac{(1+Q) * B_0}{IB} \qquad (13)$$

Where B_0 is the biomass (t/y) of sardine, anchovy and hake available for the dolphin diet at t=0, Q is the ratio between the biomass of other species available for the diet over B_0 and IB (t/y) is the amount of food (t) consumed by one dolphin in a year.

The denominator of the equation (13) corresponds to the amount of food that a bottlenose dolphin can consume in one year. It was determined by the following equation (Bearzi et al., 2010):

$$IB = 0.035 * M \qquad (14)$$

Where IB is the ingested biomass (kg day^{-1}) and M (Kg) is the body mass which for the bottlenose dolphins is 200 kg (Christensen et al., 2006). It results that the amount of food necessary in one day for a dolphin are 7 kg, which in a year correspond to 2.55 ton.

The numerator of equation (13) represent the total biomass available for the dolphin consumption or in other words it is the biomass of the species involved minus the biomass catch by fisheries and the biomass eaten by the predators except by dolphins. It is expressed in function of the only biomass available of sardine, anchovy and hake at time t=0. The biomass ratio Q was calculated considering only these three preys because in literature there are not available time series data for all the fish species present in the bottlenose dolphin diet. So the biomass ratio Q results as:

$$Q = \frac{B_{Other\ species}}{B_{sardine+anchovy+hake}} \qquad (15)$$

It represents the proportion between the biomass of the 47% of the diet available for the consumption respect to the biomass available of sardine, anchovy and hake. The biomass available were calculated considering the data of total biomass B (t km^{-2}), the production rate P/B (y^{-1}), the fishing mortality F (y^{-1}) and the predation mortality (no by dolphins) M (y^{-1}):

$$B_{available} = (B_{tot} * A) * (P/B - F - M) \qquad (16)$$

Where A is the area of interest of 32.000 km^2. These parameters are found in the study of Barausse et al., 2009 which determine the food web network of the northern Adriatic sea.

The important parameter at the base of the variation of the carrying capacity is the biomass available for the dolphin diet of sardine, anchovy and hake from 1930 to 2013. For anchovy and sardine the data of total biomass and catch by fishery regards the period between 1976-2010 and they are related to the total area GSA 17 (AdriaMed, 2011a; AdriaMed, 2011b). So first of all they were referred to the northern Adriatic sea only, taking in account one reference value for each species available from past studies. Sardine biomass was taken by Stirn and Kubik (1974) estimated by 100000 ton in the 1972 (3.13 t km^{-2}), anchovy biomass was taken by

Stirn (1969) estimated to be 250000 ton in the 1965 (7.183 t km^{-2}). With this assumptions the total biomass of both the species was reduced by the 40%. The following step was to expand the series of data to all the missing years. In order to do this I apply a relationship which involved the catch per unit effort (CPUE) of the Chioggia fleet. Indeed from the Banca dati of Chioggia it is possible to obtain the Gross Registered Tonnage (GRT) of the fleet from the 1951 to nowadays. Divided each amount of fish catch by the GRT it is possible to obtain the CPUE. So the biomass for the years 1951-1975 was calculated as follows:

$$B_N = \frac{R}{CPUE_N} \qquad (17)$$

$$R = \frac{B_{avg\ 1976-1980}}{CPUE_{avg\ 1978-1980}} \qquad (18)$$

Where N are the years 1951-1975. For the years 1930-1950 it was supposed to take the value of biomass equal to the biomass of 1976. In the same manner was calculated the catch by fishery. About the component of the biomass eaten by other predators (except dolphins), it was consider a fraction of the total biomass predated according with the food network of Barausse et al., 2009. For the anchovy it correspond to the 78% and for sardine to the 57%. So applying the equation above (17) I obtain the value of the biomass for all the time series.

The same procedure was applied for the biomass of hake. In this case the series available was only between the 1975-2002 so it was extended with the equation (17) also for the recent years. In this case the data refer to another area, but no reference value for the northern Adriatic sea were found. So I consider that the biomass is uniformly distributed in all the area and the 57% was in the northern Adriatic. Then as proceeded before the biomass predated by the other species was estimated to be the 36%.

Summing the biomass available for sardine, anchovy and hake I found the total variation in time of the 53% of the diet of the bottlenose dolphin in the area. I can calculate so the B_0 and the a value which is:

$$a = \frac{B_N}{B_0} \qquad (19)$$

Where N are the years from 1930-2013 which correspond to t=0,1,2….N=84.

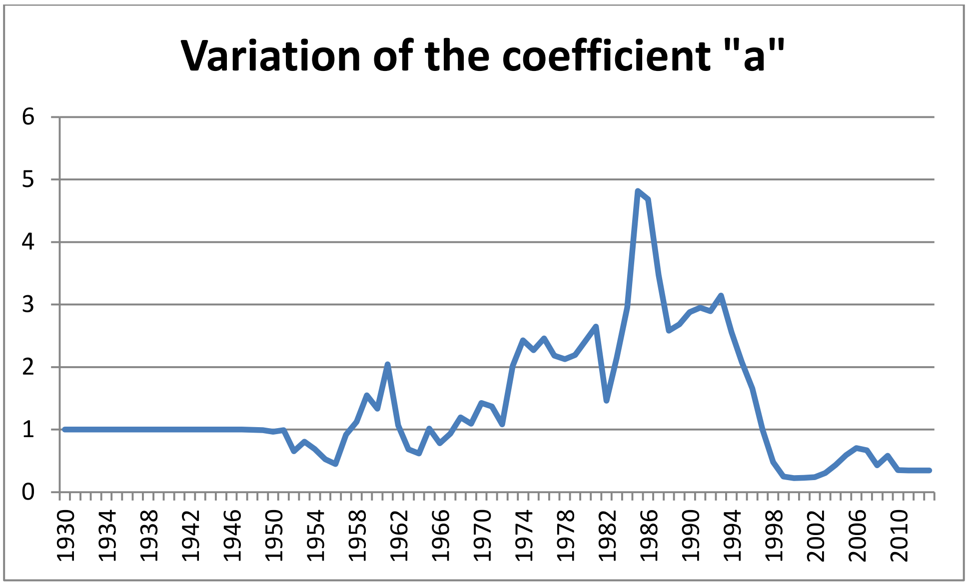

Figure 5. Graphical representation of the dimensionless parameter a showing the variation of the biomass of hake, sardine and anchovy over time.

Observed abundance population

From a survey conducted in the 2013 it was recorder that the most probable amount of dolphins is about 2754 with a CV of 20.5% and minimum 1840 and maximum 4123. It is possible that this value is underestimated due to the fact that a probable 30% of the population was immerged during the survey. Considering that the minimum population can be 3531 and minimum 2353, maximum 5256 (ISPRA, Unpublished data)

Catches

The model is dependent on the historical data available for the catching. The starting input for the series time data are the information available by Crnkovic (1958) and Marelic (1961), who give records of catches of dolphins for the years between 1930 and 1960 in the eastern coast of the northern Adriatic Sea during the killing campaign and they are reported in Bearzi 2004. This data has to be managed carefully due to the fact that first of all there are not clear indication of which kind of species are involved, if they are common dolphins or bottlenose dolphins, and second the possibility that this are just a little part of what was the real number of animals killed. About the western part of the Adriatic no data are present in the literature but it is possible to assume that the behavior of the Italian fleet would be the same as the Yugoslavian, because in the same years also the Italian government gets bounty for the dolphin killing. After the 1960s no more records of dolphins killed in the area are found, probably because no more rewards were available and so no one reported it. Anyway this doesn't mean that deliberate killing stopped.

Table 5. Numbers of dolphins killed during the culling campaign (1930-1960) along the eastern coast of the northern Adriatic sea.

Year	Number of dolphin killed	Reference
1933	99	Crnkovic, 1958
1934	160	Crnkovic, 1958
1935	76	Crnkovic, 1958
1955	60	Marelic 1961 (reported by Bearzi et al. 2004)
1956	119	Marelic 1961 (reported by Bearzi et al. 2004)
1957	150	Marelic 1961 (reported by Bearzi et al. 2004)
1958	200	Marelic 1961 (reported by Bearzi et al. 2004)
1959	214	Marelic 1961 (reported by Bearzi et al. 2004)
1960	45	Marelic 1961 (reported by Bearzi et al. 2004)

In the next years the situation changes in different way for the two side coasts of the Adriatic. In Italy, starting from the beginning of the 1980s the perception of dolphins as a big treat changes in a less severe opinion and they start to be protected by the government and the international laws. Anyway even if no more intentional killings were allowed, by-catches and accidental mortality still continue, especially at the increasing of the fishing fleet. Considering instead the east side of the Adriatic killing dolphins remain legal until the 1995 and moreover the Croatian fleet increases its numbers year after year.

No records can help in order to design a picture of the by-catches in the all area. Some study where conducted following the fisheries during their hauls but they obtain not reliable estimate (Fortuna, 2010).

Considering that, it was not possible to establish a series of data based on literature values, but anyway some hypothesis can be done:

- Even if the data of Crnkovic and Marelic does not specify the species involved, it was supposed by a study of Gomeric and al. (1998) that in the 1930s in the Adriatic sea the dolphin population was composed by the 60% of common dolphins and the remain 40% were bottlenose dolphins.

- For the first 30-40 years I take in account that only intentional catches were the main reason for the dolphin death. For the 1970s until nowadays, by-catches are instead the main threat for their depletion.

Procedure:

From the 1930 to the 1970 I take in consideration that only direct killings can affect in a substantial way the bottlenose population. Because it is no possible to know which kind of species were involved (due to the fact that in these years also common dolphins inhabit the area), I consider a study of Gomeric and al. (1998) in which the total amount of dolphins was divided as follow: 60% were common dolphins and 40% bottlenose dolphins. Considering also that nowadays only bottlenose inhabit the northern Adriatic sea, I linearly decrease the presence of common dolphins, from the 1930s to the late 1980s, when it is consider that this species is disappeared from the area. So from the 1933-1935 are available the data of Crnkovic (1958) and I consider constant the number of killing of the 1933 for each previous year. From the 1936 to 1938 I take an average value of the available data. Then I consider that during the Second World Word 1940-1945 catching activity decreased, reaching low levels, I consider the minimum value of 20 animals per year (it is the estimate by-catch of the current years). In the 1939 the number of killing animals is found by a linear relationship between 1938-1940. After the war as a consequence of the economic recovery the number of death increases until reach the values for the gap 1955-1960. So from the 1945 to 1955 I used a linear relationship between the two extreme values. This series of data, which are referred only for the eastern side of the Adriatic are repeated equally for the western coast, because similar attitude was shown by Italy in these years so similar suggestions can be done.

After the 1960, when no more rewards were available by the governments, probably deliberate killings remain anyway considerable (I consider for at least 10 years, bearing in mind that the culling campaigns probably lasts in the 1965 (Bearzi et al., 2004) and moreover remembering that only in the 1980 Italy prohibited the deliberate killings). So I take an average of the value between the 1946-1960, because I suppose it represents a scenario between the voluntary and unintentional killings. From the 1970 to 2013 I consider a linear relation for the two extreme years. For the 1970 the number of killings is equal to the average value of the potential killing between 1946-1950, because in this years no culling campaign occurs. For the 2013 it is adopted a value of by-catch of 22 mammals (Fortuna, 2010).

The linear relationship used in order to expand the time series is the following:

$$N_t = \left(\frac{N_n - N_0}{n}\right) * t + N_0 \qquad (20)$$

Where: N_t is the number of killed animals in the year t, N_n is the number of killed animals in the last year of the series, N_0 is the number of killed animals at the beginning and t is the subscript for time t=0,1…n.

Three scenarios were consider in the analysis. The first is represented by the previous procedure called minimum catches, the second doubles the minimum catches and the third triplicate the values.

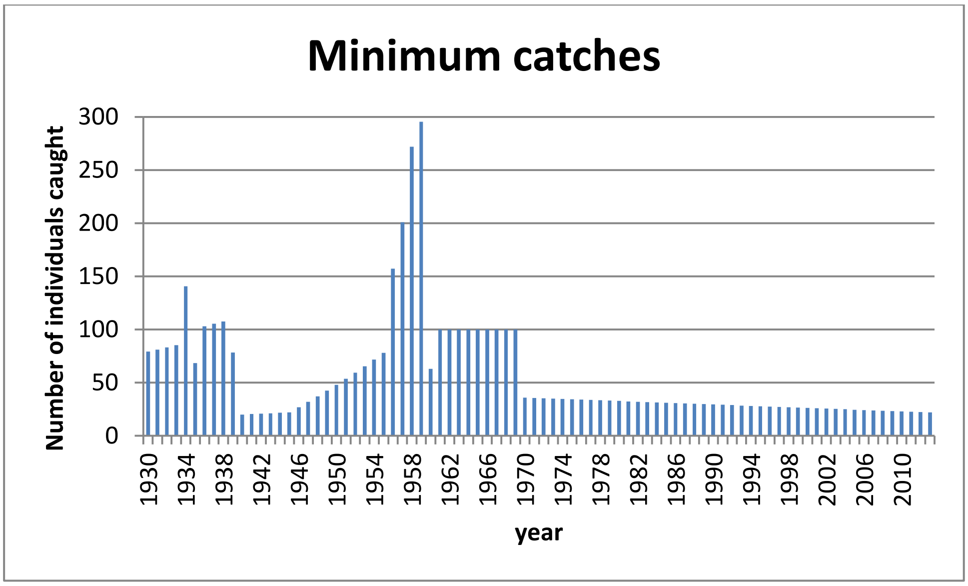

Figure 6. Graphical representation of the number of catches for each year for minimum values

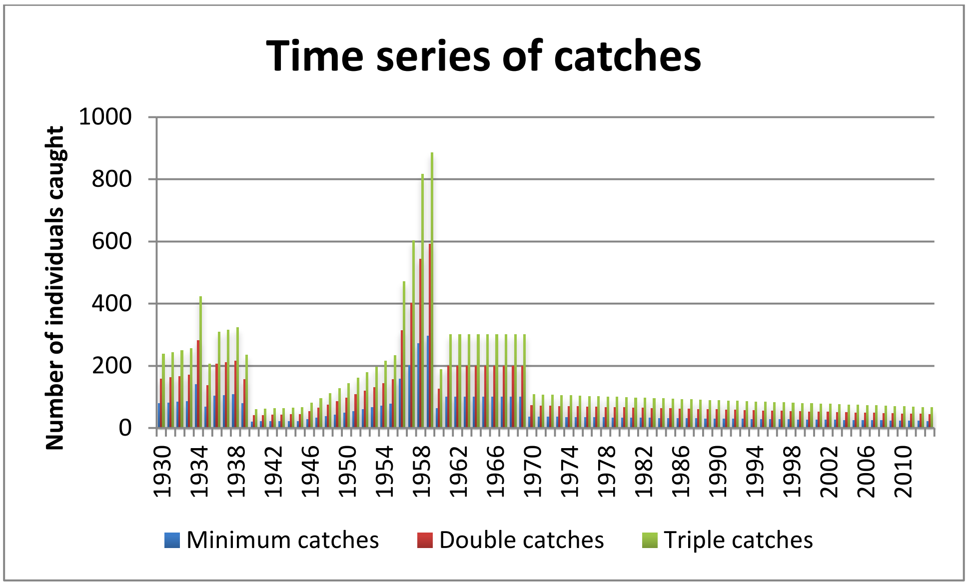

Figure 7. Graphical representation of the number of catches for each year and also a representation of the three cases of minimum, double and triple catches.

Sensitivity analysis

In order to evaluate the potential bias of the model, I generate a set of abundance observation considering that no errors occur in the r and K parameters, so w_t is set to zero. I set up r_{max} = 0.123 and K_0 = 10000. Running the first part of the model just one time I have obtained one trajectory of simulated observation abundance. Then I run the SSRA between two observation abundance of the previous part and I consider the presence of observation errors proportional to the total error for the 10% and 30%, prop = 0.1 and prop = 0.3 respectively.

In order to determine the bias I standardize the parameters with the ratio between the values estimated and the real value. Then I consider the logarithm base 2 and the normal distribution of these values.

$$\text{bias} = \log_2\left(\frac{\text{estimated}}{\text{real}}\right) \qquad (21)$$

This means that if the bias-ratio is equal to zero, no bias is present in the model. If the bias-ratio is positive there is an overestimation of the parameters by a factor of 2 if the bias is 1, and opposite if the bias-ratio is negative, cause I will have an underestimation.

In the following graphs are presented the results for an observation error of 0.1.

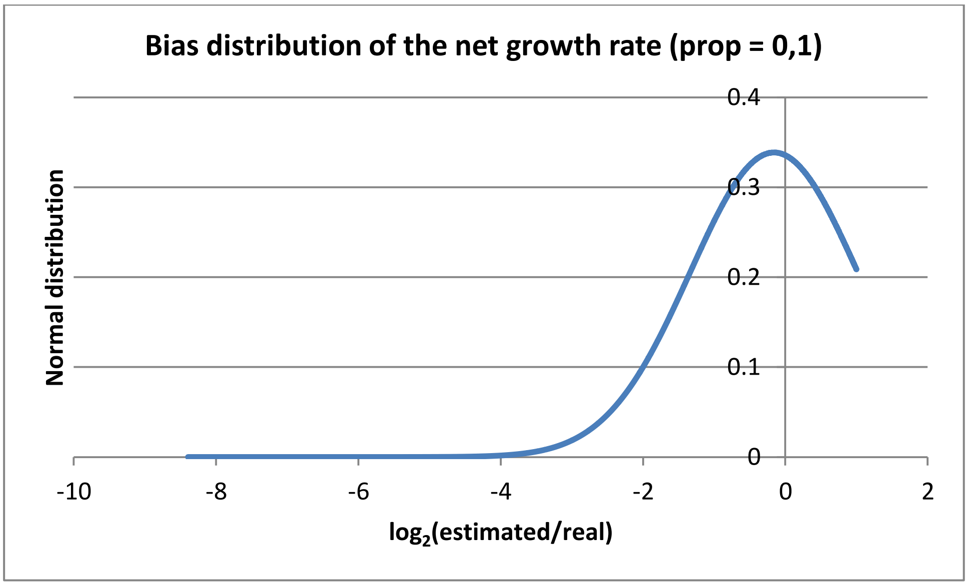

Figure 8. Distribution of the posterior sampling of the net growth rate considering an observation error proportional to the total error for the 10%

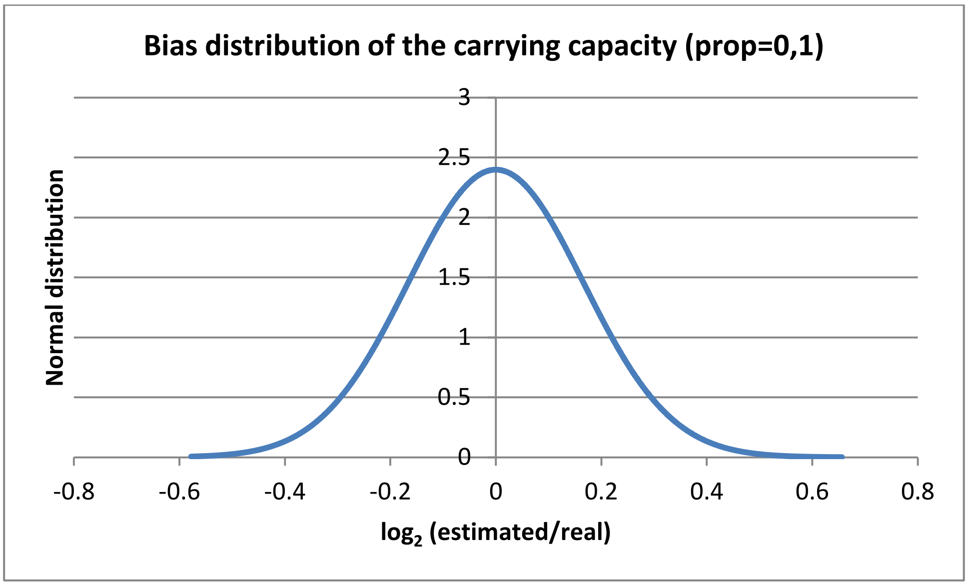

Figure 9. Distribution of the posterior sampling of the carrying capacity considering an observation error proportional to the total error for the 10%

The results presented in the two graphs above show that the net growth rate is slightly negative bias, -0.11, so underestimated. The carrying capacity instead is overestimated, showing the peak of the curve at the right side of the ax (+0.012).

Another test was done considering the proportion of the abundance error of the 30% respect the total error, which will be the proportion error used in the model.

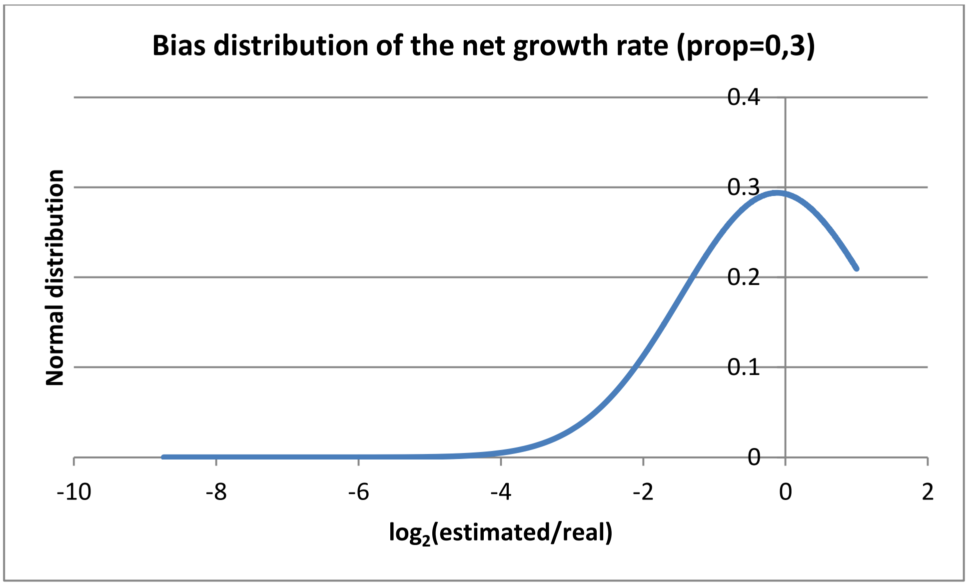

Figure 10. Distribution of the posterior sampling of the net growth rate considering an observation error proportional to the total error for the 30%

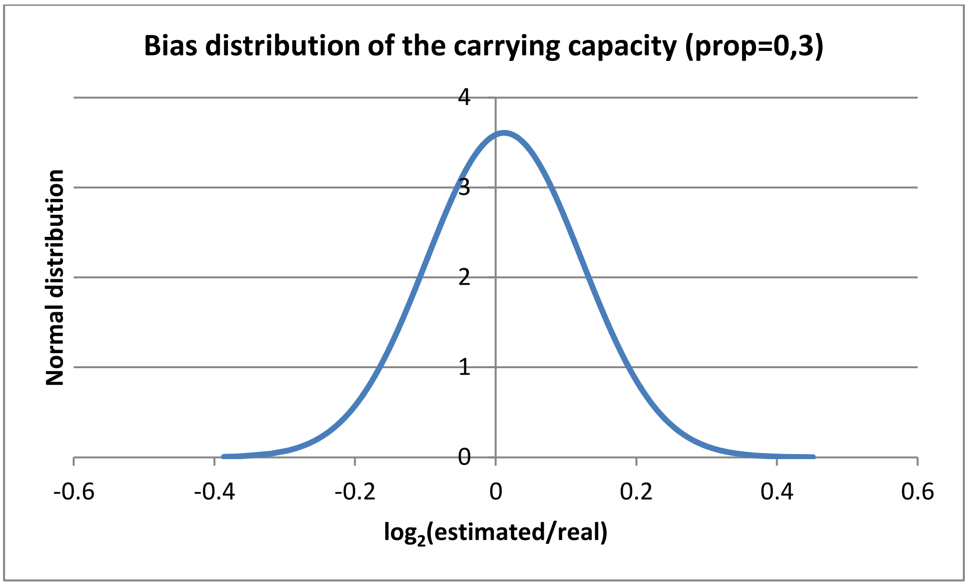

Figure 11. Distribution of the posterior sampling of the carrying capacity considering an observation error proportional to the total error for the 30%

In this case both r and K became underestimated. For the net growth rate the bias became -0.16 and the carrying capacity -0.000016. So the carrying capacity seems to be estimated correctly, instead the net growth rate increase the error.

Results

The following chapter presents the results of the input data modeling and the SSRA estimation outputs.

The net growth rate parameter (r_{max}) was obtained by the mean of the values of table 3. It results to be r_{max} = 0.123 with a standard deviation of sdr_{max} = 0.08 (this considers also the possibility that a calf can be born every 2 and 6 years also). The model was run also with a coefficient half of the previous (r_{max} = 0.06 and sdr_{max} = 0.04) in order to see what happens if I consider a worst situation than before.

The carrying capacity K_0 was determined by the equation 13. The ratio Q was 0.28 from the equation 15 and the biomass available of hake, anchovy and sardine (B_0) was calculated to be 44329 ton. The K_0 was estimated to be 22208 individuals. But because in the 1930s two dolphin species were present in the northern Adriatic sea and the common dolphins were about the 60% of the total population; the K_0, considering only the bottlenose dolphins, was calculated to be the 40% of the previous, so about 8883 individuals (Gomercic H. et al., 1998).

The model generates 50.000 trajectories by taking 50.000 couple of values of K_0 and r_{max}. The values taken are the result of the prior normal distribution of these two values. The net growth rate is normal distributed between 0 and two times its mean value, the carrying capacity is uniformly distributed between a minimum and maximum value of K_0. These trajectories are then weighed by the likelihood function which give raise to the results plotted in the graphs. Three graphs are presented for each run: the trajectory of the population estimation (the median), two quantiles (0.025 and 0.975) corresponding to the 95% confidence intervals and a red dot representing the observed abundance estimation . The second and third graph represents the posterior density distribution of the carrying capacity and the intrinsic rate of growth (the red-dot line represent the prior normal distribution of the growth rate).

The following pages present the results of the model as a combination of the net growth rate, the carrying capacity and the time series of catches.

- Scenario A: it presents the results of the model with r_{max} = 0.123considering the combination of the three time series of catches (minimum, double and triple) and two intervals for the carrying capacity K_0, ±10%K_0 and ±60%K_0;
- Scenario B: it presents the results of the model with r_{max} = 0.06considering the combination of the three time series of catches (minimum, double and triple) and two intervals for the carrying capacity K_0, ±10%K_0 and ±60%K_0;

Moreover in order to see if the carrying capacity as a function of time influenced the results of the model, I applied the Christensen methodology (Christensen, 2006) which instead uses constant carrying capacity for each year:

- Scenario C: it presents the results of the Christensen model applying a r_{max} = 0.123 with an interval of minK_0 and maxK_0 calculated by the ±60%K_0 for the three time series of catches (minimum, double and triple);
- Scenario D: it presents the results of the Christensen model applying a r_{max} = 0.06 with an interval of minK_0 and maxK_0 calculated by the ±60%K_0 for the three time series of catches (minimum, double and triple).

Scenario A: r_{max} = 0.123

Scenario A1 – first run (±10%K_0)

Table 6. Input data of net growth rate and carrying capacity of the first run of scenario A1 of minimum catches.

MINIMUM CATCHES – FIRST RUN	
Mean r_{max}	0.123
Sd r_{max}	0.08
K_0	8883
Min K_0	$K_0 - 10\%K_0$
Max K_0	$K_0 + 10\%K_0$

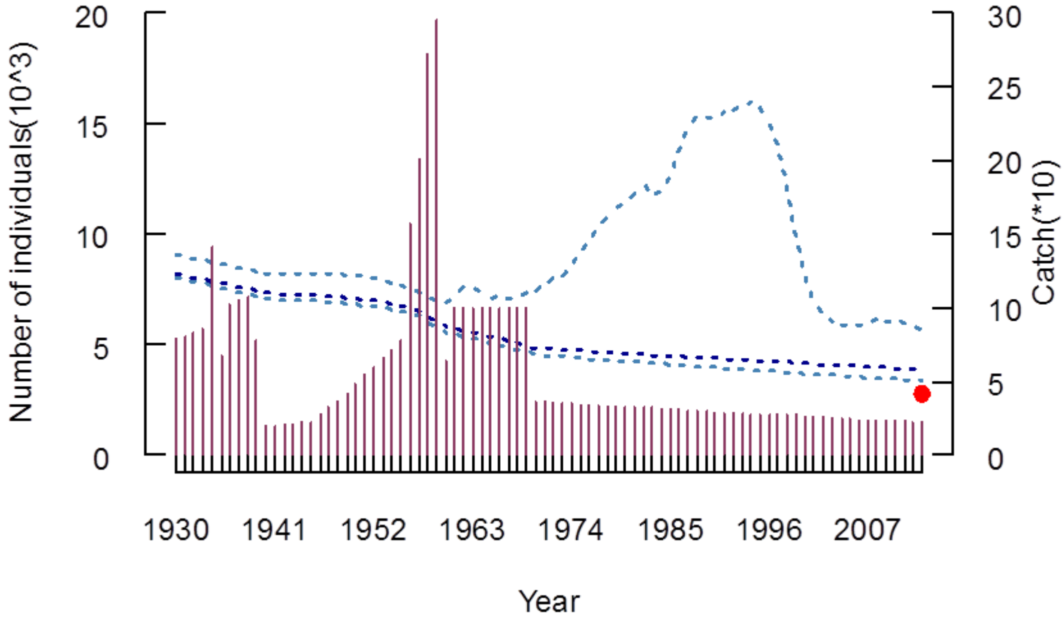

Figure 12. Trajectories for the run with minimum catches, r_{max}=0.123 and carrying capacity in a range ±10%.

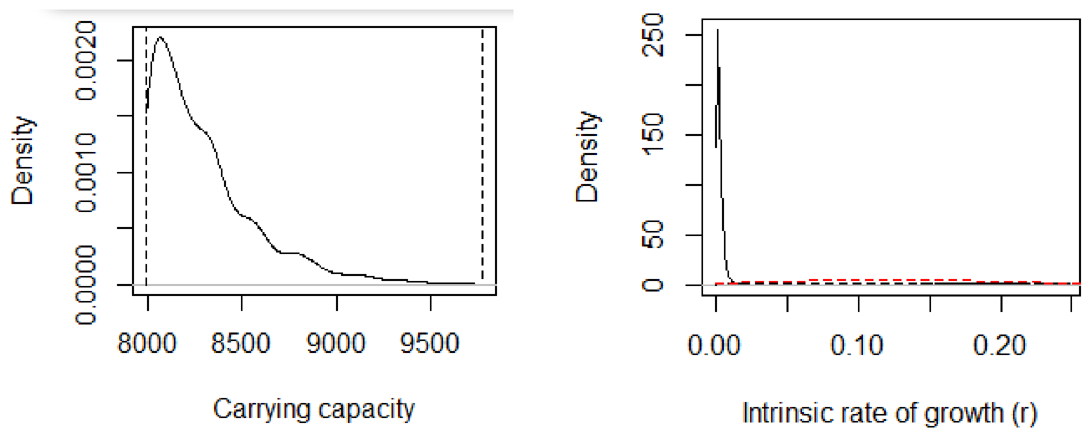

Figure 13. Posterior density distribution of K_0 and r_{max} for scenario A1 – first run.

Considering figure 12, the trajectory resulted with this data cannot reach the abundance estimation point, meaning that this set of input data picture an optimistic condition respect the real one (there is a combination of high growth rate and carrying capacity parameters with minimum catches). This is confirmed by the posterior density distribution (figure 13) which both of them are shifted on the left side of the graph, suggesting that lower values are necessary in order that the trajectory of the population pass through the abundance observation.

Scenario A1 – second run (±60% K_0)

Table 7. Input data of net growth rate and carrying capacity of the second run of scenario A1 of minimum catches.

MINIMUM CATCHES – SECOND RUN	
Mean r_{max}	0.123
Sd r_{max}	0.08
K_0	8883
Min K_0	K_0 – 60% K_0
Max K_0	K_0 + 60% K_0

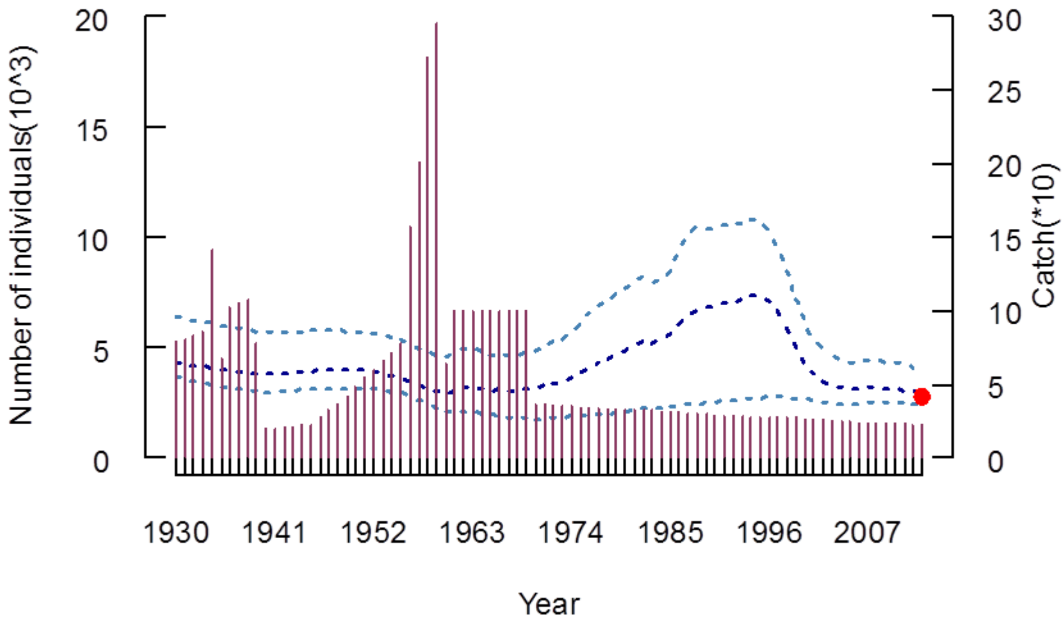

Figure 14. Trajectories for the run with minimum catches, r_{max}=0.123 and carrying capacity in a range ±60%.

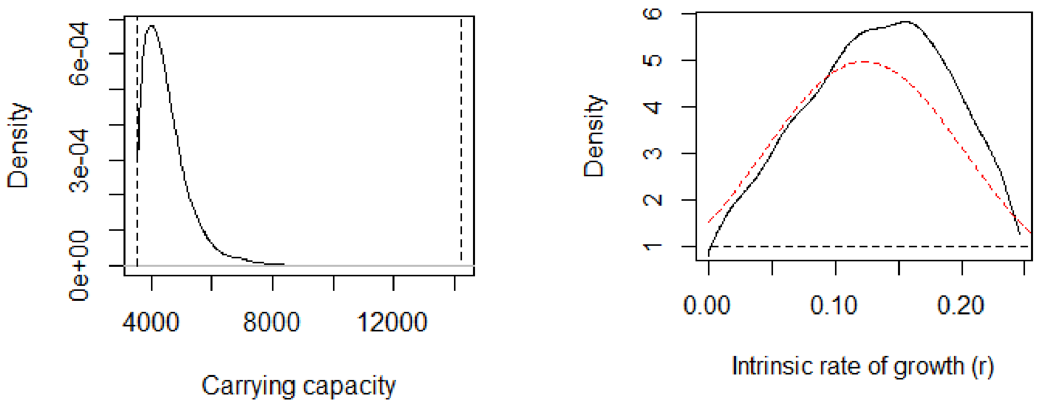

Figure 15. Posterior density distribution of K_0 and r_{max} for scenario A1 – second run.

In this second run the carrying capacity interval is increased (±60%), so the model can take its values in a wide range. The two posterior density curves shows better than the previous scenario, the intervals in which the parameters are taken. The carrying capacity is chosen in an short interval form 4000 to a maximum of 8000 instead the net growth rate values are taken in all the interval between 0 and two times the mean r_{max} (0.123). The carrying capacity established in the 1930 is K_0 = 4310 individuals and the depletion is the 32%. It is significant that the trajectories pictured by the model reflected the trend of the carrying capacity modeled with the biomass of anchovy, hake and sardine varying in time. Such kind of dolphin biomass trajectory is probably not realistic (Caterina Maria Fortuna, personal communication).

Scenario A2 – first run (±10%K_0)

Table 8. Input data of net growth rate and carrying capacity of the first run of scenario A2 of double catches.

DOUBLE CATCHES – FIRST RUN	
Mean r_{max}	0.123
Sd r_{max}	0.08
K_0	8883
Min K_0	K_0 – 10% K_0
Max K_0	K_0 + 10% K_0

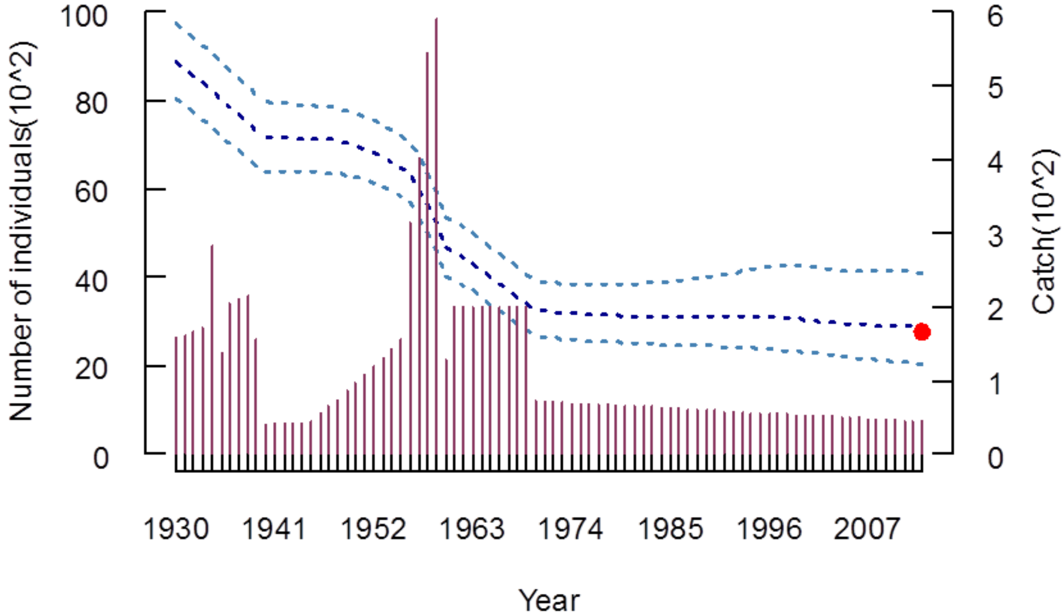

Figure 16. Trajectories for the run with double catches, r_{max}=0.123 and carrying capacity in a range ±10%.

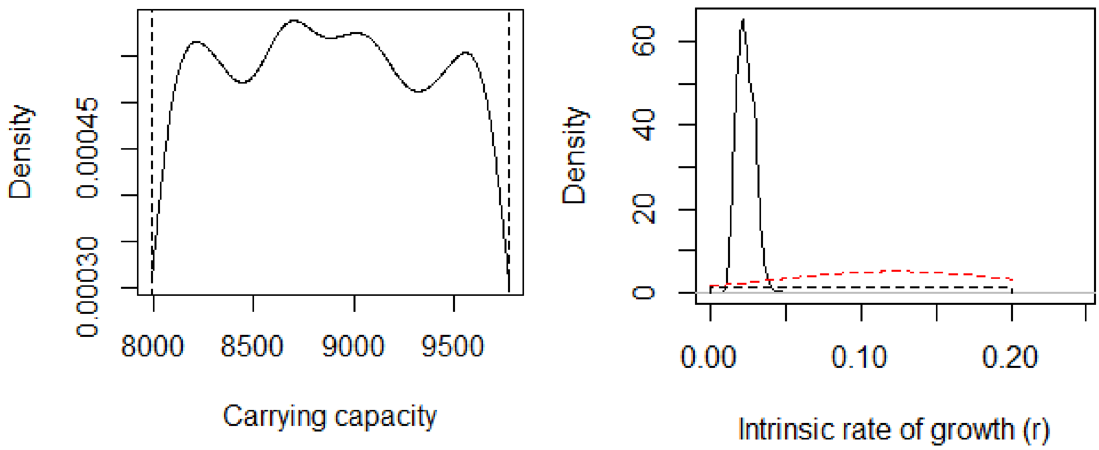

Figure 17. Posterior density distribution of K_0 and r_{max} for scenario A2 – first run.

From the median trajectory the carrying capacity results to be K_0 = 8870 individuals and the depletion is 68%. Two different behaviors are represented by the posterior density graphs: there are uncertainties in the estimation of the carrying capacity over the narrow range of variation allowed but on the contrary the intrinsic rate of growth shows that only in a narrow interval it is possible to find the value that best fits this situation.

Scenario A2 – second run (±60%K_0)

Table 9. Input data of net growth rate and carrying capacity of the second run of scenario A2 of double catches.

DOUBLE CATCHES – SECOND RUN	
Mean r_{max}	0.123
Sd r_{max}	0.08
K_0	8883
Min K_0	K_0 – 60% K_0
Max K_0	K_0 + 60% K_0

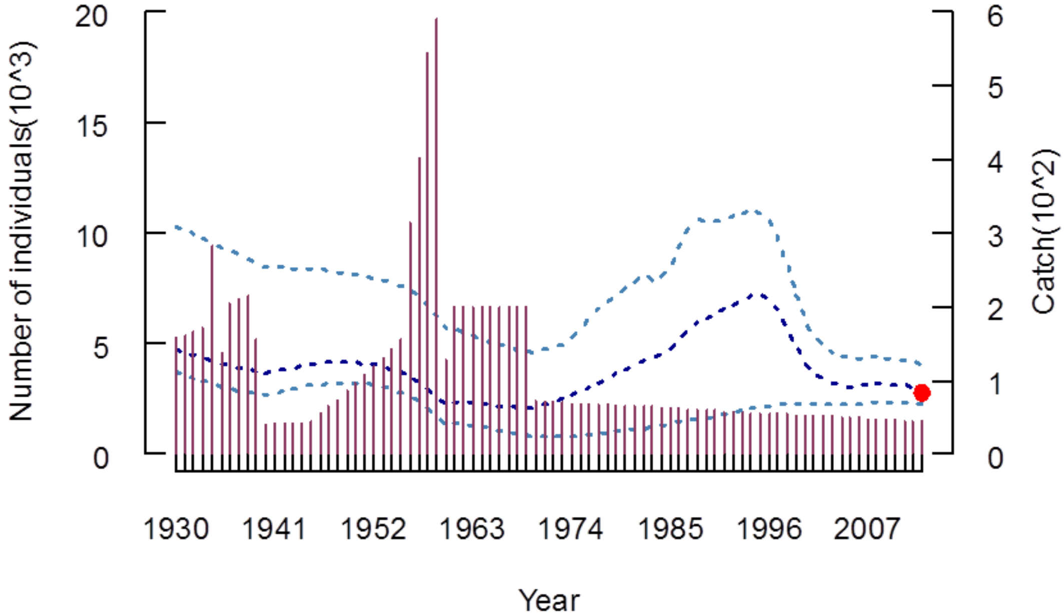

Figure 18. Trajectories for the run with double catches, r_{max}=0.123 and carrying capacity in a range ±60%.

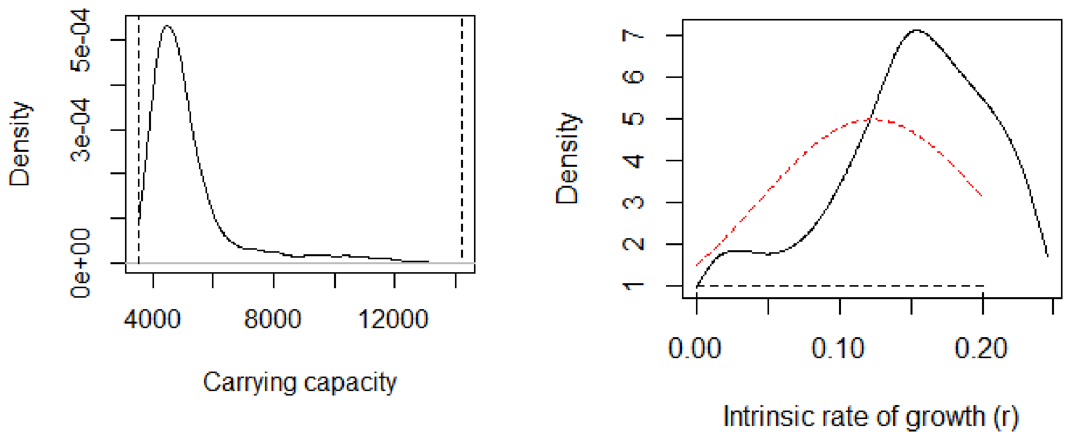

Figure 19. Posterior density distribution of K_0 and r_{max} for scenario A2 – second run.

In this scenario the K_0 reaches a value of 4770 individuals and as the consequence the depletion decrease at 38%. As it can be seen from figure 18 increasing the range of the carrying capacity has the consequence to decrease the estimation of the carrying capacity itself in the 1930. Indeed the posterior density distribution of the carrying capacity covers a narrow interval and somehow resembles a log-normal distribution. Instead the net growth rate shows a value completely different from the previous scenario (A2 – first run), showing that at the increase of the interval of the carrying capacity the model has higher uncertainties in the determination of the best fitting value of the net growth rate.

Scenario A3 – first run (±10%K_0)

Table 10. Input data of net growth rate and carrying capacity of the first run of scenario A3 of triple catches.

TRIPLE CATCHES – FIRST RUN	
Mean r_{max}	0.123
Sd r_{max}	0.08
K_0	8883
Min K_0	K_0 – 10% K_0
Max K_0	K_0 + 10% K_0

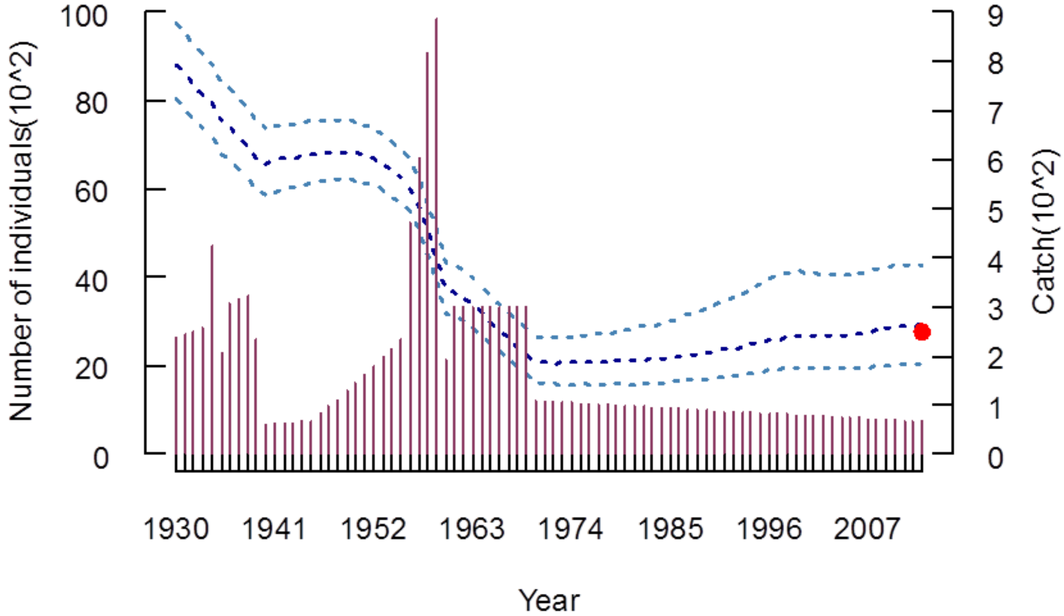

Figure 20. Trajectories for the run with triple catches, r_{max}=0.123 and carrying capacity in a range ±10%.

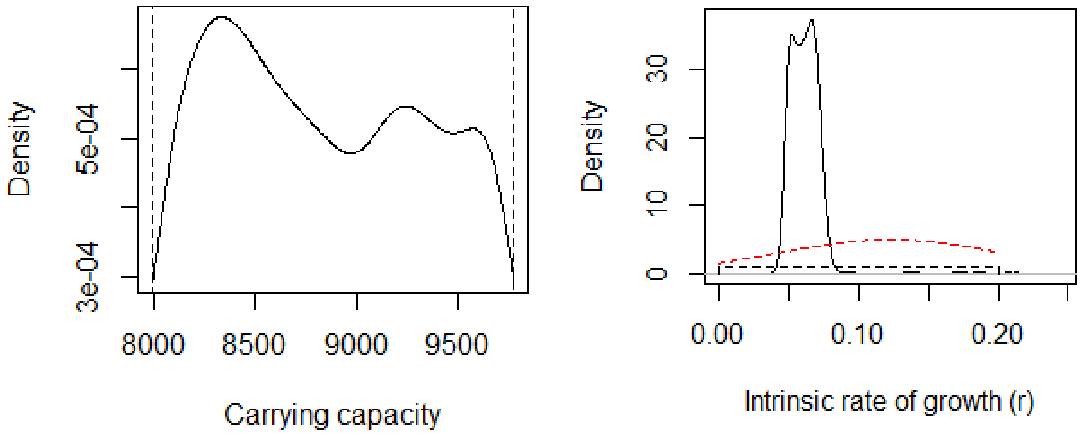

Figure 21. Posterior density distribution of K_0 and r_{max} for scenario A3 – first run.

This scenario represent the trajectories modeled considering to triplicate the minimum catches. The K_0 is reached at 8820 individuals and the depletion is 67%. This scenario is similar to the previous one (A2 – first run) in the determination of the number of individuals in the 1930 and the depletion. The density posterior distributions presented uncertainties in the determination of the carrying capacity and the net growth rate shows a high peak in a short interval of values, that are lower with respect to the mean r_{max} given as input value.

Scenario A3 – second run (±60%K_0)

Table 11. Input data of net growth rate and carrying capacity of the second run of scenario A3 of triple catches.

TRIPLE CATCHES – SECOND RUN	
Mean r_{max}	0.123
Sd r_{max}	0.08
K_0	8883
Min K_0	K_0 – 60% K_0
Max K_0	K_0 + 60% K_0

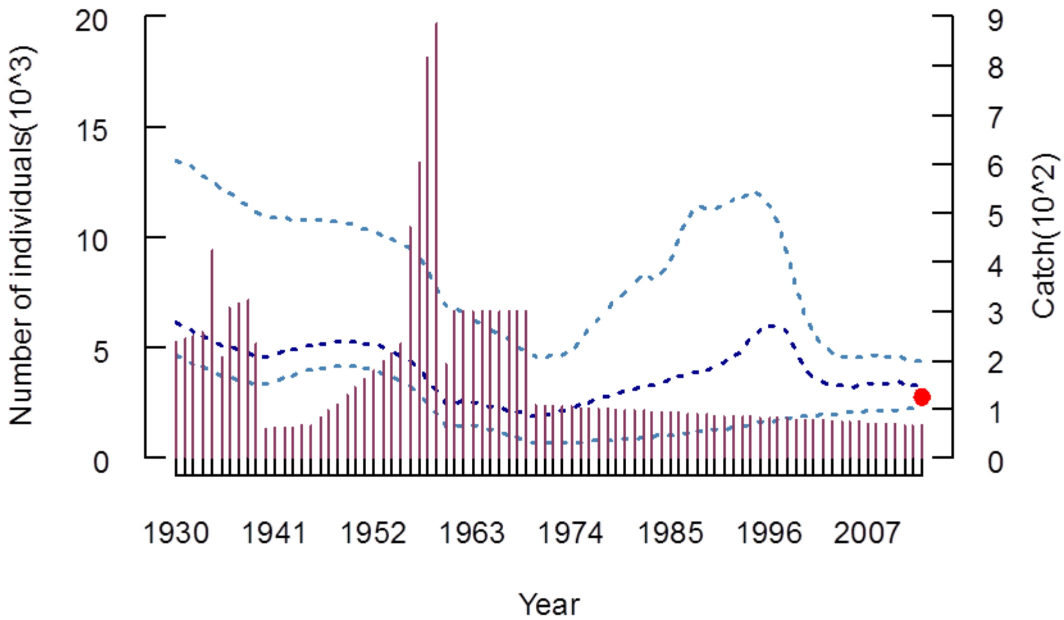

Figure 22. Trajectories for the run with triple catches, r_{max}=0.123 and carrying capacity in a range ±60%.

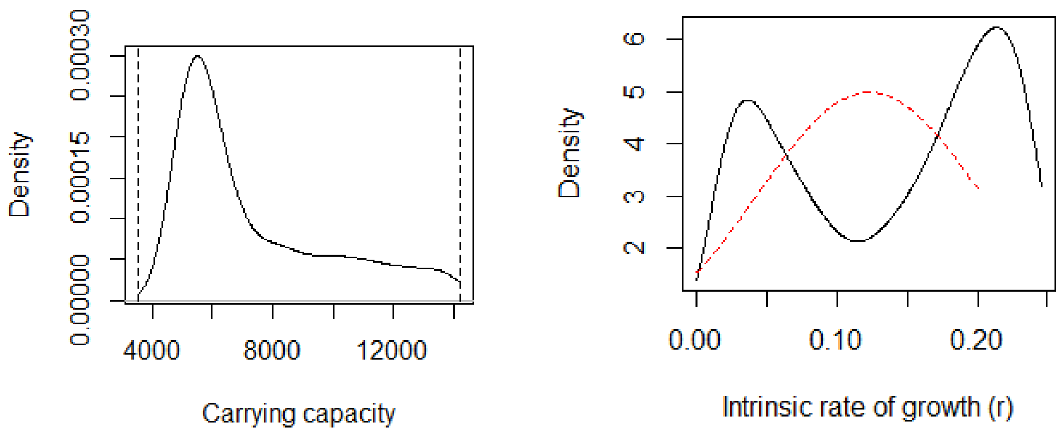

Figure 23. Posterior density distribution of K_0 and r_{max} for scenario A3 – second run.

The depletion in this case will be of 47% with a K_0 of 6160 individuals. The posterior density graphs shows an opposite distribution respect the previous case (A3 – first run): a log-normal distribution for the carrying capacity but higher uncertainties in the determination of the intrinsic net growth rate. The trajectories of the population represent a continuous decrease of the population from 1930 to 1970, which reflect the culling campaigns occurring in this period, and from 1970 to 2013 they follow the trend of the variation of the carrying capacity in function of the variation of the biomass of anchovy, sardine and hake in time.

Scenario B: r_{max} = 0.06

Scenario B1 – first run (±10%K_0)

Table 12. Input data of net growth rate and carrying capacity of the first run of scenario B1 of minimum catches.

MINIMUM CATCHES – FIRST RUN	
Mean r_{max}	0.06
Sd r_{max}	0.04
K_0	8883
Min K_0	K_0 – 10% K_0
Max K_0	K_0 + 10% K_0

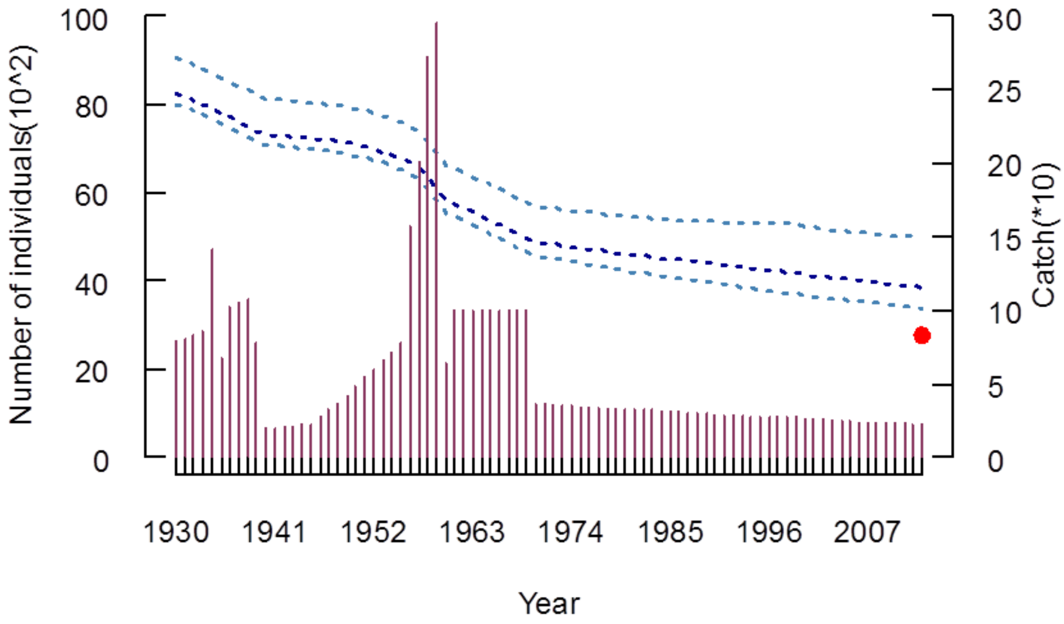

Figure 24. Trajectories for the run with minimum catches, r_{max}=0.06 and carrying capacity in a range ±10%.

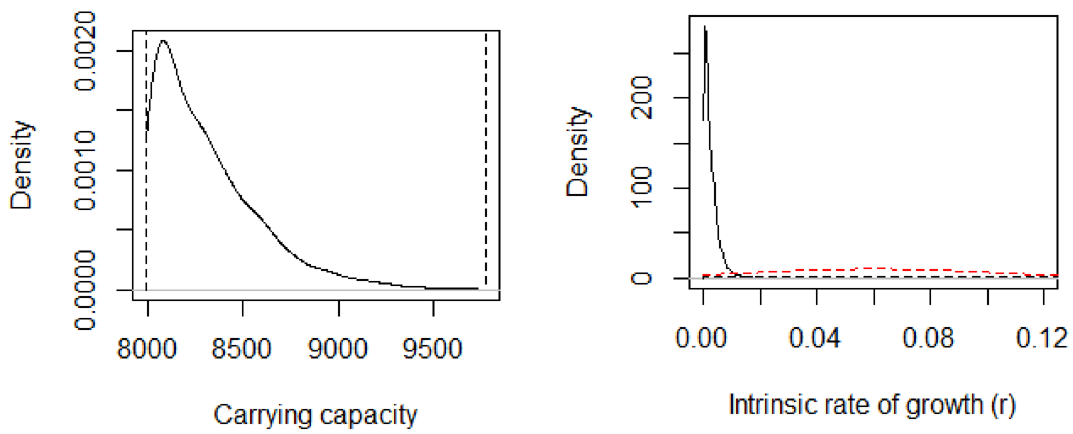

Figure 25. Posterior density distribution of K_0 and r_{max} for scenario B1 – first run.

In this scenario the model was run using a low net growth rate parameter (r_{max} = 0.06). It is similar to the A1-first run scenario because there are not marked differences in the values of $K_{0,}$ which is of about 8220 individuals and the depletion, 53%. Moreover, as in that case, both the posterior density graphs shows a shift on the left side towards low values.

Scenario B1 – second run (±60%K_0)

Table 13. Input data of net growth rate and carrying capacity of the second run of scenario B1 of minimum catches.

MINIMUM CATCHES – SECOND RUN	
Mean r_{max}	0.06
Sd r_{max}	0.04
K_0	8883
Min K_0	K_0 – 60% K_0
Max K_0	K_0 + 60% K_0

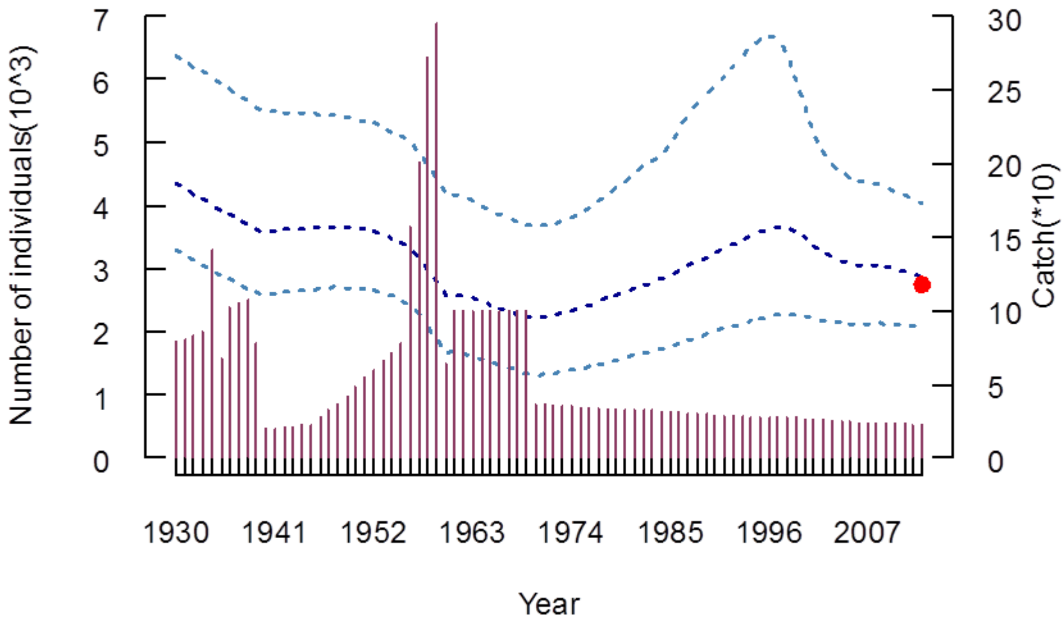

Figure 26. Trajectories for the run with minimum catches, r_{max}=0.06 and carrying capacity in a range ±60%.

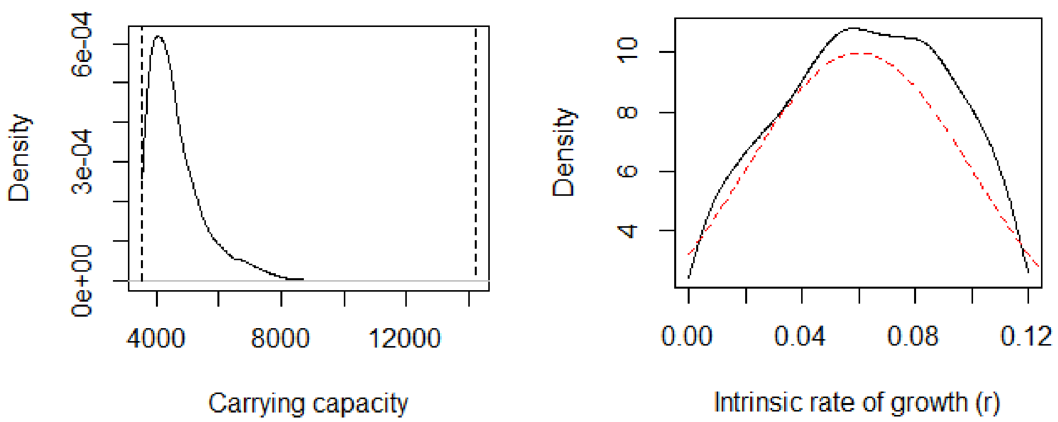

Figure 27. Posterior density distribution of K_0 and r_{max} for scenario B1 – second run.

In this scenario, with an increase of the interval of the carrying capacity, respect to the first run the K_0 is lower of almost the half (4400 individuals) and the depletion is 33%. The posterior density distribution of carrying capacity shows a log-normal distribution in a narrow interval, meaning that there is an higher certainty in the determination of the value. The net growth rate curve instead represents a more uncertainty determination of the plausible value. As in the scenario A1 – second run the trajectories depicted a trend following the variation of the biomass of hake, anchovy and sardine form the 1970 to 2013.

Scenario B2 – first run (±10%K_0)

Table 14. Input data of net growth rate and carrying capacity of the first run of scenario B2 of double catches.

DOUBLE CATCHES – FIRST RUN	
Mean r_{max}	0.06
Sd r_{max}	0.04
K_0	8883
Min K_0	K_0 – 10% K_0
Max K_0	K_0 + 10% K_0

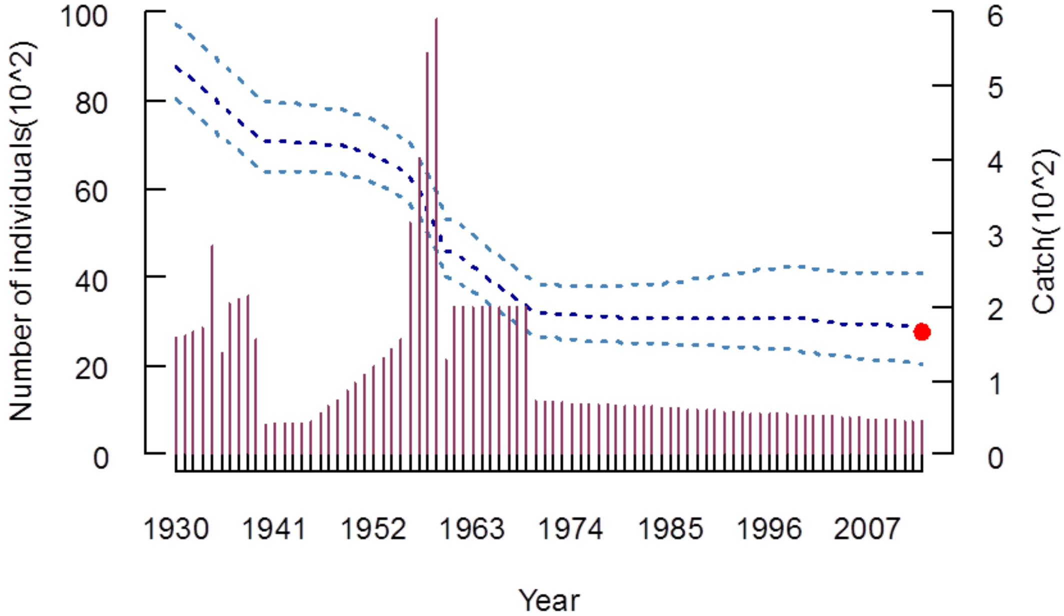

Figure 28. Trajectories for the run with double catches, r_{max}=0.06 and carrying capacity in a range ±10%.

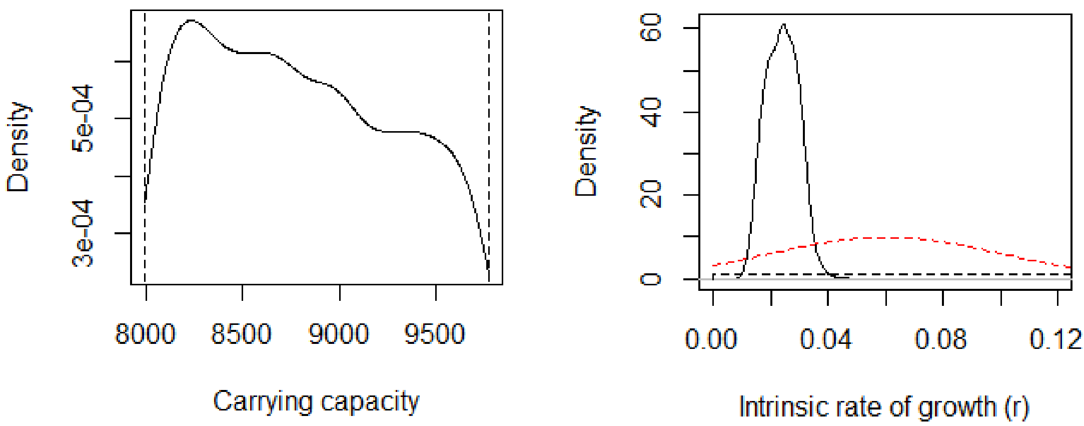

Figure 29. Posterior density distribution of K_0 and r_{max} for scenario B2 – first run.

As happened in the scenario A2 – first run for double catches, the posterior density graphs shows uncertainties in the estimation of the carrying capacity and instead a peak value of the net growth rate in a short interval which is lower than the mean r_{max} value given as input data. The K_0 = 8780 individuals and the depletion is 67%. The trajectories follow the behavior of the catches: there is a big difference between the population in the 1930 respect to the 1970 that reflects the highest catches occurred due to the culling campaigns.

Scenario B2 – second run (±60%K_0)

Table 15. Input data of net growth rate and carrying capacity of the second run of scenario B2 of double catches.

DOUBLE CATCHES – SECOND RUN	
Mean r_{max}	0.06
Sd r_{max}	0.04
K_0	8883
Min K_0	K_0 – 60% K_0
Max K_0	K_0 + 60% K_0

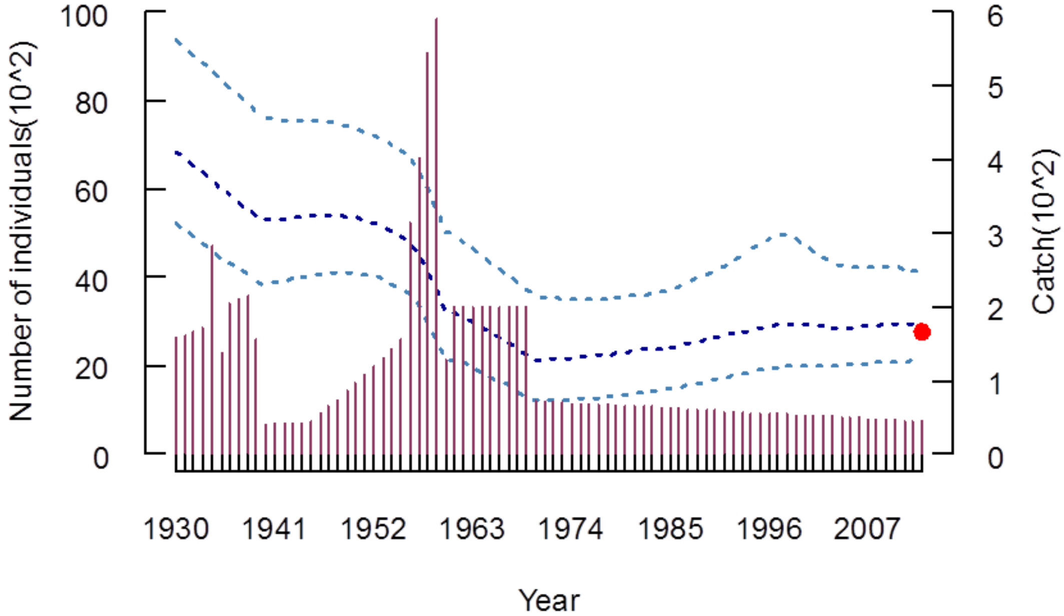

Figure 30. Trajectories for the run with double catches, r_{max}=0.06 and carrying capacity in a range ±60%.

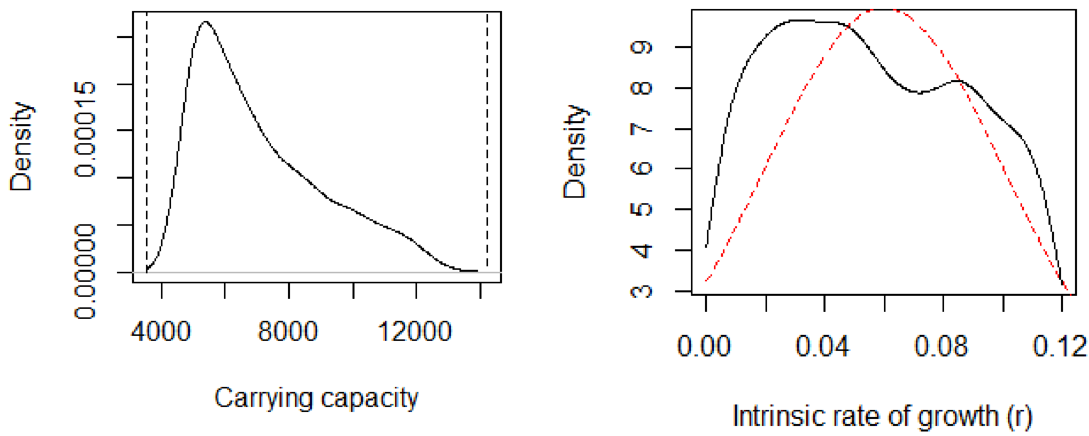

Figure 31. Posterior density distribution of K_0 and r_{max} for scenario B2 – second run.

In this scenario the posterior density distribution of carrying capacity shows a peak around 6000 individuals, instead the net growth rate shows uncertainties in its determination in the input range. So the K_0 is 6520 individuals and the depletion is 54%. The trajectories still reflect the time series of catches, especially for the first 40 years and then form the 1970 they shows a continuous increase, suggesting a recovery of the population until nowadays. Anyway in this scenario, in the last 40 years the trajectory seems not to reflect the carrying capacity varying with time and so following the biomass trend of anchovy, sardine and hake which instead is represented in the scenario B1 – second run.

Scenario B3 – first run (±10%K_0)

Table 16. Input data of net growth rate and carrying capacity of the first run of scenario B3 of triple catches

TRIPLE CATCHES – FIRST RUN	
Mean r_{max}	0.06
Sd r_{max}	0.04
K_0	8883
Min K_0	K_0 – 10% K_0
Max K_0	K_0 + 10% K_0

Figure 32. Trajectories for the run with triple catches, r_{max}=0.06 and carrying capacity in a range ±10%.

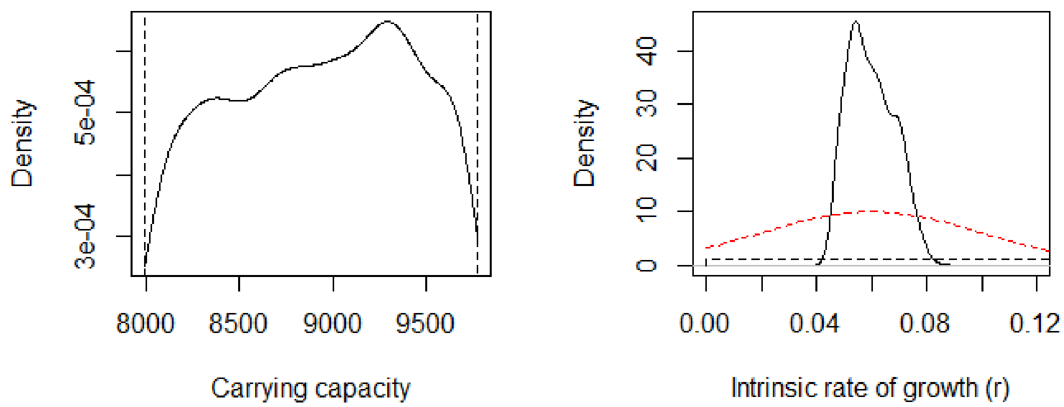

Figure 33. Posterior density distribution of K_0 and r_{max} for scenario B3 – first run.

This scenario is similar to the B2 – first run. The posterior density distribution curves show a trend like the previous of B2. Moreover also the carrying capacity and depletion rate are similar: K_0 = 8920 individuals and depletion 67%.

Scenario B3 – second run (±60%K_0)

Table 17. Input data of net growth rate and carrying capacity of the second run of scenario B3 of triple catches

TRIPLE CATCHES – SECOND RUN	
Mean r_{max}	0.06
Sd r_{max}	0.04
K_0	8883
Min K_0	K_0 – 60% K_0
Max K_0	K_0 + 60% K_0

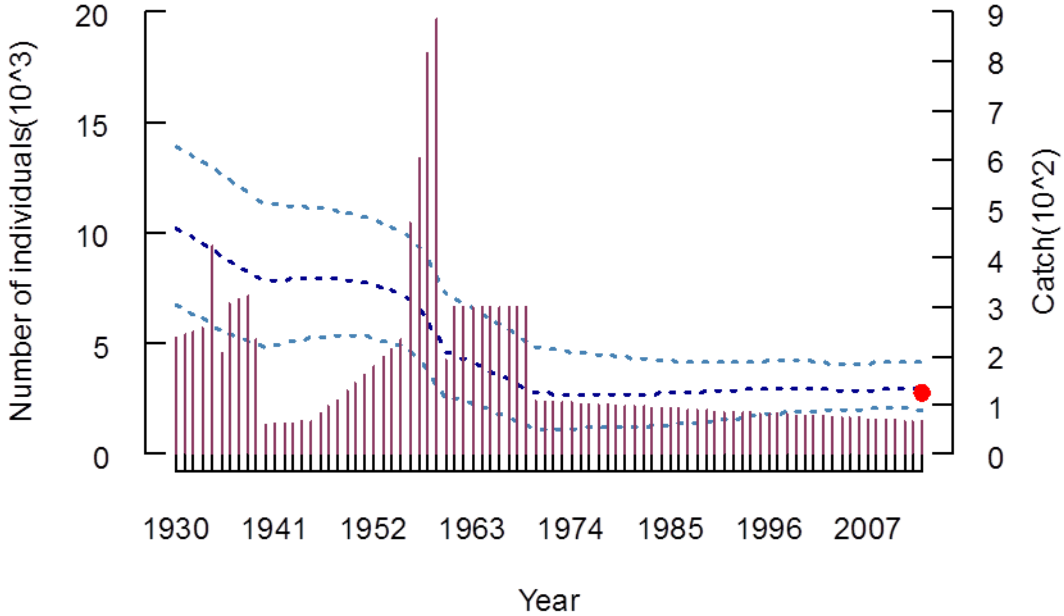

Figure 34. Trajectories for the run with triple catches, r_{max}=0.06 and carrying capacity in a range ±60%.

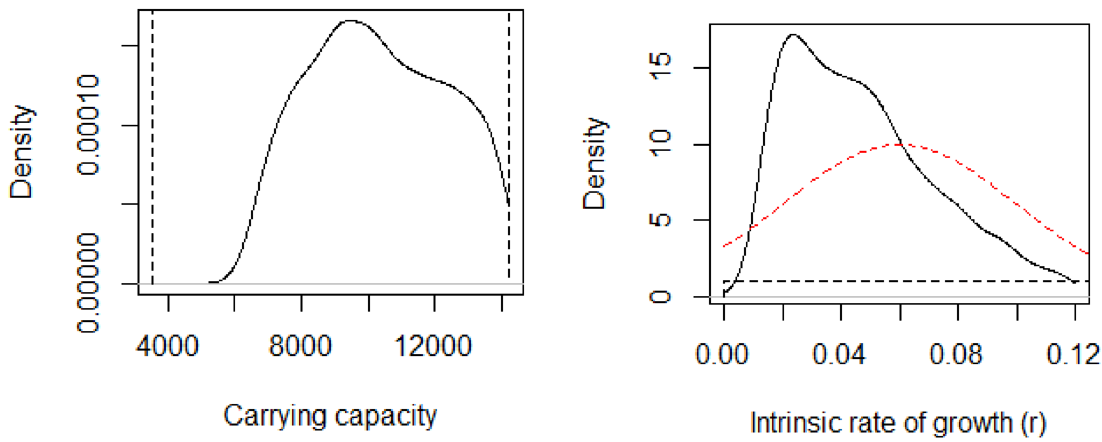

Figure 35. Posterior density distribution of K_0 and r_{max} for scenario B3 – second run.

In this case the two density distribution graphs show both uncertainties in the determination of the carrying capacity and net growth rate parameters. Probably the carrying capacity would assume a trend like a normal distribution if increasing the interval. Here K_0 = 10200 and depletion 72%, which represent the maximum population and depletion reached by the simulations. In figure 33, the trajectories depicted an large difference in population from 1930 to 1970 due to the high catches and an almost constant population from the 1970 to 2013.

Christensen model – Scenario C: r_{max} =0.123

Scenario C1

Table 18. Input data of net growth rate and carrying capacity of the scenario C1.

MINIMUM CATCHES	
Mean r_{max}	0.123
Sd r_{max}	0.08
K_0	8883
Min K_0	3000
Max K_0	15000

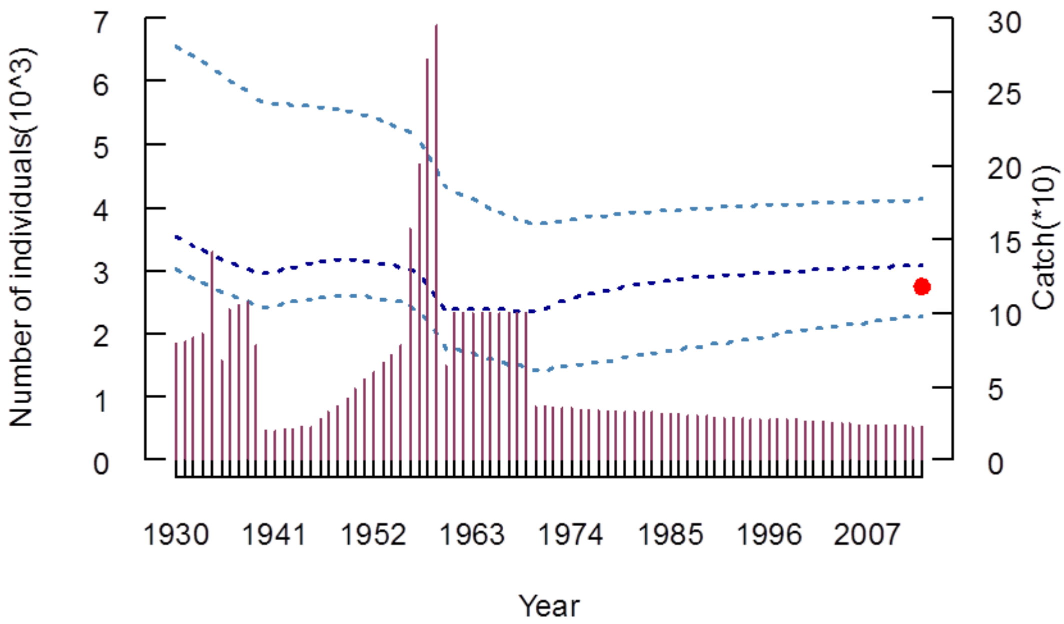

Figure 36. Trajectories for the run with minimum catches, r_{max}=0.123.

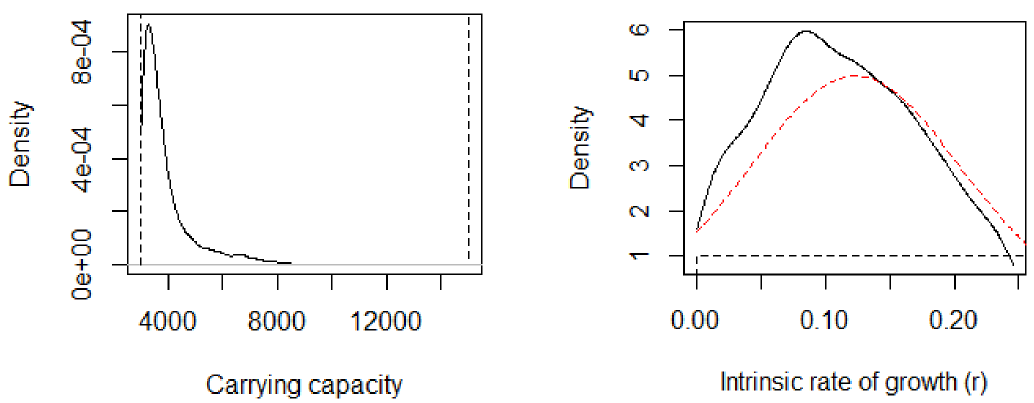

Figure 37. Posterior density distribution of K_0 and r_{max} for scenario C1.

This scenario will represent the case A1 – second run modeled using a constant carrying capacity which does not vary with time. The two posterior density distributions are similar but in this case the carrying capacity estimated in the 1930 is lower, 3550 individuals, and as a consequence also the depletion decreases, 13%. With this input parameters the model is not able to intercept the red dot which correspond to the observed abundance estimation.

Scenario C2

Table 19. Input data of net growth rate and carrying capacity of the scenario C2.

DOUBLE CATCHES	
Mean r_{max}	0.123
Sd r_{max}	0.08
K_0	8883
Min K_0	3000
Max K_0	15000

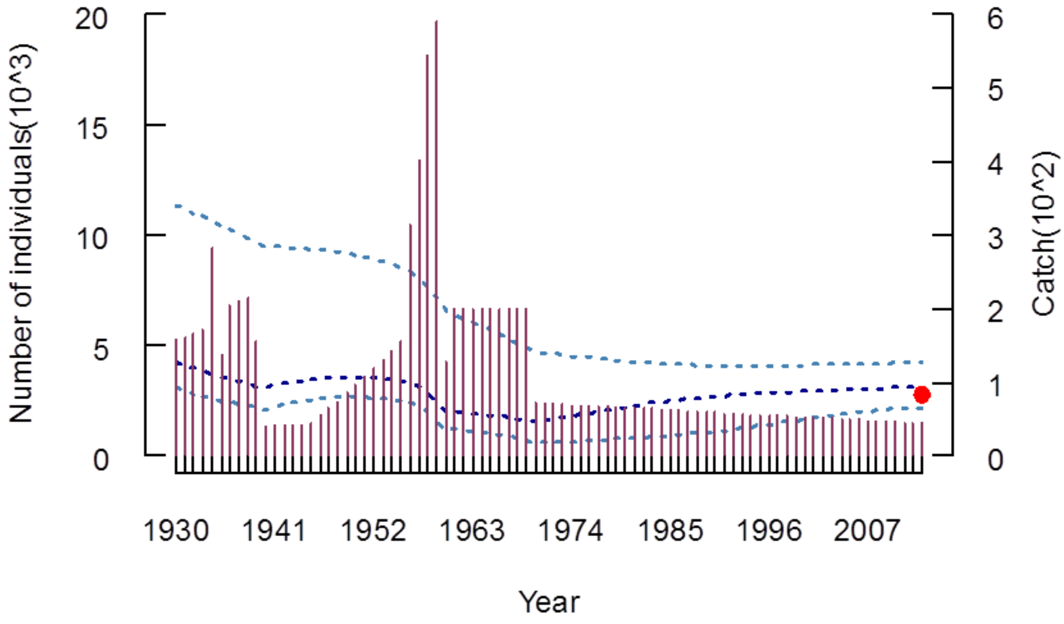

Figure 38. Trajectories for the run with double catches, r_{max}=0.123.

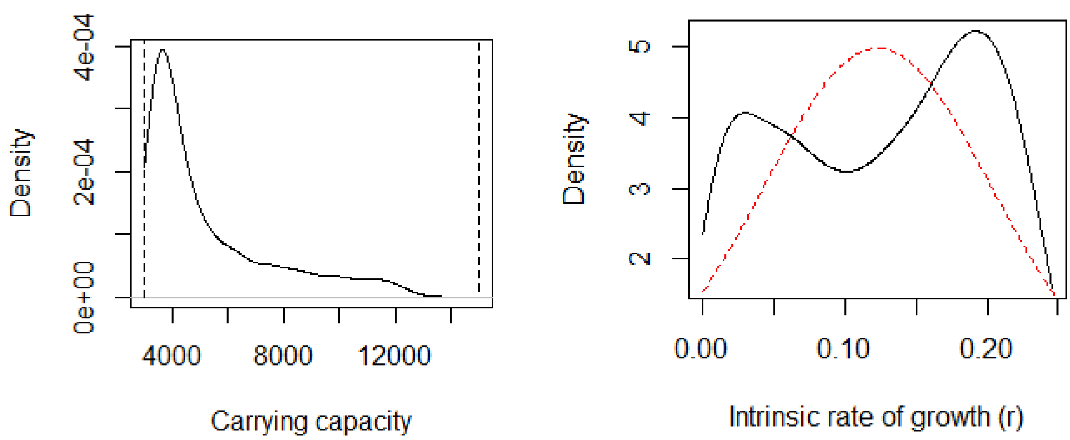

Figure 39. Posterior density distribution of K_0 and r_{max} for scenario C2.

Doubling the number of catches the carrying capacity increases of about 1000 individuals, K_0 = 4220, and the depletion raises of more than 10 points, 25%. The posterior density distribution shows a log-normal shape for the carrying capacity, and instead an uncertain trend for the net growth rate. In this case it is not represented the difference of the number of individuals between the 1930 and 1970, which was instead the main feature of the scenario with the variation of the carrying capacity with time.

Scenario C3

Table 20. Input data of net growth rate and carrying capacity of the scenario C3.

TRIPLE CATCHES	
Mean r_{max}	0.123
Sd r_{max}	0.08
K_0	8883
Min K_0	3000
Max K_0	15000

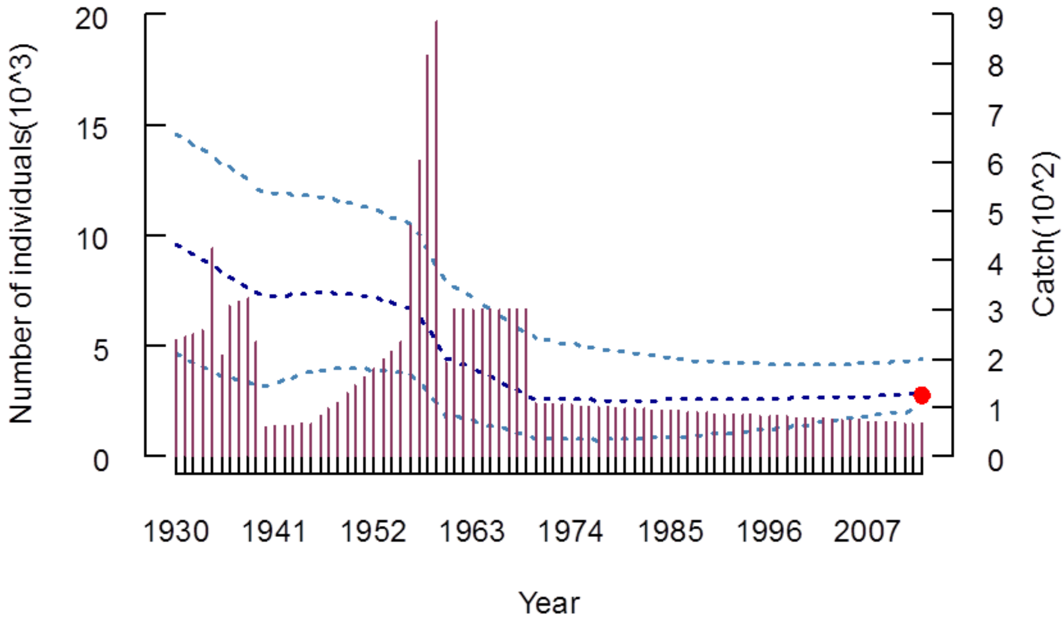

Figure 40. Trajectories for the run with triple catches, r_{max}=0.123.

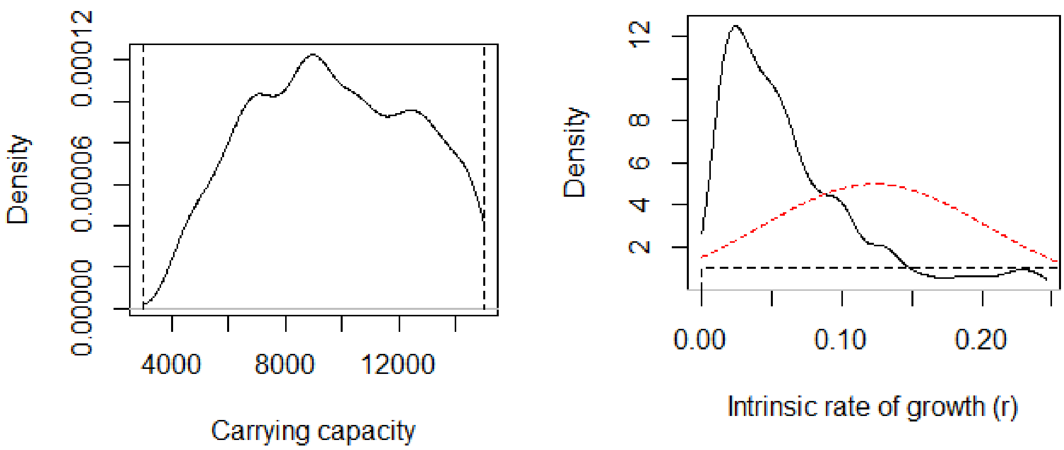

Figure 41. Posterior density distribution of K_0 and r_{max} for scenario C3.

In the scenario of triple catches the carrying capacity increases to 9520 individuals but the posterior density distribution graph shows an uncertain look. The depletion became 69%. The net growth rate posterior density distribution shows a peak for lower values respect the input mean r_{max}. On the contrary of the scenario C2 here the trajectories shows a higher slope between the 1930-1970 and an almost constant trend for the last 40 years.

Christensen model – Scenario D: r_{max} =0.06

Scenario D1

Table 21. Input data of net growth rate and carrying capacity of the scenario D1.

MINIMUM CATCHES	
Mean r_{max}	0.06
Sd r_{max}	0.04
K_0	8883
Min K_0	3000
Max K_0	15000

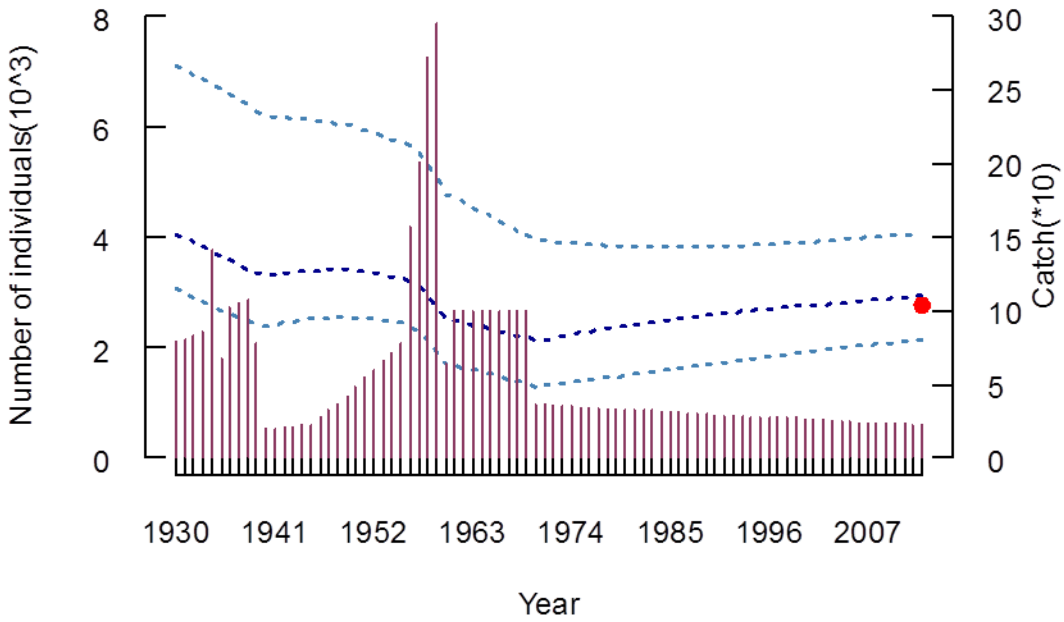

Figure 42. Trajectories for the run with minimum catches, r_{max}=0.06.

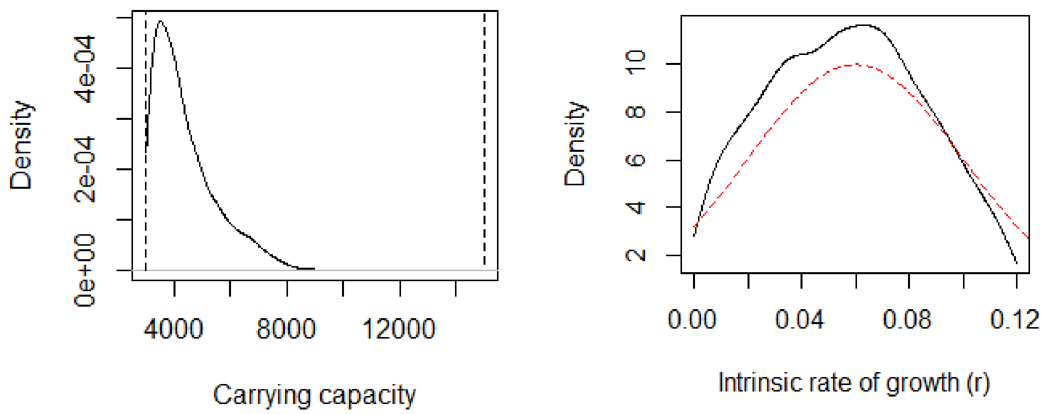

Figure 43. Posterior density distribution of K_0 and r_{max} for scenario D1.

This scenario is quite equal to the B1 – second run, the trends of the two posterior density graphs are very similar. Moreover also the carrying capacity and the depletions are calculated around the same values; K_0 is 4050 individuals and the depletion is 28%. The difference is represented by the shape of the population trajectories which in this case clearly can not follow the behavior of the variation of the biomass of anchovy, sardine and hake which were used for the determination od the carrying capacity in the scenario A and B.

Scenario D2

Table 22. Input data of net growth rate and carrying capacity of the scenario D2.

DOUBLE CATCHES	
Mean r_{max}	0.06
Sd r_{max}	0.04
K_0	8883
Min K_0	3000
Max K_0	15000

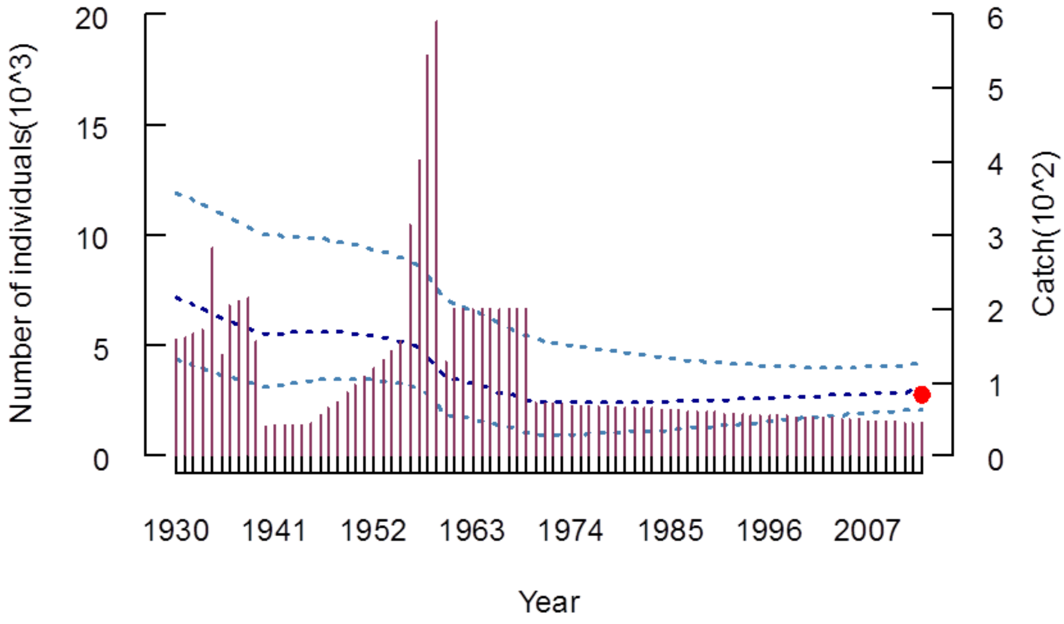

Figure 44. Trajectories for the run with double catches, r_{max}=0.06.

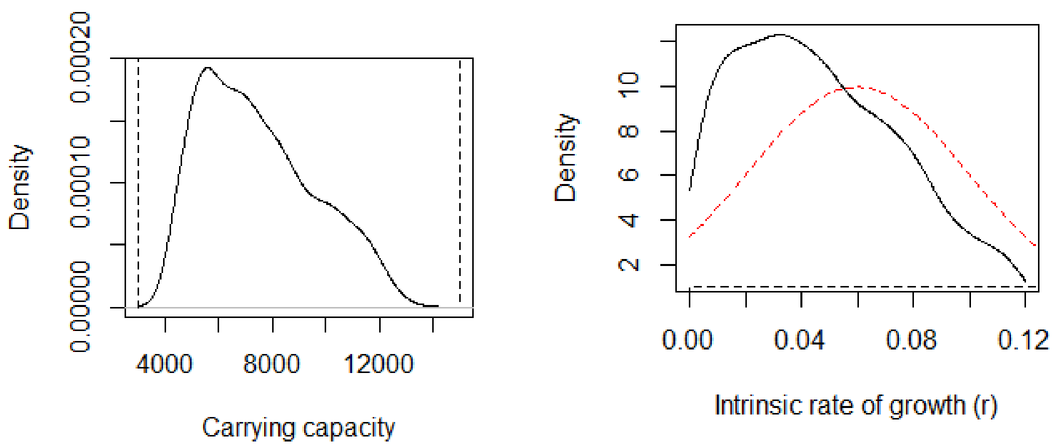

Figure 45. Posterior density distribution of K_0 and r_{max} for scenario D2.

This scenario represents higher uncertainties in the determination of the carrying capacity and the net growth rate, like the posterior distribution graphs show. Anyway as expected, with a double catches, the K_0 increases to more than 7000 individuals, 7140, and also the depletion to 59%.

Scenario D3

Table 23. Input data of net growth rate and carrying capacity of the scenario D3.

TRIPLE CATCHES	
Mean r_{max}	0.06
Sd r_{max}	0.04
K_0	8883
Min K_0	3000
Max K_0	15000

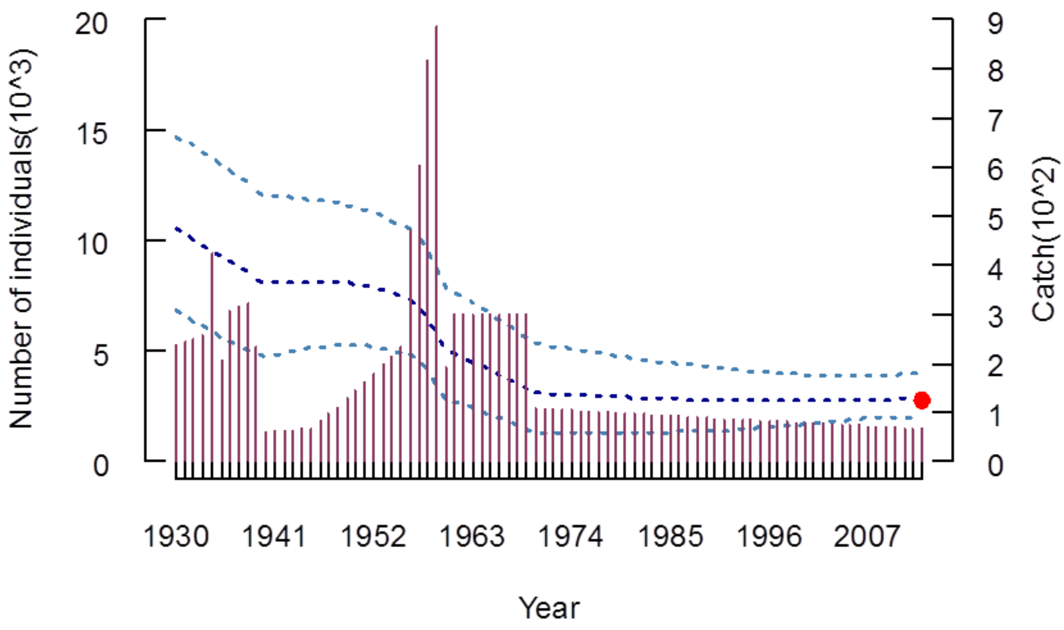

Figure 46. Trajectories for the run with triple catches, r_{max}=0.06.

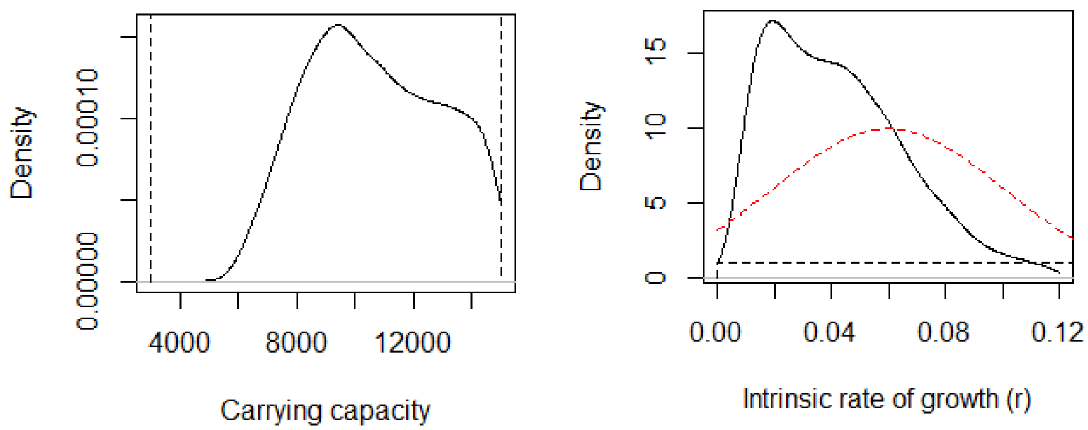

Figure 47. Posterior density distribution of K_0 and r_{max} for scenario D3.

When triplicating the catches the carrying capacity increases to the maximum of 10500 individuals and the depletion goes beyond the 70%, (73%). Anyway there are some uncertainties in the estimation of both the carrying capacity and the net growth rate. The trajectories shows a trend similar to the scenario C3, with a high population difference between the 1930-1970 and almost constant number of individual for the last 40 years.

Discussion

In order to discuss the results, there can be made some considerations and comparisons between the different scenarios bearing in mind the variation of the key parameters: net growth rate, carrying capacity and time series of catches.

As a general conclusion it is possible to establish that a depletion of the bottlenose dolphin population in the northern Adriatic sea of at least 32% has occurred over the past decades. This minimum depletion estimate is given by the first scenario (A1 – second run) which considers the lowest time series of catches. A maximum depletion is not as well defined, but considering that the K_0 reaches a value higher than 10000 individuals just in few cases, I can say that the maximum depletion could around the 70%. This depletion estimate are consistent with the assessment of the IUCN on the current state of the bottlenose dolphin in the Adriatic sea which is considered to be Endangered, with a suspected population size reduction of ≥50% over the last 10 years or three generations. So as a consequence of the simulations in this thesis, it is possible to establish that the bottlenose dolphin population was most probably between 4400 and 9000 individuals in the 1930 in the northern Adriatic sea.

This interval is established looking at the scenario A and B, which tested for different situations based on different time series of catches and different values for the growth rate parameter and the interval of carrying capacity. Here it has been observed that there is a mutual relationship between K_0 and r_{max}. They are inversely proportional and this is clear from a comparison between the second runs ($\pm60\%K_0$) of scenario A (r = 0.123) and scenario B (r = 0.06).

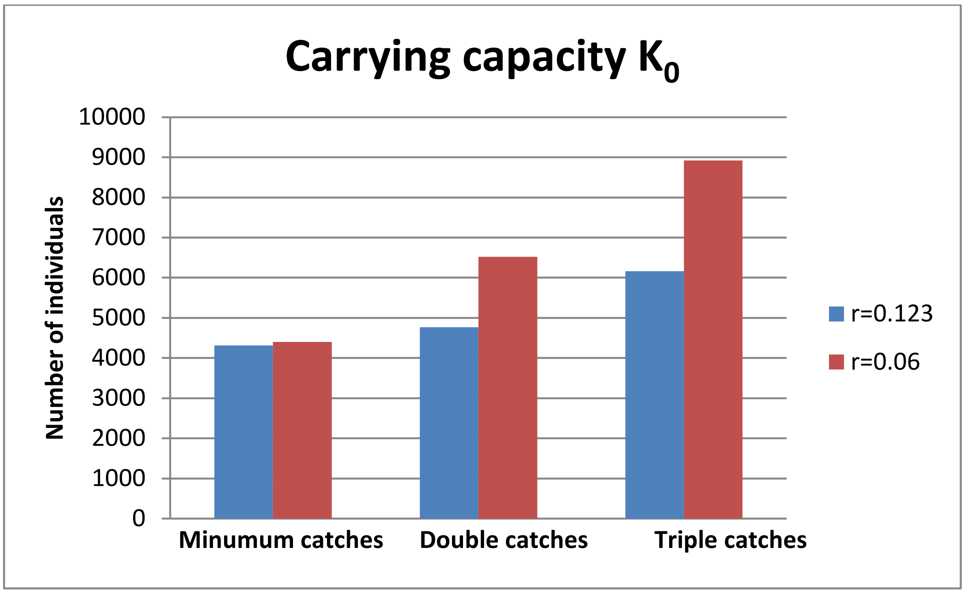

Figure 48. Comparison between the carrying capacity K_0 of scenario A (r = 0.123) and scenario B (r = 0.06) considering the variation of the time series of catches and $K_0 = \pm 60\%$.

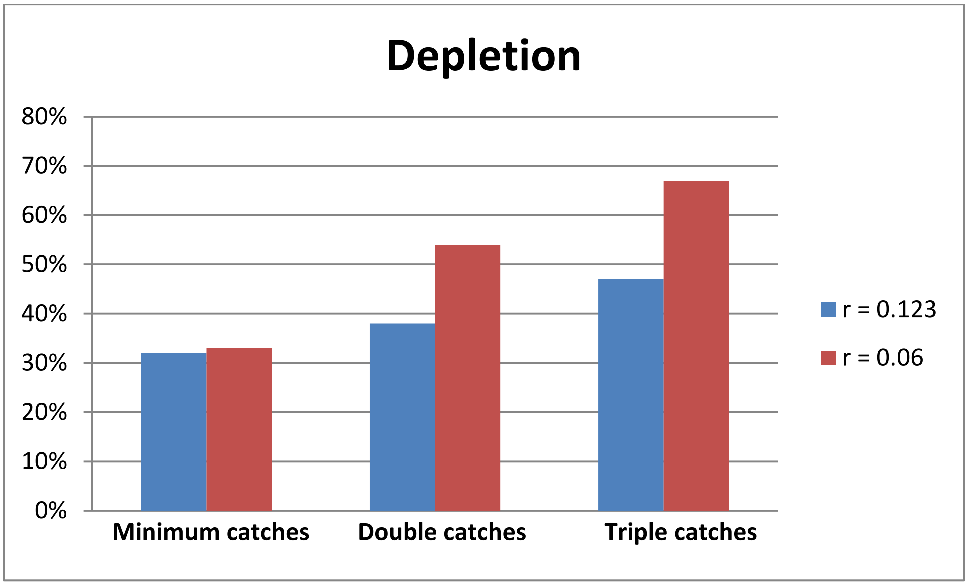

Figure 49. Comparison between the depletion of scenario A (r = 0.123) and scenario B (r = 0.06) considering the variation of the time series of catches and $K_0 = \pm 60\%$.

Indeed from figure 48 in the second and third group of columns it is evident that with r_{max} = 0.123 the carrying capacity and the depletion are lower with respect to r_{max} = 0.06. This is a direct consequence of the meaning of the net growth rate parameter, because if the bottlenose dolphin has a low growth rate it means that it reproduces slowly, consequently the catches influence their population more strongly and, in order to counterbalance this increased vulnerability to catches, the carrying capacity has to be higher. For the minimum catches instead, the difference between the different carrying capacities is not marked, and there is just a little increase of 1% in the depletion.

Another consideration on the relationship between the carrying capacity and the net growth rate parameter, is that when the interval of K_0 is increased from ±10% to ±60% the behavior of the posterior density distribution curves change. The carrying capacity assumes the shape of a log-normal distribution curve, showing to take the resampled values on a narrow interval. The net growth rate instead behaves in an opposite way, showing that the increase of the interval of the carrying capacity causes larger uncertainties in the determination of the net growth rate parameter.

The catches also influence the results of the model. In all the cases the carrying capacity and the depletion increase following the increase of the catches. This is of course obvious because it is expected that killing a huge amount of these mammals means that there is also a high number of individuals inhabiting the area, otherwise the population would become locally extinct. Anyway other considerations can be done how on the time series of catches influence the shape of the population abundance trajectory.

In all the cases presented there is a marked difference in the number of individuals on the first 40 years, which is clearly a consequence of the culling campaign occurred in these years. From 1970 to nowadays the trajectory shows a slightly or marked positive trend reflecting the recovery of the population. This different behavior in the population trajectory in this last period is influenced by two factors: the catches and the modeled carrying capacity. Indeed, recent catches have been represented through a linear relationship which is for sure not the best representation of the catches that probably will be higher. Also, the carrying capacity has been modeled using the available biomass of sardine, anchovy and hake reached a peak in the 1980s, and in some cases this is fish trend is exactly reflected by the dolphin biomass in the model.

Moreover in order to see if the choice of a time dependent makes a difference in the model, I have also applied the methodology of the Christensen (2006) model. It considers that the logistic growth equation (3), is in function of a constant carrying capacity and the thousand trajectories are calculated taking it in an interval of minimum and maximum K_0 which correspond to the ±60% of K_0.

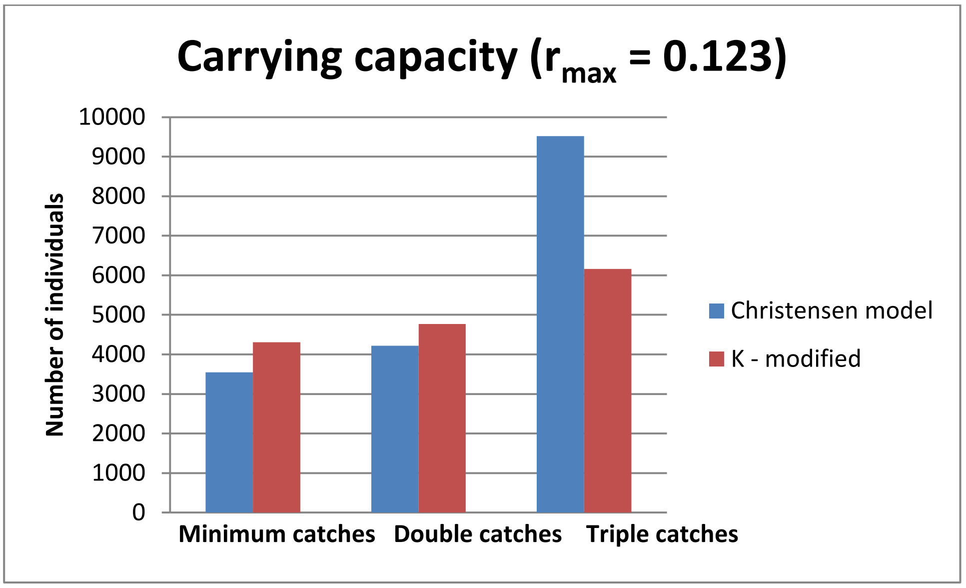

Figure 50. Comparison between the carrying capacity K_0 of scenario A and scenario C considering the variation of the time series of catches.

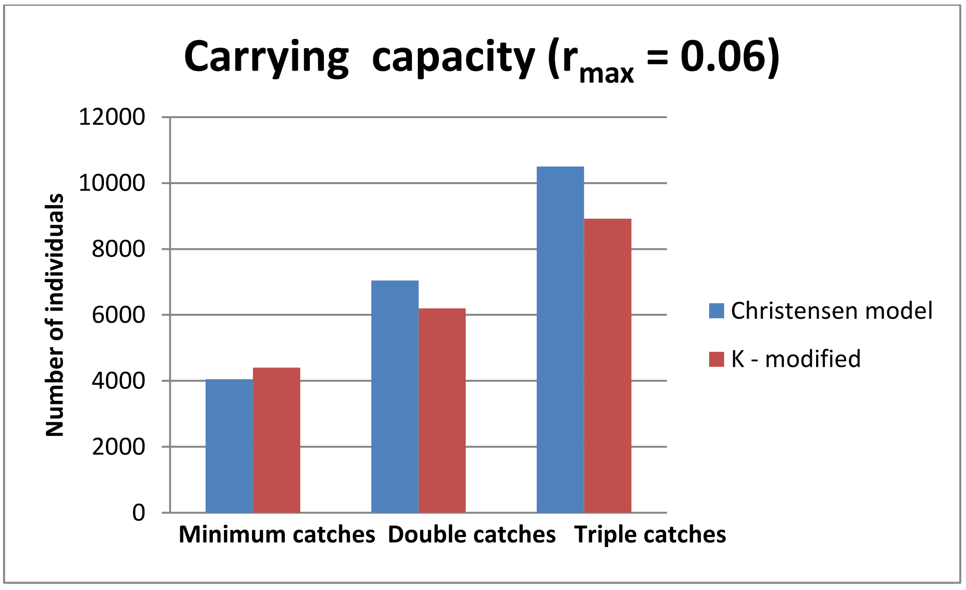

Figure 51. Comparison between the carrying capacity K_0 of scenario B and scenario D considering the variation of the time series of catches.

It is evident that there are some differences using the two models. Considering r_{max} = 0.123 for minimum and double catches the carrying capacity corresponding to the modified model is a little bit higher with respect to the one calculated with the Christensen model, but the contrary happen for triple catches where the two models estimate the K_0 with a large difference of almost 3000 individuals. Also for the case of r_{max} = 0.06 it is possible to see some differences. The Christensen model estimate a higher carrying capacity with respect to the modeled K but anyway the difference is not so marked. The minimum catches behave similar to the previous case with r_{max} = 0.123 with K_0 remaining similarly in the order of 4000 individuals. Moreover the carrying capacity influenced the number of the population but especially it influenced the trend of the trajectory year by year. Indeed as I said before over the last 40 years the trend of the trajectory in some cases clearly follow the trajectory of the carrying capacity derived from the available preys.

Another important observation can be done looking at the graphs of the population trajectories: it can be see that when the number of catches is increased the spread of the results (i.e., the gap between the three curves representing the median and the two quantiles giving the 95% confidence intervals) is reduced and the three curves become closer one to the other, due to the fact that the K_0 and r_{max} parameters are taken in a narrow interval so just few parameter combinations (and consequently population trajectories) are possible.

Conclusions

The aim of the study was to establish which was the population of bottlenose dolphins in the northern Adriatic sea in the 1930s. Looking at the results of the model the conclusion is that this modeling exercise is useful to place some bounds on the past levels of bottlenose dolphins in the area, but it is unfeasible to define a precise abundance estimation. This is due to the fact that there are uncertainties and variability in the input parameters and so the scenarios studied can picture varied situations. Anyway it is possible to define an interval between a minimum and maximum number of past individuals population that is between 4400 and 9000 animals. So as a consequence the depletion will be from the 30% to 70%, which broadly confirms the assessment of the IUCN considering the bottlenose dolphins as an Endangered species in the northern Adriatic sea. The precise depletion identified by the model is function of the growth rate parameter, the carrying capacity modeled accounting for dolphin diet, and the observed catches. When it is considered a small growth rate (r=0.06) and high captures the carrying capacity increases reaching the top value of the interval, on the contrary when I consider minimum catches and double the growth rate the carrying capacity in 1930 gets near to 4000 individuals. Although what is the best scenario that represent the real situation is hard to tell, for sure we can say that the past catches were higher with respect to the minimum ones reported and used here, especially during the initial 40 years of the series where it was allowed to kill dolphins and nobody reported the real number of killed animals. Moreover over the last years even if dolphins became fully protected by the governments the fisheries clearly influenced their living condition, not only through unintentional killings but also through the depletion of their favorite preys. Indeed it is observed that the carrying capacity dependent on the bottlenose diet clearly influenced the trend of the population. So, probably, the number of bottlenose dolphins in the 1930s was higher than the minimum estimate of 4000 individuals identified here. Anyway this work strongly suggest that the depletion of this vulnerable specie is mostly probably a consequence of the culling campaigns occurring in the 1930-1960 and of the current fishing activity.

Further studies are of course necessary in this field to reach more robust conclusions. Considering that bottlenose dolphin are biological indicators of the ecosystem it has to be investigated if the eutrophication and the environmental pollution of the northern Adriatic sea have played an important role in their actual vulnerable condition. Moreover it is necessary to implement further studies in the evaluation of the impact of fishery on these animals, especially regarding the by-catches during the fishing activity. With these information it would be possible to establish more complex, realistic model which can simulate additional factors and processes, making it possible to identify proper measures in order to protect and the defend this specie seriously threatened with extinction in this area.

Appendix

Appendix I: Catch data

Year	Minumum cathes	Double catches	Triple catches
1930	79	158	238
1931	81	162	244
1932	83	166	249
1933	85	170	255
1934	141	282	422
1935	68	137	205
1936	103	206	309
1937	105	211	316
1938	108	215	323
1939	78	157	235
1940	20	40	60
1941	20	41	61
1942	21	42	62
1943	21	42	64
1944	22	43	65
1945	22	44	66
1946	27	54	81
1947	32	64	96
1948	37	74	111
1949	42	85	127
1950	48	96	144
1951	54	107	161
1952	60	119	179
1953	66	131	197
1954	72	143	215
1955	78	156	234
1956	157	314	471
1957	201	402	603
1958	272	544	816
1959	295	591	886
1960	63	126	189
1961	100	200	300
1962	100	200	300
1963	100	200	300
1964	100	200	300
1965	100	200	300
1966	100	200	300
1967	100	200	300
1968	100	200	300

Year	Minumum cathes	Double catches	Triple catches
1969	100	200	300
1970	36	72	108
1971	36	71	107
1972	35	71	106
1973	35	70	105
1974	35	69	104
1975	34	69	103
1976	34	68	102
1977	34	67	101
1978	33	67	100
1979	33	66	99
1980	33	65	98
1981	32	65	97
1982	32	64	96
1983	32	64	95
1984	31	63	94
1985	31	62	93
1986	31	62	92
1987	30	61	91
1988	30	60	90
1989	30	60	89
1990	29	59	88
1991	29	58	87
1992	29	58	87
1993	29	57	86
1994	28	56	85
1995	28	56	84
1996	28	55	83
1997	27	54	82
1998	27	54	81
1999	27	53	80
2000	26	52	79
2001	26	52	78
2002	26	51	77
2003	25	51	76
2004	25	50	75
2005	25	49	74
2006	24	49	73
2007	24	48	72
2008	24	47	71
2009	23	47	70
2010	23	46	69
2011	23	45	68
2012	22	45	67
2013	22	44	66

Appendix II: Parameter "a"

year	a	Year	a
1930	1	1972	1.083415
1931	1	1973	2.017658
1932	1	1974	2.431129
1933	1	1975	2.27244
1934	1	1976	2.459602
1935	1	1977	2.184602
1936	1	1978	2.124976
1937	1	1979	2.195849
1938	1	1980	2.422421
1939	1	1981	2.646162
1940	1	1982	1.461322
1941	1	1983	2.146143
1942	1	1984	2.95716
1943	1	1985	4.819305
1944	1	1986	4.681807
1945	1	1987	3.471262
1946	1.002819	1988	2.582156
1947	0.999715	1989	2.683181
1948	0.995667	1990	2.880429
1949	0.992901	1991	2.949615
1950	0.965432	1992	2.892887
1951	0.989859	1993	3.143527
1952	0.653387	1994	2.557394
1953	0.806736	1995	2.081785
1954	0.689846	1996	1.655806
1955	0.52826	1997	0.998644
1956	0.450605	1998	0.478325
1957	0.921186	1999	0.24987
1958	1.122965	2000	0.224613
1959	1.54988	2001	0.229981
1960	1.336146	2002	0.241028
1961	2.046564	2003	0.307776
1962	1.070193	2004	0.43236
1963	0.686938	2005	0.594019
1964	0.61994	2006	0.707785
1965	1.017984	2007	0.667283
1966	0.779595	2008	0.430853
1967	0.93632	2009	0.583059
1968	1.195327	2010	0.351746
1969	1.094836	2011	0.349265
1970	1.426991	2013	0.349659
1971	1.367858		

Appendix III: R Code

This is the code of the model implemented in order to obtain the trajectories of the dolphin population.

CODE FILE

```
graphics.off()
memory.size(4095)
seed=round(runif(1,1,1000))
set.seed(seed)

spec=scan("inputmod.txt",what='character',sep='\n',nlines=1)
area=scan("inputmod.txt",skip=1,what='character',sep='\n',nlines=1)
kap=scan("inputmod.txt",skip=2,nmax=1)
byr=scan("inputmod.txt",skip=3,nmax=1)
nyr=scan("inputmod.txt",skip=4,nmax=1)
syr=scan("inputmod.txt",skip=5,nlines=1)
yt=scan("inputmod.txt",skip=6,nlines=1)
ct=scan("catturemax2.txt")

coeffa=scan("a.txt")
Kzero=8883 #Carrying capacity at time t=0

prop=0.3 #proportion of error attributed to observation errors

meanr=0.123
sdr=0.08
sig=sqrt(prop)*sqrt(kap) #observation errors
tau=sqrt(1-prop)*sqrt(kap) #process errors
yr=byr:nyr
n=length(yr)
iyr=syr-min(yr)+1
ci=matrix(nrow=n,ncol=3)
meanEst=vector(length=n)

minimoK=(Kzero – 0.1*Kzero) #Intervals for the carrying capacity
massimoK=(Kzero + 0.1*Kzero)
```

POPDY FUNCTION

```
"popdy"=function(theta,niter=1,tau=0)

{r=theta[1,]
k=theta[2,]
Nt=matrix(0,nrow=n,ncol=niter)
Nt[1,]=k
aa=matrix(0,nrow=n,ncol=niter)
wt=matrix(rnorm(n*niter)*tau,nrow=n,ncol=niter)
like=vector(mode="numeric",length=niter)
for(i in 1:(n-1))
{
```

```
      aa[i,]=r*(1-(Nt[i,]/(k*(0.47+(0.53*coeffa[i])))))*exp(wt[i,])
      Nt[i+1,]=Nt[i,]+Nt[i,]*aa[i,]-ct[i]
      Nt[i+1,Nt[i+1,]<0]=0
}

#calculate the likelihood
zt=0
zt=matrix((log(Nt[iyr,])-log(yt)),nrow=1,ncol=niter)
zbar=0

if(niter==1)like=sum(dnorm(zt,zbar,sig,log=T))
if(niter>1)like=rowSums(apply(zt,1,dnorm,mean=zbar,sd=sig,log=T))
like[Nt[n,]<=0]=0
like=like-min(like)
like[Nt[n,]<=0]=-1e70

prior=dnorm(r,mean=meanr,sd=sdr,log=T)
pop=list()
pop$Nt=Nt[1:n,]
pop$like=like+prior
pop$wt=exp(wt)
return(pop)}
```

CALCY

```
"calcY"=function(Nmax)

{b=integer
a=1
exponent=0
while(Nmax/a>99){a=a*10;exponent=exponent+1}
b=Nmax/a;b=ceiling(b)

while(b%%10!=0){b=b+1}
if(b==10){b=b/10;exponent=exponent+1}
if(b==50||b==60||b==70||b==80||b==90){b=b/10;exponent=exponent+1}
byval=c(20,10,5,2,1);i=3
if(b%%byval[5]==0&&b/byval[5]>=4){i=5}
if(b%%byval[4]==0&&b/byval[4]>=4){i=4}
if(b%%byval[3]==0&&b/byval[3]>=4){i=3}
if(b%%byval[2]==0&&b/byval[2]>=4){i=2}
if(b%%byval[1]==0&&b/byval[1]>=4){i=1}
vals=seq(0,b,by=byval[i])

yaxis=list()
yaxis$vals=vals
yaxis$exponent=exponent
return(yaxis)}
```

SIR

```
"sir"=function(niter=50000)
{
rtry=runif(niter,0,(meanr*2))
ktry=runif(niter,minimoK,massimoK)
theta=rbind(rtry,ktry)

sir=popdy(theta,niter,tau)

#importance weights
p=sir$like
maxp=max(na.omit(p))
p=exp(p-maxp)
p[p=="NA"]=0

ix=sample(1:niter,niter,replace=T,prob=p)
a=seq(1930,2013,by=1)
b=a[a>=(byr-9)]

dd=calcY(max(ct))
if(dd$exponent==0){
      ylabel2="Catch"
}else if(dd$exponent==1){
      ylabel2="Catch(*10)"
}else {
      ylabel2=paste("Catch(10^",dd$exponent,")",sep="")
}

for(i in 1:n)
ci[i,]=signif(quantile(sir$Nt[i,ix],c(0.025,0.5,0.975)),3)

ninit=ci[1,2]
nend=ci[n,2]

d=calcY(max(ci[,3]))
if(d$exponent==0){
      ylabel="Number of individuals"
}else if(d$exponent==1){
      ylabel="Number of individuals(*10)"
}else {
ylabel=paste("Number of individuals(10^",d$exponent,")",sep="")
}

write(ci[1,1],file=paste(spec,area,"popCImin.txt"))
for(i in 2:n)
      write(ci[i,1],file=paste(spec,area,"popCImin.txt"),append=T)
write("\n#Depleted
by",file=paste(spec,area,"popCImin.txt"),append=T)

depmin=(ci[1,1]-ci[n,1])/ci[1,1]*100
if(depmin>90)depmin=signif(depmin,3)
else depmin=signif(depmin,2)
```

```
write(depmin,file=paste(spec,area,"popCImin.txt"),append=T)

write(ci[1,3],file=paste(spec,area,"popCImax.txt"))
for(i in 2:n)
      write(ci[i,3],file=paste(spec,area,"popCImax.txt"),append=T)
write("\n#Depleted
by",file=paste(spec,area,"popCImax.txt"),append=T)

depmax=(ci[1,3]-ci[n,3])/ci[1,3]*100
if(depmax>90)depmax=signif(depmax,3)
else depmax=signif(depmax,2)
write(depmax,file=paste(spec,area,"popCImax.txt"),append=T)

#plot confidence intervals
X11(height=4,width=6)
par(mar=c(5,4,2,4))
plot(yr,ci[,3]/(10^d$exponent),ylim=c(0,max(d$vals)),xlab="Year",
      ylab="",type='n',xaxt="n",frame=F,axes=F)
axis(side=1,at=b,las=1,tcl=0.5)
axis(side=2,tcl=0.5,las=1,at=d$vals)
mtext(ylabel,2,line=3)
lines(byr:nyr,ci[,3]/(10^d$exponent),col="steelblue",lty=3,lwd=2)
lines(byr:nyr,ci[,1]/(10^d$exponent),col="steelblue",lty=3,lwd=2)
lines(byr:nyr,ci[,2]/(10^d$exponent),col="darkblue",lty=3,lwd=2)
points(syr,yt/(10^d$exponent),pch=20,cex=1.8,col="red")
par(new=TRUE)
plot(yr,ct/(10^dd$exponent),xaxt="n",yaxt="n",xlab="",ylab="",type='
h',lty=1,col='hotpink4',frame=F,axes=F,ylim=c(0,max(dd$vals)))
axis(side=4,tcl=0.5,las=1,at=dd$vals)
mtext(ylabel2,4,line=2);

savePlot(filename=paste(spec,area,"popSimplePlot"),type="wmf",device
=dev.cur())

write(ci[1,2],file=paste(spec,area,"pop.txt"))
for(i in 2:n)
{
      write(ci[i,2],file=paste(spec,area,"pop.txt"),append=T)
}
dep=(ninit-nend)/ninit*100
if(dep>90)
dep=signif(dep,3)
else
dep=signif(dep,2)

write("\n#Depleted by",file=paste(spec,area,"pop.txt"),append=T)
write(dep,file=paste(spec,area,"pop.txt"),append=T)
rm(ci)

X11()
plot(ktry[ix],rtry[ix],pch=20)
savePlot(filename=paste(spec,area,"Posterior"),type="jpg",device=dev
.cur())
```

```
windows()
split.screen(c(2,1))
split.screen(c(1,2),2)
screen(1)
plot(rtry[ix],type="l",ylab="Intrinsic rate of growth
(r)",las=1,main="(a)")
screen(3);hist(rtry[ix],xlab="Intrinsic rate of growth
(r)",main="(b)",breaks=50)
yy=density(rtry[ix],adjust=2,from=0,to=meanr*2)
screen(4)
plot(yy,xlab="Intrinsic rate of growth (r)",main="(c)")
      lines(c(0,0,0.2,0.2),c(0,1,1,0),lty=2)
      xx=seq(0,0.2,by=0.001)
      yy=dnorm(xx,mean=meanr,sd=sdr)
      lines(xx,yy,lty=2,col="red")
close.screen(all=TRUE)
savePlot(filename=paste(spec,area,"R"),type="jpg",device=dev.cur())

#Now plot statistics for carrying capacity K
windows()
split.screen(c(2,1))
split.screen(c(1,2),2)
screen(1)
plot(ktry[ix],type="l",ylab="Carrying capacity",las=1,main="(a)")
screen(3)
hist(ktry[ix],xlab="Carrying capacity",main="(b)",breaks=50)
yy=density(ktry[ix],adjust=2,from=minimoK,to=massimoK)
screen(4)
plot(yy,xlab="Carrying capacity",main="(c)")
      lines(c(minimoK,minimoK,massimoK,massimoK),c(0,0.1,0.1,0),lty=
2)
close.screen(all=TRUE)
savePlot(filename=paste(spec,area,"K"),type="jpg",device=dev.cur())

return(sir)
}
```

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