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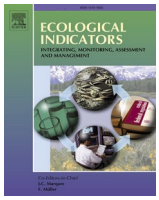
Ecological Indicators 160 (2024) 111820

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind



Short Note

A risk-based forecast of extreme mortality events in small cetaceans: Assessing trends and changes over time

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ARTICLE INFO

Keywords:
Strandings
Extreme value theory
Good environmental status
Ecological forecasting
Die-off
Mass mortality event

ABSTRACT

Numerous conservation programs are now targeting the mitigation or reduction of anthropogenic pressures to restore biodiversity. The aspirational and ambitious objectives underlying these programs need to translate into timely management actions for maximum impact, a process whose first steps assume efficient monitoring and appropriate indicators. Capitalizing on a well-coordinated stranding network, we developed further a risk-based indicator informing indirectly on pressures resulting in at-sea-mortality events of small cetaceans. This indicator uses Extreme Value Theory to forecast the expected maximum number of cetacean strandings on the French seaboard adjacent to three sub-regions defined by the 'Marine Strategy Framework Directive' of the European Union. A comparison of forecasts and observations allows (i) a risk assessment, and (ii) inference on the trajectory towards 'Good Environmental Status' on a time-scale aligning with the 6-years cycle required by the Directive, thereby allowing stakeholders to make informed and timely decisions. We applied the use of the indicators on 3 species illustrating different case studies: the harbour porpoise (*Phocoena phocoena*) in the Channel, the common dolphin (*Delphinus delphis*) in the Bay of Biscay, and the striped dolphin (*Stenella coeruleoalba*) in the Western Mediterranean Sea. Our results showed notably how by-catch in fisheries remains a large threat on short-beaked common dolphins, with no sign of abating.

1. Introduction

Biodiversity in the Anthropocene is threatened by the scale and magnitude of human activities (Intergovernmental and Ecosystemd Ecosystem Services, 2018; McQuatters-Gollop et al., 2022). Ambitious policy goals are being discussed in order to curb biodiversity loss, both in terrestrial and marine ecosystems (*e.g.* the European Union Biodiversity Strategy 2030 esp. Target 4 [1]). The latter, however, have historically lagged behind terrestrial ones with respect to conservation, due in part to daunting challenges in monitoring mobile species and implementing management objectives at ecologically-relevant scales (Authier et al., 2017). These challenges are pregnant in the conservation of marine megafauna, a broad functional group of organisms that includes seabirds and marine mammals (Moleón et al., 2020).

The combined effects of several pressures acting at the same place and time may result in mortality events of low frequency yet acute intensity. In marine ecosystems, these events may happen at sea, far from monitoring schemes, and remain undocumented[2]. In some cases, extreme events can become perceivable when their consequences are visible. In the past, mass strandings of cetaceans have revealed for instance the impact of military sonar, particularly on beaked whales (D'Amico et al., 2009), as well as various episodes of epizootics around the world (Gulland and Hall, 2007). In the Northeast Atlantic, high numbers (several hundreds) of strandings of common dolphins (*Delphinus delphis*) are regularly being reported on the French seaboard during the winter months (Peltier et al., 2021). The majority of carcasses show evidence of by-catch in fishing gears (Bouchard et al., 2019; Supplementary Fig. S1), pointing to the impact of fisheries in the Bay of

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[1] https://ec.europa.eu/environment/nature/biodiversity/strategy_2020/index_en.htm

[2] a single pressure may also occasion extreme mortality; *e.g.* oil spills or fishing (see https://www.theguardian.com/environment/2022/feb/05/shock-in-france-after-giant-trawler-sheds-100000-dead-fish-off-coast)

https://doi.org/10.1016/j.ecolind.2024.111820
Received 4 October 2023; Received in revised form 17 February 2024; Accepted 26 February 2024
Available online 23 March 2024

Biscay. The European Commission (EC) started an infringement procedure against several member states, including France, Spain and Portugal, for failing to implement the strict protection of common dolphins. More generally, by-catch, the unintentional catch of non-target species, is the main threat looming on small cetaceans such as dolphins and porpoises (Avila et al., 2018; Brownell et al., 2019).

By-catch monitoring of cetaceans remains inadequate in the Northeast Atlantic despite several legislative requirements (ICES, 2022; Murphy et al., 2022). Consequently, cetacean by-catch data collected for official statistics is, overall, of poor quality (ICES, 2022). Modelling can partly address the issue of non-representative samples for by-catch estimation from past data (Authier et al., 2021; Rouby et al., 2022), yet better measurements from monitoring schemes dedicated to cetaceans would be the most effective for increased accuracy. Current monitoring prevents a precise and accurate assessment of the drivers of by-catch. Another data gap is demographic parameters. Common dolphins, for example, are wide-ranging and have little distinctive marks to allow for photo-identification: longitudinal monitoring of individually identifiable animals would be extremely costly. Photo-identification can provide detailed demographic information on individual survival and reproduction over time, but requires significant manpower. In practice, demographic parameters remain largely undocumented for most cetacean species and populations (*e.g.* Ashe et al., 2021).

This data gap is particularly problematic: detecting declines in abundance is often required to inform decision makers of the need for conservation measures. The reactive approach of conditioning any decision on a preliminary detection of decline is failing in practice to curb decline or alleviate pressure as only large declines are readily detectable: by the time a decline is detected, it is already too late to remedy (Taylor and Gerrodette, 1993; Taylor et al., 2007). To promote a more proactive approach, Bouchard et al. (2019) proposed to study extreme at-sea mortality events (ASMEs) from on-land observations of stranded cetaceans. Their rationale for modelling extremes (that is, maxima and minima) rather than averages is to focus on the severity of pressures generating additional mortality on long-lived species with a low per-capita fecundity, features characterizing cetaceans. Strandings are an important source of data on many cetacean species, especially for biological sample collection (Wund et al., 2023) or species identification (Yamada et al., 2019). The interpretation of stranding numbers, however, requires caution as the stranding process includes a nexus of (non-mutually exclusive) causes. While the ecological significance of average stranding events can be debated, that of extreme events involving tens or hundreds of cetaceans is salient given their life-history pace.

Bouchard et al. (2019) outlined a predictive framework to compare an out-of-sample forecast of expected strandings with observed strandings. This framework is customary in ecological assessment studies (*e.g.* Chambert et al., 2023) and fits within the imperatives of predictive ecology (Clark et al., 2001) to enable pro-active approaches in conservation. The impact of pressures on cetaceans can be assessed via their effects on additional mortality as revealed by strandings. In other words, the framework allows to estimate the rate of pressures (their effects) but is agnostic of the identity of those pressures. We developed further the existing cetacean stranding-based indicator on ASMEs: Bouchard et al. (2019) showed how Extreme Value Theory could be leveraged for comparing observed strandings to a forecast generated from extrapolating the past pressure rate to the future. This assumption can be problematic as management actions targeted to reduce pressures are precisely expected to change pressure intensity over time, that is to decrease rate over time. We relaxed the assumption of a global rate in pressures over the study period model to allow for regular change in rates over time using penalized Béziers-splines (*i.e.* generalized additive models). Extrapolating the past pressure rate, the model forecasts out-of-sample return levels[3], that is the expected maxima of stranded cetaceans, which can be compared to actual observations to infer on changes in mortality pressures acting on the studied species. The expected pressure rate (under the assumption of extrapolating the past) can be compared to the actual one, making the indicator a trend-based one (Palialexis et al., 2021) that is operational for assessing the status of cetaceans in European marine ecosystems. Our work leans heavily on prediction (Billheimer, 2019), comparing a counterfactual (that is an expectation under some assumptions) to a factual (that is an observation) situation in order to carry out scientific assessments on the demography (*i.e.* mortality, and more precisely ASMEs) of cetaceans. We illustrate below our risk-based indicator and its relevance to management in three small cetacean species in the Northeast Atlantic.

2. Methods

2.1. Legislative framework

One important instrument to protect and conserve the health status of marine ecosystem in Europe is the Marine Strategy Framework Directive (MSFD; Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 [4]). The MSFD requires from EU member states monitoring of marine ecosystems (Art. 11), and employing marine mammals as indicators of good environmental status under Biodiversity Descriptor 1. Reporting is mandatory at the scale of marine sub-regions, 4 of which overlap with waters adjacent to mainland France: 'Greater North Sea', 'Celtic Seas', 'Bay of Biscay and Iberian Coast'; and 'Western Mediterranean Sea' (Fig. S2). Marine mammals, including seals and cetaceans, are to be assessed on 5 criteria, including population demographic characteristics (Criteria 3, Descriptor 1). There are currently no operational indicator on the latter (Palialexis et al., 2021). France has developed a national indicator based on cetacean strandings, and hence mortality, to report on demography (Bouchard et al., 2019; Spitz et al., 2022).

2.2. Data Collection

The French Ministry in charge of Ecology mandates La Rochelle University to coordinates the national strandings network ('Réseau National Échouages'), which encompasses more than 400 trained professionals and citizens to monitor and document any marine mammal strandings occurring on French coasts (including oversea territories). The French stranding network is highly centralized (ICES, 2021a) and achieved a high coverage due to its constituency (which includes civil servants from governmental bodies such as Office Français de la Biodiversité, veterinarians, trained citizens, *etc.*) and mandatory reporting of any marine mammal strandings by local authorities (Authier et al., 2014).

Strandings of marine mammal species are registered daily by La Rochelle University, including over week-ends. Three species of small odontocete were the focus of this study: the harbour porpoise (*Phocoena phocoena*), the common dolphin, and the striped dolphin (*Stenella coeruleoalba*). Each species is the most abundant in one of the MSFD sub-regions: harbour porpoises in the 'Greater North Sea', common dolphins in the 'Bay of Biscay and Iberian Coast'; and striped dolphins in the 'Northwestern Mediterranean'. The abundance of harbour porpoises in the English Channel, common dolphins in the Bay of Biscay, and striped dolphins in the Western Mediterrean Sea showed no change in the 2010s

[3] 'Return level' is the statistical term in use for a forecast from an extreme value distribution. The interested reader is referred to Eastoe (2017) for a non-technical introduction.

[4] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri = CELEX:32008L0056

(Laran et al., 2021; Laran et al., 2022). ASMEs were investigated for each combination of species-subregion over the period 1990–2020.

2.3. Modelling

Registered stranding data were "blocked" over a 3-day block length to smooth a possible weekend effect in reporting and to account for ASMEs extending several days (Bouchard et al., 2019). Daily counts of stranded animals were summed over a sliding 3-days window for each month and M_{ij}, the monthly maximum of the ith month in year j, was computed and stored for Extreme Value Theory modelling. Data from 1990 to 2020 were considered in this study.

Following Bouchard et al. (2019), we used a Generalized Extreme Value (GEV) distribution for modelling $y_{ij} = \log(M_{ij} + 1)$. A logarithmic transform was used to ensure positivity. The log-likelihood for datum y_{ij} is:

$$\ell(\mu_{ij}, \sigma, \xi | y_{ij}) = -\log\sigma - \left(1 + \frac{1}{\xi}\right)\log\left[1 + \xi\left(\frac{y_{ij} - \mu_{ij}}{\sigma}\right)\right] - \left[1 + \xi\left(\frac{y_{ij} - \mu_{ij}}{\sigma}\right)\right]^{-\frac{1}{\xi}} \quad (1)$$

where μ_{ij}, σ and ξ are location, scale and shape parameters respectively. The location parameter μ_{ij} was further assumed to vary with year j and month i (Bouchard et al., 2019) as is customary within the more familiar framework of generalized linear mixed models (Bolker et al., 2009):

$$\mu_{ij} = \mu_0 + \alpha_j + \beta_i \quad (2)$$

where μ_0 is an intercept parameter, and both α_j and β_i are Gaussian random effects. Expanding further the work initiated in Bouchard et al. (2019) where a Gaussian random effect was assumed, we used structured priors for parameters α_j. Specifically, year effects were modeled semi-parametrically with splines and month effects with a first-order random walk:

$$\begin{cases} \alpha_j = \sum_{k=1}^{p+3} \alpha_k^* \times \text{BSpline}_k\left(j\right), & \forall k \in [1:(p+3)], \alpha_k^* \sim \mathcal{N}(0, \tau) \\ \beta_i = \beta_{i-1} + \beta_i^*, & \beta_0 = 0; \forall i \in [1:12], \beta_i^* \sim \mathcal{N}(0, \sigma_{\text{month}}) \end{cases}$$

where $\text{BSpline}_k(j)$ is the kth polynomial piece of degree 3 used to represent year j as cubic Bézier-splines with a second-order penalty ($d = 2$) (Eilers and Marx, 2010). $\mathcal{N}(m, s)$ denotes a Gaussian distribution of location parameter m and scale parameter s. p is the number of knots: knots were placed every 6 years to match MSFD reporting cycles: this means that pressure rate is allowed to change every 6 years in the underlying model. These choices allow to estimate parameters from the model (Eg. 1) using all data up to year t, and then to make monthly predictions (return levels) for the period $t+1$ to $t+6$. These predictions can then be compared to actual data to carry out an assessment on change in pressures underlying ASMEs. Importantly, time-ahead predictions are extrapolations. Eilers and Marx (2010) detailed the behavior of B-splines with respect of inter- and extra-polation. When interpolating, the Bézier-spline coefficients form a polynomial sequence of degree $2d-1$, and for extrapolation the degree is $d-1$. With $d = 2$, interpolation is cubic and extrapolation is linear. This choice enables leveraging the flexibility a generalized additive model when estimating the location parameter μ_{ij} and ensuring a linear extrapolation when predicting return levels from the recent past.

A first model (see below) was fitted to data up to 2014 (included). Estimates from this model were then used to predict return levels for each month between 2015 and 2020 (included). These predictions were then compared to data over the same period, that is 2015–2020. A second model was then fitted to the complete data (up to 2020) to compare the 2009–2014 trend with the estimated trend for 2015–2020. The predicted trend (from the model excluding 2015–2020) corresponds to a counterfactual scenario wherein pressures behind ASMEs over the period 2015–2020 are extrapolated from the period 2009–2014. This counterfactual was compared to the factual trend, estimated from the data between 2015 and 2020, to make an assessment with respect to changes in the intensity of pressures behind ASMEs over this period.

2.4. Estimation

Estimation of the GEV parameters (Eq. 1) was carried out in a Bayesian framework using programming language `Stan` (Carpenter et al., 2017) called from `R` v.4.2.2 (R Core Team, 2022) with library `Rstan` (Stan Development Team, 2023). Weakly-informative priors on parameters were used. In particular the prior for shape parameter ξ was a uniform: $\xi \sim \mathcal{U}(-0.5, 2.0)$. The prior for the intercept μ_0 was $\mu_0 \sim \mathcal{N}(0, 5.0)$. A variance partitioning parametrization was used:

$$\begin{cases} \textbf{prop} \sim \mathcal{D}(1,1,1) \\ \sigma_{\text{total}} \sim \mathcal{GG}\left(\frac{1}{2}, 1.0, \frac{\log 2}{10}\right) \end{cases}$$ where $\mathcal{D}()$ denotes the Dirichlet distribution for modelling proportions (such that $\sum_{i=1}^{3} \text{prop}_i = 1$) and $\mathcal{GG}()$ the Gamma-Gamma distribution for scale parameters (Griffin and Brown, 2017; Pérez et al., 2017). With this parametrization, the several variance components of the model were:

$$\begin{cases} \sigma^2 = \sigma_{\text{total}}^2 \times \text{prop}_1 \\ \tau^2 = \sigma_{\text{total}}^2 \times \text{prop}_2 \\ \sigma_{\text{month}}^2 = \sigma_{\text{total}}^2 \times \text{prop}_3 \end{cases}$$

Four chains were initialized and run for a total of $2,000$ iterations, discarding the first $1,000$ as warm-up and retaining 1 iterations out of 5. Control parameters for the No-U-Turns algorithm were changed to `max treedepth` $= 15$ and `adapt delta` $= 0.99$. Parameter convergence was assessed using the $\widehat{R}$ statistics (Vehtari et al., 2021) and assumed if $\widehat{R} < 1.01$. Upon convergence, return levels were predicted in `R` and plots made using the library `ggplot2` (Wickham, 2016). Reproducible codes are provided in supplementary information. The workflow is summarized on Fig. 1.

3. Results

Parameter convergence was diagnosed in all combinations of model/data with $\widehat{R} < 1.01$. Return levels for 2015–2020 predicted from extrapolating the pressure rate from the period 2009–2014 were congruent with observed maxima of stranded common dolphins in the 'Bay of Biscay and Iberian coast' and of stranded striped dolphins in the 'Western Mediterranean Sea' (Figs. 2 and 3). The magnitude of strandings differed between these two species by two order of magnitude: strandings of common dolphins were the highest during the winter months with more than 100 animals from 2016 onwards (Fig. 2A); whereas strandings of striped dolphins were less than 5 (Fig. 3A). The predicted trend in pressures behind strandings matched closely the observed one for common dolphins (Fig. 2B) and overestimated the decline for striped dolphins (Fig. 3B). Predicted return levels for harbour porpoises in the English Channel (southern part of the 'Greater North Sea' MSFD sub-region) always exceeded the observed maxima, revealing a mismatch between the trend observed in 2009–2014 and that borne out in 2015–2020 (Fig. 4).

Observed maxima of stranded common dolphins for 4 consecutive winters matched predictions out of the forecasted 6 winters. These maxima corresponded to a total tally (over 3 consecutive days within a month) of more than 50 animals that were registered as strandings along the Atlantic seaboard of France (Fig. 2A). Maxima of more than 100 stranded common dolphins over 3 consecutive days were observed in February 2017 and March 2019, in agreement with forecasts (Fig. 2A).

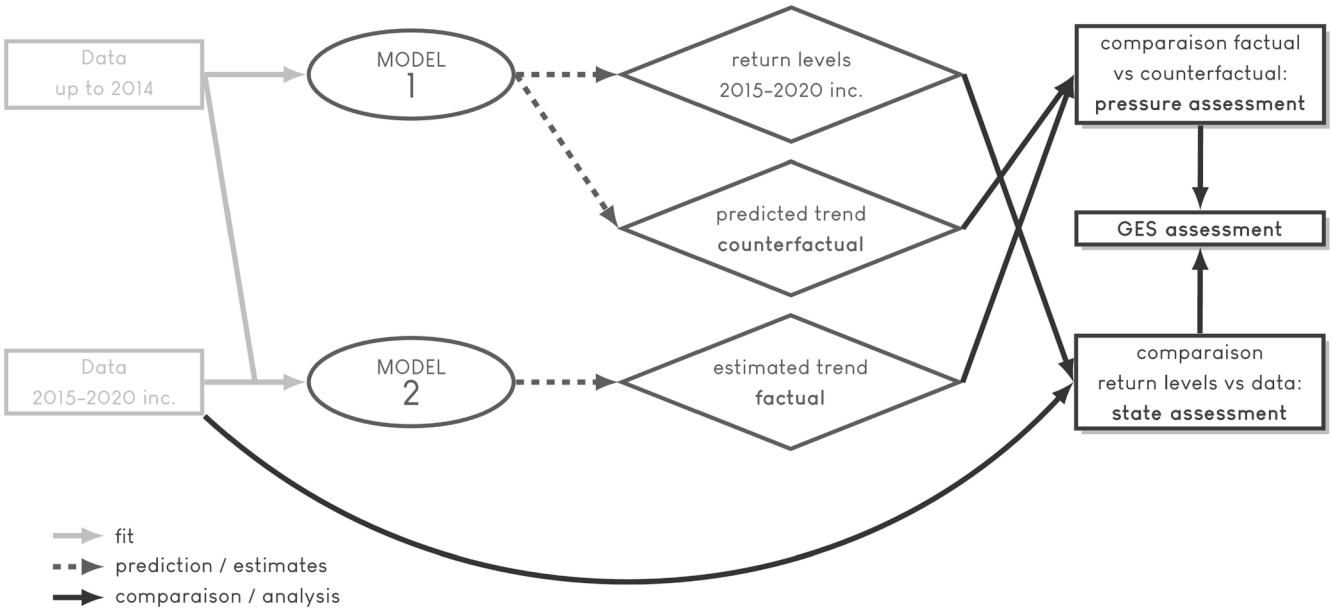

Fig. 1. Assessment chartflow: schematic representation of the proposed approach for a risk-based indicator using small cetacean strandings. GES means "Good Environmental Status" *sensu* the EU Marine Strategy Framework Directive.

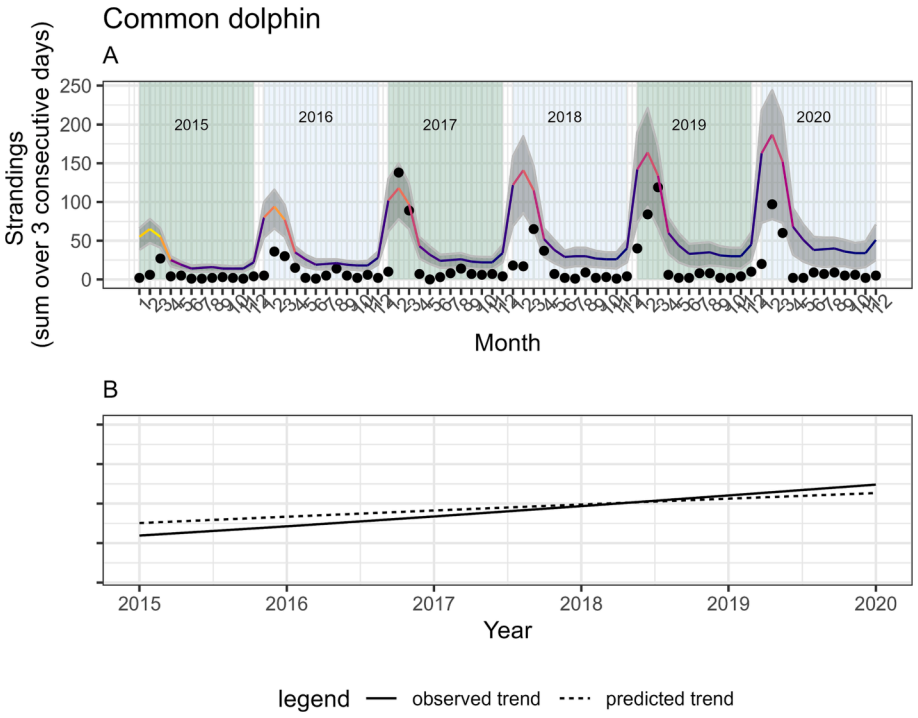

Fig. 2. Forecasted and observed maximum numbers of stranded common dolphins on the Atlantic seaboard of France. (A) The grey area delineate a 80% predictive interval for return levels and black dots are observed monthly maxima of stranded animals over a sliding 3-days window. The colored line represents the mean predicted return level, with a scale for low to high risk. (B) Comparison of the predicted and observed trend in pressures (parameters α_j in Eq. 2).

4. Discussion

We updated and developed the risk-based indicator of Bouchard et al. (2019) informing on mortality on cetaceans using stranding data. In particular, we expanded the model with the use of structured priors (penalized B-splines) on parameters related to year effects in order to allow for changes in pressure rates over time. This modelling choice operationalized a comparison between a forecast under an assumption of similar trend in pressure rates (*i.e.* prediction under the same rate, or a counterfactual) and factual observations. Applying this methodology with stranding data on three species of small toothed cetacean species (odontocetes) over the period 1990–2020 we evidenced an ongoing intensification of mortality on common dolphins in the sub-region 'Bay of Biscay and Iberian Coast' with ASMEs resulting in strandings of more than 100 animals over 3 consecutive days. Agreement between forecasts and observations was also found for striped dolphins in the 'Western Mediterranean Sea' sub-region. In contrast, strandings data on harbour porpoises contradicted the forecast, providing evidence of an observed

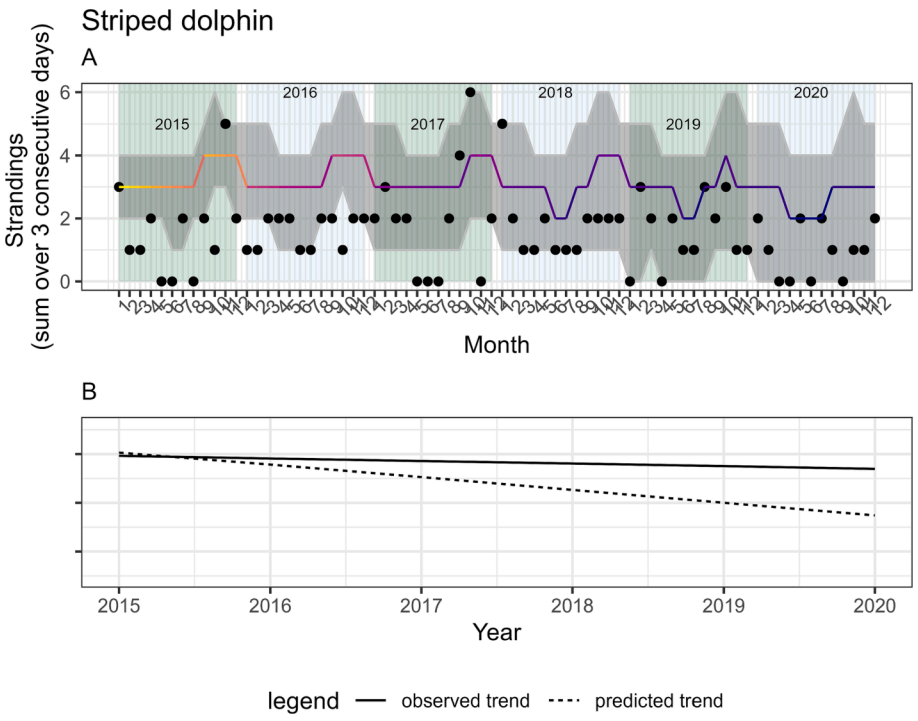

Fig. 3. Forecasted and observed maximum numbers of stranded striped dolphins on the Mediterranean seaboard of France (including Corsica). (A) The grey area delineate a 80% predictive interval for return levels and black dots are observed monthly maxima of stranded animals over a sliding 3-days window. The colored line represents the mean predicted return level, with a scale for low to high risk. (B) Comparison of the predicted and observed trend in pressures (parameters α_j in Eq. 2).

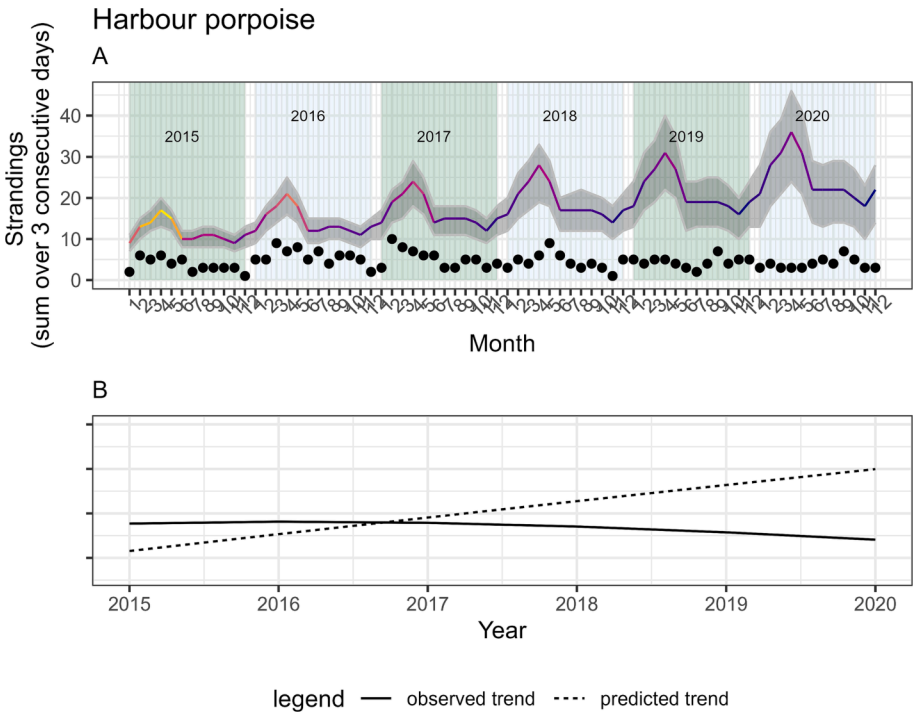

Fig. 4. Forecasted and observed maximum numbers of stranded harbour porpoises on the French seaboard adjacent to the Channel. (A) The grey area delineate a 80% predictive interval for return levels and black dots are observed monthly maxima of stranded animals over a sliding 3-days window. The colored line represents the mean predicted return level, with a scale for low to high risk. (B) Comparison of the predicted and observed trend in pressures (parameters α_j in Eq. 2).

decline in pressures generating ASMEs for this species in the English Channel ('Greater North Sea' sub-region).

Interpreting our stranding-based indicator requires care as the assumption made with forecasting is one of all-else-being-equal (see Table 1). One important limitation is that change in risk can be due to either a change in exposure or a change in hazard. A change in exposure could result from changes in cetacean abundance. A change in hazard, on the other hand, can result from changes in human practices inducing increase or decrease of a pressure (*e.g.* implementation of mitigation measures, changes in fisheries practices, …) as well as potential

Table 1
Interpretation of the risk-based indicator. The indicator is a forecast of the expected maximum number of strandings (summed over 3 consecutive days) under an assumption of all-else-being-equal (or *ceteribus paribus*) to the previous assessment cycle. Any mismatch between the forecasts and the observations reveals a violation of this assumption, betraying a change between previous and current conditions.

Previous MSFD assessment	Current MSFD assessment		
	Forecast	Observation	Interpretation
GES	↗ or = or ↘	↗	increase in pressures
	↗ or = or ↘	= or ↘	GES
non-GES	↗ or = or ↘	= or ↗	non-GES
	↗ or = or ↘	↘	decrease in pressures

cumulative effects from different pressure sources (*e.g.* pollutants, marine noise, collision, …). Our statistical indicator is agnostic to the causes of change as it only reveals changes in the observed effects (maximum numbers of strandings). The contrasted context between strandings of common and striped dolphins provides an illustration for careful interpretation of the indicator: common dolphins are under a high risk of by-catch in the Northeast Atlantic (Dolman et al., 2016; Murphy et al., 2021). This by-catch risk is less for striped dolphins in the Western Mediterranean Sea where past extreme mortalities are more likely to be due to Morbilivirus outbreaks (Aguilar and Raga, 1993). The intensity of common dolphin strandings during winter months on the French Atlantic seaboard has increased since 2016, with hundreds of animals being registered [5]. Strandings of striped dolphins with by-catch evidence on the French Mediterranean seaboard however remains few, suggesting a low intensity of the associated pressure and during the last decade, Morbillivirus would evolve into a chronic endemic rather than an acute epidemic episodes. Risk, which is the product of the likelihood of an event and the consequences of that same event (*i.e.* an expected loss; Cressie, 2022), are markedly different between common and striped dolphins. Our forecast were congruent with observations in both species (Figs. 2 & and 3), yet the associated risks different by two order of magnitudes due to a very high stranding intensity of common dolphins reflecting a heavy pressure and impact of anthropic activities in the Bay of Biscay.

Different conclusions with respect to 'Good Environmental Status' (GES, *sensu* the MSFD) for these two small odontocete species are warranted. In the case of striped dolphins, the relatively good agreement between forecasts and observations, even though the predicted trend over-estimated a decline in pressure rates (Fig. 3B), can indicate that GES was maintained between 2015 and 2020 as GES was previously achieved (Table 2; Spitz et al., 2017): by-catch mortality risk was low to begin with and remained low. For common dolphins, the previous MSFD assessment was non-GES previously due to by-catch, and no change in abundance has yet been evidence in the Northeast Atlantic (Geelhoed et al., 2023). Our results showed that the pressures have kept increasing at the same rate, with ASMEs resultings in hundreds of strandings during winter months. Extrapolating the pressure rate from the period 2009–2014 to the period 2015–2020 is thus compatible with observed stranding data, indicating that GES is not on a trajectory to improve for this species in the sub-region 'Bay of Biscay and Iberian Coast' (Table 2). By-catch mortality risk was already high before 2015 and increased between 2015 and 2020.

The winter abundance in the Bay of Biscay was estimated at ≈ 182,000 individuals (95% confidence interval 128,000-258,000; Laran et al., 2022). Assuming that roughly one fourth of carcass float and can strand (Peltier et al., 2024) and assuming conservatively a forecast for 2021 similar to 2020 (*i.e.* roughly 150 animals; Fig. 2), the cumulative forecasted intensity of ASMEs in the three winter months of 2021 were $\approx 3 \times 150 \times 4 = 1{,}800$, corresponding to at least $\frac{1800}{182000} \approx 1\%$ of the estimated winter abundance. These back-of-the-enveloppe calculations illustrate the level of pressures currently experienced by common dolphins because of anthropogenic activities in the Bay of Biscay. Peltier et al. (2024) estimated by-caught common dolphins in winter 2021 to number several thousands from both aerial survey and strandings, again showing congruence in magnitude between the back-of-the-enveloppe forecast (an extrapolation from the recent past) and data independent from it.

With respect to harbour porpoises, our indicator forecasted an increase in strandings between 2014 and 2020 from the observed increase in strandings registered along the French coasts on the Channel between 2009 and 2014 (Bouchard et al., 2019). Over the same period, a steep increase in harbour porpoise strandings was documented along the southern North Sea (IJsseldijk et al., 2020). The large-scale SCANS surveys dedicated to the abundance estimation of small cetaceans showed a southern distributional shift between 1994 and 2005, a pattern which was confirmed in 2016 (Hammond et al., 2021) and in 2022 (Gilles et al., 2023). Redistribution of harbour porpoises within the North Sea can partly explain the increase in strandings but is unlikely to be the only cause (IJsseldijk et al., 2020), especially as the redistribution predates the increase in strandings in the 2010s. By-catch of harbour porpoises is an additional cause of mortality: it remains high in the sub-region 'Greater North Sea', numbering in the several thousands (ICES, 2021b). The previous MSFD assessment of harbour porpoise for France concluded of non-GES due to an increase in pressure rate (Bouchard et al., 2019). However, over the period 2015–2020, a decrease in maximum numbers of strandings along French coasts of the Channel was observed, suggesting an abatement in pressures (Table 2). This interpretation needs to be caveated: the causes behind the change in trend (Fig. 4B) remains to be fully understood and results from the latest SCANS-IV survey that took place in summer 2022 will be invaluable (Gilles et al., 2023). Extrapolations from 2009–2014 to 2015–2020 were not aligned with observations: although the observed pressure rate did not increase, it did not decrease either and remains high (Fig. 4B) preventing to conclude on GES achievement for this species (Table 1).

The risk-based indicators informed on cetacean mortality at sea: it is a demographic indicator, albeit an indirect one which requires complementary contextual information (notably on abundance, among other pieces of information) for correct interpretation. A such it is no substitute for other MSFD indicators such as those on by-catch mortality or abundance, but complements them by providing early warnings or integrating cumulative effects, for example. The interpretation of strandings is fraught with caveats as these data are largely observational, and subjected to variations in drift conditions and in reporting rates. The former can be tackled with the use of physical drift models

[5] see https://mer.gouv.fr/cetaces (in French).

Table 2
Summary of results. Assessment with respect to 'Good Environmental Status' (GES) for the three small odontocete species based on the risk-based indicator.

Species	Previous MSFD assessment	Current MSFD assessment		
		Forecast	Observation	Interpretation
Common dolphin	non-GES	↗	↗	non-GES increase in pressures
Striped dolphin	GES	↘	↘	GES decrease in pressures
Harbour porpoise	non-GES	↗	=	non-GES decrease in pressures

calibrated to small cetaceans (Peltier and Ridoux, 2015). The latter depends largely on national stranding networks. In France, reporting rates are close to 1 as local authorities are required by law to report the occurrence of marine mammal strandings [6], and the public readily engage with marine megafauna [7]. The French Stranding Network is highly centralized (see ICES, 2021a for an overview of stranding networks, esp. pages 113–138), with a single research institute dedicated to the registration of strandings and training of accredited fieldworkers for carrying out necropsies according to a standardized protocol (see also Wund et al., 2023). The latter is paramount for diagnosing consistently any evidence of by-catch (Supplementary Fig. S1).

5. Conclusion

No operational indicator on cetacean demography are currently available despite the need for such an indicator for assessing the GES of marine ecosystems within the European Union (Palialexis et al., 2021). Capitalizing on the strength of stranding networks, we have further developed an indicator to assess trends in mortality which compares forecasted and observed cetacean strandings (Fig. 1). This indicator assumes changes at the same rate between two MSFD assessment cycles to assess whether GES is being maintained, or on a path to being restored, or deteriorating. Current GES assessment depends thus on whether GES was attained previously as the forecast used in the assessment is conditional on the previous MSFD cycle (Tables 1 & 2). Importantly, the assessment needs auxiliary information on causes of mortality (also collected by stranding networks) to understand what are the drivers of the pressures evidenced by the indicator.

In the case of common dolphins in the sub-region 'Bay of Biscay and Iberian Coast', the indicator showed that ASMEs of common dolphins have intensified over the period 2015–2020. The main pressure behind these ASMEs is well identified: by-catch in fisheries is currently so large that it threatens the long-term viability of the population (ICES, 2023). However, a decline in abundance of this species has yet to be detected: in general, only large decline can be readily detected for cetaceans (Taylor et al., 2007; Jewell et al., 2012; Authier et al., 2020). Detecting such a decline is often perceived by some stakeholders as a pre-requisite for implementing mitigation measures, delaying decisions and mitigation actions to a point where recovery of the population may never materialize. The risk-based indicator we have developed can inform on what to expect under current conditions in order to act accordingly. In particular, it can serve as an early trigger for management actions at a pace commensurate with pro-active conservation (6 years as per MSFD cycles in the European Union) to align with the aspirations of the European Union and curb biodiversity loss.

[6] https://www.observatoire-pelagis.cnrs.fr/wp-content/uploads/2022/01/Flash-organisation-echouage_2021.pdf

[7] *e.g.* https://www.observatoire-pelagis.cnrs.fr/stranding/report-a-sighting/?lang = en

CRediT authorship contribution statement

Matthieu Authier: Conceptualization, Data curation, Formal analysis, Methodology, Writing - original draft, Writing - review & editing. **Colin Bouchard:** Formal analysis, Methodology, Writing - original draft, Writing - review & editing. **Cécile Dars:** Data curation, Writing - review & editing. **Jérôme Spitz:** Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data are avaialble in an R package hosted on a public repository

Acknowledgement

The authors thank the French Ministry of Ecology ("DEB-Direction de l'Eau et la Biodiversité") for financial support; and all of the Réseau National Échouages for their dedication in stranding monitoring for 50 years. This manuscript benefited from the critical and constructive feedback of two anonymous reviewers. MA thanks Floriane Plard for suggesting the visual display of factual and counterfactual trends. This study is part of the long-term Studies in Ecology and Evolution (SEE-Life) program of the CNRS.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ecolind.2024.111820.

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