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SUPPLEMENT ARTICLE

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Common dolphins in the Gulf of Corinth are Critically Endangered

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Abstract

1. Regional populations ("subpopulations") of globally abundant species can be exposed to human impacts that threaten their viability. Given the value of cetacean subpopulations as evolutionary significant units, keystone and umbrella species, it is important to assess their conservation status separately and propose area-specific conservation measures.
2. We used a threat assessment process and applied IUCN Red List criteria to a regional population of common dolphins *Delphinus delphis* in the semi-enclosed Gulf of Corinth, Greece. We compiled subpopulation-specific information about abundance and trends, estimated the geographic range of the subpopulation (area of occupancy and extent of occurrence), and calculated the probability of extinction through stochastic modelling.
3. The subpopulation qualified as Endangered according to criteria A (population size reduction over three generations) and B (geographic range), and as Critically Endangered under criteria C (population size and decline) and D (very small or restricted population). The probability of extinction was estimated to be ≥50% in three generations, qualifying the subpopulation as Critically Endangered under criterion E (quantitative analysis). We concluded that the subpopulation should be classified as Critically Endangered.
4. Considering the high extinction risk faced by common dolphins in the Gulf of Corinth, we recommend that: (a) immediate action is taken to mitigate anthropogenic activities known or suspected to have a negative impact on cetaceans in the area (particularly commercial fishing); and (b) a marine protected area is established in the Gulf of Corinth as a management tool for enforcing conservation action and facilitating the recovery of common dolphins.

KEYWORDS

common dolphin, conservation status, *Delphinus delphis*, extinction risk, IUCN Red List

1 | INTRODUCTION

Failure to recognize and prevent the decline of a subpopulation can threaten the regional and global status of a species. Because of insufficient information at the local scale, the unfavourable conservation status of a subpopulation can go unnoticed, resulting in continued decline (Casey & Myers, 1998; Currey, Dawson, & Slooten, 2009; Vermeulen & Bräger, 2015). A fine-scale assessment of species conservation status is advocated *inter alia* by the International Union for Conservation of Nature ([IUCN], 2012a). Cetaceans in the Mediterranean Sea offer examples of worsening conservation status when reducing the geographic scale of IUCN Red List evaluation (IUCN, 2012b). Of five Mediterranean subpopulations with sufficient data for conservation status assessment, four are more threatened at the local scale than at the global scale (IUCN, 2012b). The common dolphin *Delphinus delphis*, in particular, is globally classified as Least Concern (Hammond et al., 2008), but its Mediterranean subpopulation is Endangered (Bearzi, 2012; Bearzi et al., 2003). Furthermore, based on genetic evidence of subpopulation structure, discrete populations in the western and eastern Mediterranan may be separate management units (Natoli et al., 2008). In particular, population structure has been hypothesized in the Ionian Sea (Moura, Natoli, Rogan, & Hoelzel, 2013; Natoli et al., 2008).

Common dolphins in the semi-enclosed Gulf of Corinth, Greece, make a special case. Their distribution and abundance have been assessed through extensive monitoring (Bearzi et al., 2016; Santostasi, Bonizzoni, Bearzi, Eddy, & Gimenez, 2016). In this area, a few individuals (*n* = 22, 95% CI 16–32) occur exclusively within mixed groups with the much more abundant striped dolphins (*Stenella coeruleoalba*; *n* = 1,331, 95% CI 1,122–1,578). Dolphins showing intermediate pigmentation between the two species (*n* = 55, 95% CI 36–84) also occur within mixed groups and are thought to be hybrids (Bearzi et al., 2016; Frantzis & Herzing, 2002). The hypothesis of geographic isolation of common dolphins in the Gulf of Corinth is supported by genetic evidence (Moura et al., 2013), as well as by absence of records in the western portion of the gulf and throughout the adjacent Gulf of Patras (Bearzi et al., 2016; Bearzi, Bonizzoni, Agazzi, Gonzalvo, & Currey, 2011; Frantzis, 2009; Frantzis et al., 2003). Geographic isolation has long been a source of concern (Bearzi et al., 2016; Frantzis et al., 2003).

In this study, we provide a quantitative assessment of conservation status in the framework of IUCN Red List criteria (IUCN, 2012c) applied to the subpopulation of common dolphins just described. Such a small and isolated subpopulation would be expected to face a high risk of extinction (Gilpin & Soulé, 1986). To test such a hypothesis, all available data on abundance and distribution were used to assess this subpopulation against IUCN Red List criteria and to perform a quantitative evaluation of its probability of extinction. We concluded that common dolphins in the Gulf of Corinth are facing a high extinction risk and that immediate action should be taken to prevent their complete eradication.

2 | METHODS

2.1 | Application of IUCN Red List criteria

A subpopulation or regional population (isolated from other populations of conspecifics; Gärdenfors, Hilton-Taylor, Mace, & Rodríguez, 2001) can be classified as Critically Endangered (CE), Endangered (EN) or Vulnerable (VU) if it is found to meet any of five criteria described in Table 1. Where possible, subpopulation status should be assessed against all criteria (IUCN, 2012c). Moreover, assessments of regional populations should address the degree of such isolation (Gärdenfors et al., 2001). Because the extinction risk of an isolated subpopulation is identical to that of an endemic taxon, we performed the assessment using the IUCN Red List criteria with unaltered thresholds (Gärdenfors et al., 2001; IUCN, 2012a).

2.2 | Sampling methods

2.2.1 | Study area

The Gulf of Corinth (Figure 1) is a semi-enclosed embayment of 2,400 km^2 located in central Greece. The Strait of Rion (maximum width 2 km, maximum depth 65 m) connects it to the Gulf of Patras and the Ionian Sea, while the artificial Corinth Canal (width 21 m, length 6.4 km, maximum depth 8 m) connects it to the Saronic Gulf and the Aegean Sea. The Gulf of Corinth is characterized by shallow waters and gentle slopes on its northern part and by deep waters (maximum 935 m) and steep slopes in its central southern sector.

2.2.2 | Survey effort and individual photo-identification

Because survey and photo-identification methods have been described in detail by Bearzi et al. (2016) and Santostasi et al. (2016), here we provide a more concise description. Navigation was conducted from small boats between 2011 and 2015 during summer months (May–October) for a total of 211 survey days and 21,435 km. All surveys started and ended at the port of Galaxidi (Figure 1) and were designed to cover different sectors of the gulf on different days. A map of the survey effort can be found in Santostasi et al. (2016). Individual photo-identification was conducted following Würsig and Würsig (1977) using 18-megapixel reflex cameras equipped with 70–200 mm f2.8 zoom lenses. Dolphin movements were tracked by following them with the boat and recording the boat's position with a GPS at 1 min intervals. The presence of common dolphins was recorded in the field and then confirmed photographically as described in Bearzi et al. (2016). Individual identification of common dolphins relied on nicks and notches visible from both sides of the dorsal fin (Würsig & Jefferson, 1990), based on strict photographic selection criteria (Santostasi et al., 2016; Urian et al., 2014).

2.2.3 | Geographic range

Criteria A and B deal with the geographic range of a subpopulation in the form of extent of occurrence and/or area of occupancy. Extent of occurrence is defined as “the area contained within the shortest continuous imaginary boundary which can be drawn to encompass all the known, inferred or projected sites of present occurrence of a taxon, excluding cases of vagrancy”, and area of occupancy is described as “the area within its extent of occurrence which is occupied by a taxon, excluding cases of vagrancy” (IUCN, 2012a). Extent of occurrence was calculated by (a) plotting the tracked positions – recorded in 2011–2015 with a GPS at 1 min intervals (Bearzi et al., 2016) – of dolphin groups where at least one common dolphin was present, and (b) creating around these positions the minimum convex polygon intended as “the smallest polygon in which no internal angle exceeds 180 degrees and which contains all the sites of occurrence” (IUCN, 2012a). Area of occupancy was calculated by dividing the entire study

TABLE 1 Summary of Red List criteria adapted from IUCN (2012c)

	CE	EN	VU
A. Population size reduction measured over three generations[a]			
A1	>90%	>70%	>50%
A2, A3 and A4	>80%	>50%	>30%
B. Geographic range in the form of either B1 and/or B2			
B1. Extent of occurrence	<100 km^2	<5,000 km^2	<20,000 km^2
B2. Area of occupancy	<10 km^2	<500 km^2	<2,000 km^2
AND at least two of the following three conditions:			
(a) Severely fragmented OR number of locations	1	≤5	≤10
(b) Continuing decline observed, estimated, inferred or projected in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals			
(c) Extreme fluctuations in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) number of locations or subpopulations; (iv) number of mature individuals			
C. Small population size and decline			
Number of mature individuals	<250	<2,500	<10,000
AND at least one of C1 or C2			
C1. An observed, estimated or projected continuing decline of at least:	25% in 3 years or 1 generation	20% in 5 years or 2 generations	10% in 10 years or 3 generations
C2. An observed, estimated, projected or inferred continuing decline AND at least one of the following three conditions:			
(a, i) Number of mature individuals in each subpopulation	≤50	≤250	≤1,000
(a, ii) Percentage of mature individuals in one subpopulation	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals			
D. Very small or restricted population			
Number of mature individuals	≤50	≤250	≤250
E. Quantitative analysis			
Probability of extinction in the wild:	≥50% in 3 generations	≥20% in 5 generations	≥10% in 100 years

A1, Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND have ceased. A2, Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible. A3, Population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years). A4, An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a maximum of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

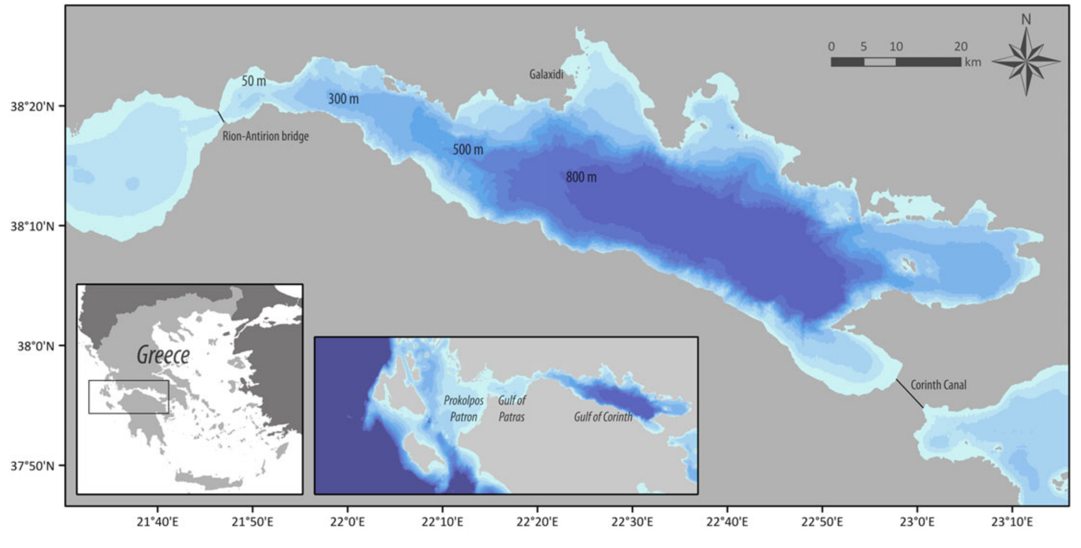

FIGURE 1 The Gulf of Corinth study area in Greece, showing 50, 300, 500 and 800 m isobaths and some of the locations cited in the text

area in a grid cell of 2 × 2 km^2 as advocated by IUCN guidelines (Maes et al., 2015) and summing the area of the grid squares hosting the common dolphin tracked positions. All mapping was performed using geographic information system software (ESRI ArcMap 10).

2.3 | Population size and trends

Red List criteria A, C and D deal with total subpopulation abundance and trends; in particular, criteria C and D specify thresholds for the number of mature individuals (Table 1). Subpopulation size of common dolphins in the Gulf of Corinth for years 2011–2015 has been estimated by Santostasi et al. (2016) as 22 individuals (95% CI 16–32). Abundance trends could not be investigated owing to the short time frame (5 years) and the low number of individuals (Santostasi et al., 2016; Taylor, Martinez, Gerrodette, Barlow, & Hrovat, 2007).

2.4 | Population projections

Red List criterion E deals with the probability of extinction in the wild over three generations, five generations and 100 years. Age structure, survival and reproduction rates are not available for this subpopulation. Therefore, we used the simplest possible stochastic projection approach, multiplying the initial abundance by a range of biologically plausible growth rates (Currey et al., 2009; Morris & Doak, 2002). The modelling process was programmed in R (R Core Team, 2015) and involved the following steps. *Step 1*: To take uncertainty in abundance estimates into account, a value for initial abundance was selected from a normal distribution with a mean equal to the average abundance estimated for this subpopulation (Santostasi et al., 2016) and a standard deviation equal to the average of the standard error of the estimates (n = 22, SE = 7.13). *Step 2*: An initial growth rate λ_0 was selected from a uniform distribution whose lower limit was the mean effective growth rate estimated for a North Atlantic common dolphin subpopulation subject to bycatch and the upper limit was the maximum growth rate under optimal conditions estimated for that subpopulation (0.945–1.045; Mannocci et al., 2012). Upper and lower confidence limits were calculated as ±1.96(SD). *Step 3*: Growth rates fluctuate over time as a result of different sources of stochasticity (e.g. environmental, demographic). Overlooking such fluctuations causes an underestimation of extinction probability (Morris & Doak, 2002). Therefore, we took temporal stochasticity into account by simulating scenarios with increasing yearly variability in the growth rate. The scenarios were built by drawing λ_t from a normal distribution with mean equal to λ_0 and standard deviations ranging from 0 to 0.02. *Step 4*: To estimate abundance in the following year N_{t+1} we rounded the predicted N_t to the nearest integer, then multiplied by λ_t obtained in step 2. Abundance was projected up to a maximum of 100 years. *Step 5*: The abundance of mature individuals was calculated based on the proportion of mature individuals in common dolphin populations (0.54; Taylor, Chivers, Larese, & Perrin, 2007). For each year, a binomial distribution was used, with Nt trials (number of individuals at time t) with a probability of success of 0.54 to obtain the number of mature individuals in the subpopulation (Currey et al., 2009). *Step 6*: The previous steps were repeated 5,000 times. *Step 7*: We estimated the probability of extinction under different quasi-extinction thresholds; namely, between two and six reproductive individuals. If any of the projections fell below such a threshold the subpopulation was considered as extinct. We estimated the quasi-extinction probability over three generations, five generations and 100 years to be the number of projections that reached quasi-extinction threshold over the total number of projections. For the projections, we used a generation time of 14.8 years (rounded to 15), as estimated for common dolphins by Taylor, Chivers, et al. (2007).

3 | RESULTS

3.1 | Sampling results

Between 2011 and 2015 we made 468 sightings of mixed-species groups including striped dolphins, common dolphins and/or animals of intermediate pigmentation. Sampling details can be found in Bearzi et al. (2016) and Santostasi et al. (2016). Ten common dolphins carrying natural marks suitable for long-term recognition were individually photo-identified. Two individuals were sighted in one year, three in two years, three in three years, one in four years and one in all the five years of the study. The rate of discovery curve (Figure 2) reached an asymptote during the third year of the study, reflecting the absence of new individuals being added to the catalogue after the third year.

3.2 | Geographic range

The extent of occurrence varies from 448 to 651 km^2 depending on the year, while the area of occupancy varies between 234 and 311 km^2 (Table 2). The total extent of occurrence was estimated as 1,014 km^2 and the area of occupancy as 708 km^2 (Figure 3). The total area occupied by this subpopulation only accounts for 30% of the Gulf of Corinth total area (2,400 km^2) and corresponds to its central and southern portion.

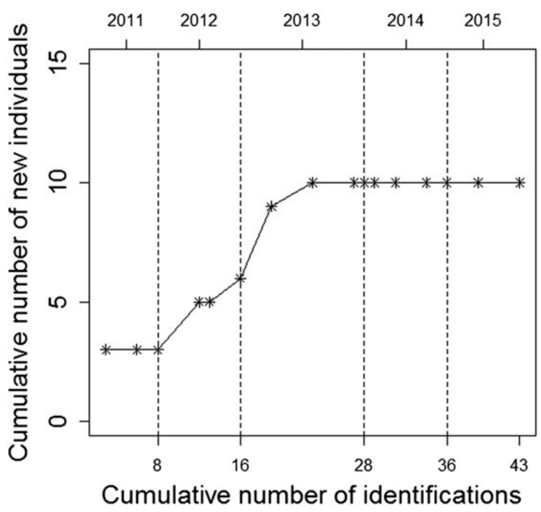

FIGURE 2 Rate of discovery curve for 10 common dolphins identified in the Gulf of Corinth

TABLE 2 Estimates for extent of occurrence (EOO) and area of occupancy (AOO) divided by year, relative to common dolphins movements tracked in 2011–2015

Year	EOO (km^2)	AOO (km^2)
2011	651	295
2012	497	264
2013	466	311
2014	448	292
2015	466	234
2011–2015	1,014	708

3.3 | Population projections

The estimated extinction probabilities are listed in Table 3 and shown in Figure 4. Based on a quasi-extinction threshold of two mature individuals and a constant growth rate (scenario 1) the subpopulation would qualify as Endangered based on criterion E (Figure 4, Table 3). The introduction of environmental variability greatly increases the quasi-extinction probability, which becomes ≥0.5 (dashed lines in Figure 4) and qualifyies the common dolphin subpopulation as Critically Endangered based on criterion E. Figure 5 shows the expected abundance of mature individuals after three generations. For all the scenarios, more than 90% of the projected abundance of mature individuals after three generations would fall in the interval 0–50 mature individuals (Figure 5), indicating that, even if the subpopulation does not go extinct, it will remain below the abundance threshold that qualifies it as Critically Endangered.

4 | DISCUSSION

4.1 | Population isolation

When assessing subpopulations, the occurrence and status of conspecific units that may affect the risk of extinction within the region should be considered (Taylor, 2005). The closest area with quantitative information on abundance and trends is the Inner Ionian Sea archipelago, where common dolphins have declined dramatically (Bearzi et al., 2005, 2008; Bearzi, Politi, Agazzi, & Azzellino, 2006; Piroddi, Bearzi, Gonzalvo, & Christensen, 2011). Based on the available information, it cannot be assumed that common dolphins surviving in the eastern Ionian Sea may represent a 'source' population capable of having a 'rescue effect' on common dolphins in the Gulf of Corinth. Additionally, no movements between the Gulf of Corinth and the Gulf of Patras (across the Strait of Rion), or even common dolphin sightings in the Gulf of Patras, have ever been reported (Bearzi et al., 2016; Frantzis et al., 2003). For the purposes of IUCN Red List, the common dolphin subpopulation qualifies as being isolated from conspecifics (Bearzi et al., 2016). Therefore, according to Gärdenfors et al. (2001), the assessment must be based on unaltered IUCN Red List criteria.

TABLE 3 Quasi-extinction probabilities after three generations, five generations and 100 years

Quasi-extinct state	Quasi-extinction probability		
	Scenario 1	Scenario 2	Scenario 3
q = 2 mature individuals			
After three generations	0.29	0.65	0.80
After five generations	0.32	0.69	0.83
After 100 years	0.35	0.70	0.84
q = 4 mature individuals			
After three generations	0.50	0.65	0.72
After five generations	0.54	0.69	0.76
After 100 years	0.55	0.70	0.78
q = 6 mature individuals			
After three generations	0.66	0.76	0.80
After five generations	0.69	0.78	0.83
After 100 years	0.70	0.80	0.84

q, quasi-extinction threshold.

4.2 | Geographic range, population size and trends

Geographic range estimates (criterion B) meet the threshold for the subpopulation to be classified as Endangered if coupled with decline and extreme fluctuations of the number of mature individuals. Criteria A (population size reduction over three generations) and C (small population size and decline) require a subpopulation decline to be observed, estimated, inferred or suspected in the past present or future (IUCN, 2012c). Detecting a future decline would not be possible given the low power of abundance estimates from monitoring programmes with small population sizes (Santostasi et al., 2016; Taylor, Martinez, et al., 2007). Although no baseline abundance data exist for this area, sharp declines have been documented for the adjacent Ionian Sea (Bearzi et al., 2008), the Adriatic Sea (Bearzi,

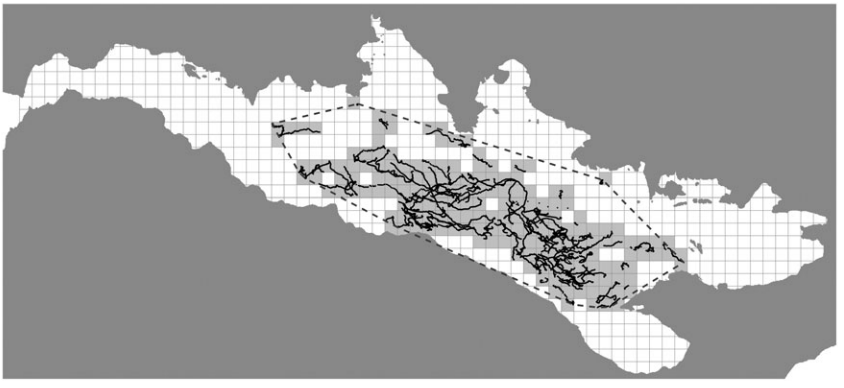

FIGURE 3 Movements of common dolphins (black lines) recorded in the Gulf of Corinth between 2011 and 2015. The dashed line encloses the estimated extent of occurrence within the study area (the entire Gulf of Corinth). The grey cells (on a grid cell of 2 × 2 km^2) were used to estimate the area of occupancy

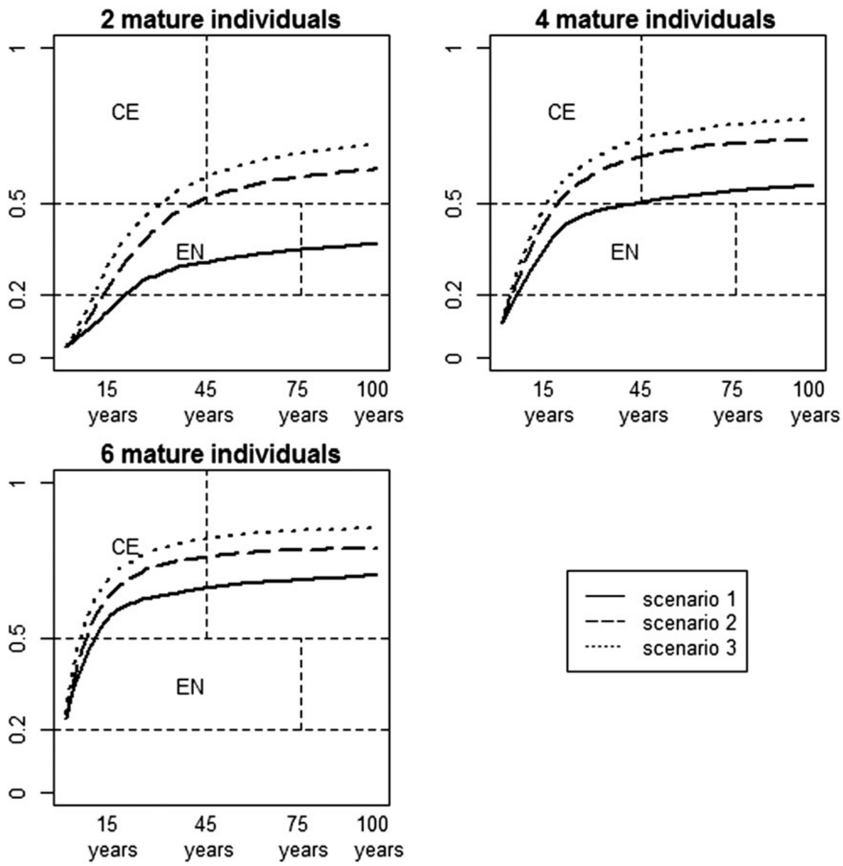

FIGURE 4 Quasi-extinction probability of common dolphins in the Gulf of Corinth after one generation (15 years), three generations (45 years), five generations (75 years) and 100 years. The *y*-axis is the quasi-extinction probability; the *x*-axis is the time expressed in years. The different scenarios represent increasing levels of growth rate stochasticity simulated by drawing the growth rate for each year from normal distributions with increasing standard deviations (from 0 to 0.02)

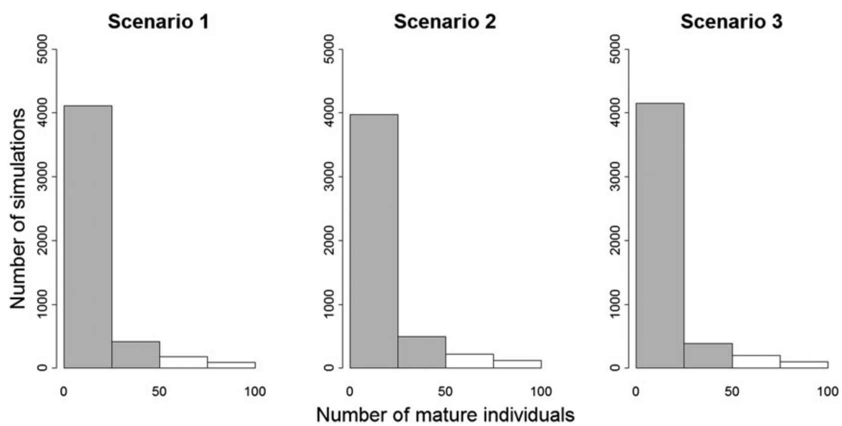

FIGURE 5 Distribution of projected number of mature individuals after three generations (45 years). Projections that reached an abundance of more than 100 individuals (<4% of the simulations for all the scenarios) are not shown. In the three scenarios, the vast majority of the projections fall in the interval between 0 and 25 mature individuals. Solid bars indicate the projected abundances after three generations that would result in a population of less than 50 mature individuals (>90% in all the scenarios)

Holcer, & Notarbartolo di Sciara, 2004), the Alborán Sea (Cañadas & Vázquez, 2017) and the entire Mediterranean Sea (Bearzi et al., 2003), resulting in a regional classification as Endangered (Bearzi, 2012). Based on the principle of precaution advocated by the IUCN Red List (Mace & Stuart, 1994), a decline of common dolphins in the Gulf of Corinth similar to declines reported in other Mediterranean areas and throughout the region (50% decline over three generations; Bearzi, 2012) cannot be ruled out. Fluctuations in the number of reproductive individuals are expected as a result of demographic stochasticity (temporal variation in population vital rates, driven by chance whose effect is more severe when population size is small; Engen, Bakke, & Islam, 1998). Lastly, the common dolphin subpopulation of the Gulf of Corinth was estimated to contain an average of 22 (95% CI 16–32) individuals (Santostasi et al., 2016). Even assuming an upper CI limit and 100% being mature individuals (i.e. complete absence of immatures), the abundance of mature individuals would be well below the threshold for classifying this subpopulation as Critically Endangered under criterion C (n = 250) and criterion D (n = 50). Consequently, the Gulf of Corinth subpopulation should be listed as Endangered under Red List criteria A and B and Critically Endangered under criteria C and D (very small or restricted population).

4.3 | Probability of extinction in the wild

The inclusion of temporal stochasticity in the growth rate led to a ≥50% probability of quasi-extinction in all the simulated scenarios (Table 3). The effect of demographic stochasticity is likely present in the study subpopulation, given its low size. Therefore, it should be listed as Critically Endangered under criterion E (quantitative analysis). Moreover, the effects of extant anthropogenic threats were not considered, and therefore assumed to be null in the projections. Important ongoing threats, however, do occur and have been documented in this area (Bearzi et al., 2016). Finally, hybridization with a 60-fold larger population of striped dolphins is a source of concern (Bearzi et al., 2016; Frantzis & Herzing, 2002), as hybridization and introgression may increase the probability of extinction through genetic and demographic swamping (Allendorf, Luikart, & Aitken, 2013). Research aimed at assessing the effects of hybridization and its consequences for common dolphin viability is currently under way.

4.4 | Conservation and management implications

Because small populations are exposed to the Allee effect (a positive correlation between population density and individual fitness), potentially leading to extinction (Courchamp, Clutton-Brock, & Grenfell, 1999), a population composed of only a few tens of individuals may be already non-viable (Traill, Brook, Frankham, & Bradshaw, 2010). Consistently, the projections suggest that the chances of recovery are scant even without considering the threats posed by human activities and hybridization. However, as shown by success stories worldwide (Duangchantrasiri et al., 2016; Lotze, Coll, Magera, Ward-Paige, & Airoldi, 2011), recovery of a severely depleted population is possible, provided that conservation measures are established and enforced.

Considering the severity of the situation, immediate action should be taken to mitigate anthropogenic impacts known or suspected to have a negative impact on cetaceans in the Gulf of Corinth. Fisheries management measures aimed at the recovery of depleted fish stocks (particularly of common dolphin key prey) have been identified as a priority for common dolphin recovery in the Ionian Sea (Bearzi et al., 2008; Piroddi et al., 2011). Such measures should be implemented and enforced without delay in the Gulf of Corinth, targeting as a matter of priority those commercial fisheries known to cause food-web damage and deplete common dolphin prey, including purse seiners and trawlers. Moreover, underwater noise (e.g. caused by geoseismic surveys) should be avoided (Weilgart, 2007; Wright et al., 2007). Pollutant discharges should be curtailed and their impacts on the food web evaluated, also considering the large amount of industrial waste discharged into the gulf over the last 50 years (Bearzi et al., 2016; Issaris et al., 2012). Finally, high-speed boat traffic should be strictly regulated in dolphin critical habitat (Bearzi et al., 2016).

The repeatedly advocated creation of a marine protected area in the Gulf of Corinth (ACCOBAMS, 2007, resolution 3.22; Notarbartolo di Sciara & Bearzi, 2010) would be a tool for establishing measures to aid the recovery and long-term survival of the local dolphin populations (Gormley et al., 2012). Using a multizone approach, the protected area may be divided into zones allowing different levels of human impact (Hoyt, 2012), taking into account habitat use by dolphins. A marine protected area would provide a valuable framework for sustainable economic growth in the area primarily based on tourism — a key element of the Greek economy (Potts et al., 2014; Rees et al., 2015). In this context, the continued monitoring of dolphin subpopulation status is needed to evaluate the effectiveness of conservation measures and help prevent the eradication of common dolphins from one of their last areas of occurrence in the Mediterranean.

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