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ARTICLE

Bycatch of Myliobatid Rays in the Central Mediterranean Sea: the Influence of Spatiotemporal, Environmental, and Operational Factors as Determined by Generalized Additive Modeling

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Abstract

Identification of the factors influencing the distribution of vulnerable species can be useful for predicting their occurrence at a local to regional scale and for identifying the most suitable measures of management and conservation. We used generalized additive models to assess the effects of spatiotemporal, environmental, and operational factors on the catches of two myliobatids: the Common Eagle Ray *Myliobatis aquila* and the Bull Ray *Pteromylaeus bovinus*. Fishing data were collected from commercial midwater trawlers operating in the north-central Adriatic Sea during 2006–2013. Presence/absence and abundance (CPUE) data were modeled separately, and each model was then validated by using a test data set. The presence/absence and abundance of Common Eagle Rays and Bull Rays were mostly influenced by spatial (haul location) and temporal predictors. The major occurrences of Common Eagle Rays and Bull Rays were observed in the upper Adriatic Sea between late spring and early autumn. During winter, a southward shift in the catch was recorded for both species. In accordance with a significant effect of depth, Common Eagle Rays were more likely to be caught in hauls conducted between 10- and 60-m depths. The CPUEs of Common Eagle Rays and Bull Rays declined significantly with haul duration and net vertical opening. The validation procedure indicated that the predictive accuracy of the models was rather good. Giving new insight into the ecological requirements of Common Eagle Rays and Bull Rays, the results of this study may contribute to the development of conservation strategies and can be used to direct future monitoring and research programs.

The Common Eagle Ray *Myliobatis aquila* and the Bull Ray *Pteromylaeus bovinus* are two benthopelagic elasmobranchs that occur in the eastern Atlantic from the southern North Sea and Ireland to Morocco and the Canary Islands, throughout the Mediterranean Sea, and along the coast of South Africa (Froese and Pauly 2015). Both species are primarily found in coastal and warm-temperate waters (down to 150–200-m depths), sometimes entering shallow lagoons and estuaries (El Kamel et al. 2009), but they also occur offshore (Serena 2005; Froese and Pauly 2015). Common Eagle Rays are usually recorded on sandy and muddy substrates, often in small groups swimming close to the bottom, where they feed almost exclusively on benthic invertebrates (mainly gastropods and bivalves; Capapé 1976; Jardas et al. 2004). In the Mediterranean Sea, the breeding period of the ovoviviparous Common Eagle Ray likely occurs between September and February (Notarbartolo di Sciara and Bianchi

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1998). After a gestation period of 6–8 months, female Common Eagle Rays give birth to three to seven young (Serena 2005). Bull Rays are not confined to the bottom; rather, they are frequently seen close to the surface and in small groups, sometimes leaping from the water (Van der Elst 1988; Compagno et al. 1989). Bull Rays mainly feed on bottom-living crustaceans, gastropods, and bivalves, also occasionally consuming cephalopods and teleosts (Capapé 1977; Compagno et al. 1989). The Bull Ray is an ovoviviparous species that reproduces on a yearly cycle, with a gestation period of about 6 months and three to seven pups per litter (Compagno et al. 1989).

Like other large elasmobranchs, the Common Eagle Ray has suffered a dramatic decline in abundance and distributional range in recent decades, mainly due to overfishing and habitat degradation (Ferretti et al. 2005; Holtzhausen et al. 2009). Reported as a common species in the Bay of Biscay at the end of the last century, the Common Eagle Ray became very rare in the early 1990s (Quéro 1998). In the Gulf of Lion (Mediterranean Sea), a clear decreasing trend in Common Eagle Ray commercial landings from the demersal fishery during 1970–1995 indicated a rapid decline in their stocks (Aldebert 1997). There are currently no time series data with which to assess trends in other areas of the Mediterranean Sea, but population declines are likely to have occurred elsewhere; the International Union for Conservation of Nature (IUCN) designated the Common Eagle Ray as "near threatened" in the Mediterranean Sea (Holtzhausen et al. 2009; Malak et al. 2011).

For the Bull Ray, the IUCN global conservation assessment is noted as "data deficient" since the abundance status in many areas of the species' wide distributional range remains poorly known (Wintner 2006). In the Mediterranean Sea, the Bull Ray has been locally considered as potentially threatened due to its life history traits (a long-lived species with delayed maturity and low reproductive rates) and overfishing bycatch pressure (Zogaris and Dussling 2010). Vulnerability of Bull Rays to overfishing can be especially high in nearshore habitats, where this species frequently forages and aggregates in small schools (Seck et al. 2002; Serena 2005).

Despite a growing global concern about elasmobranch conservation and management, the lack of biological information and appropriate fisheries data sets for some vulnerable species at local and regional scales hinders assessment and conservation planning (Cavanagh and Gibson 2007). Valuable information on distribution and abundance patterns for Common Eagle Rays and Bull Rays may be obtained by fishery-dependent surveys. In fact, several fishing gears and techniques (pelagic, midwater, and bottom trawls; trammel nets and gill nets; and bottom longlines) include Common Eagle Rays and Bull Rays as either target species or bycatch species (Serena 2005; Wintner 2006; Holtzhausen et al. 2009; Fortuna et al. 2010; Ferretti et al. 2013). Unfortunately, catch data from commercial fisheries for both species are frequently unavailable since these and other fish of low commercial value are usually discarded at sea by fishers (Mavrič et al. 2004; Capapè et al. 2008; Dulčić et al. 2008).

Since 2006, a project aimed at quantifying the accidental capture of large vertebrates (e.g., sharks, manta rays, sea turtles, and dolphins) in midwater trawl fisheries has been conducted in the north-central Adriatic Sea (Fortuna et al. 2010). Initial monitoring data on this fishing activity, which mainly targets anchovies, sardines, and mackerels, provided evidence for a substantial bycatch of Common Eagle Rays and Bull Rays. Based on those results, we attempted to identify the most important factors explaining the spatiotemporal pattern of Common Eagle Ray and Bull Ray catches in midwater trawl fisheries.

Relationships between fishing performance and environmental variables are frequently modeled by using linear regression techniques even though these relationships are often nonlinear (e.g., Bigelow et al. 1999). Linear regression techniques are straightforward in determining model parameters and in their interpretation, but they have a relatively restricted range of application and little flexibility (Chong and Wang 1997). To overcome these drawbacks, the generalized additive model (GAM) approach has been applied to modeling the catch rates of fishes as a function of spatial, temporal, and environmental variables (Bigelow et al. 1999; Walsh and Kleiber 2001; Damalas et al. 2007; Katsanevakis et al. 2009; Murase et al. 2009; Damalas and Megalofonou 2010; Maravelias et al. 2012; Drexler and Ainsworth 2013). The strength of GAMs, which are semiparametric extensions of generalized linear models, is their ability to deal with highly nonlinear and non-monotonic relationships between the response and a set of covariates (Hastie and Tibshirani 1986). In general, GAMs can be useful for (1) defining optimal conditions for a given species by using an array of environmental descriptors and (2) predicting a species' abundance or its likelihood of inhabiting a particular environment (Maravelias 1997; Stoner et al. 2001; Walsh and Kleiber 2001).

Identification of the factors that influence changes in the spatiotemporal distribution of fishes may have important implications for vulnerable species, such as the Common Eagle Ray and the Bull Ray, leading to the implementation of suitable management and conservation measures. In the present study, our main objective was to use a fishery-dependent data set to identify the most important environmental and operational factors explaining the spatiotemporal patterns in Common Eagle Ray and Bull Ray catches within the north-central Adriatic Sea. The underlying relationships between catch rates and the selected factors were analyzed via nonparametric GAMs. The predictive capabilities of the best-fitting models were then evaluated with a test data set (Valavanis et al. 2008).

METHODS

Study area and data collection.—Between 2006 and 2013, fishing data were collected from 47 midwater pair-trawling vessels that operated in the central and northern portions of the Adriatic Sea (Figure 1). Onboard observers monitored the trawlers for a total of 1,098 d. The nature of this fishery-dependent survey prevented the use of an experimental design with fixed sampling

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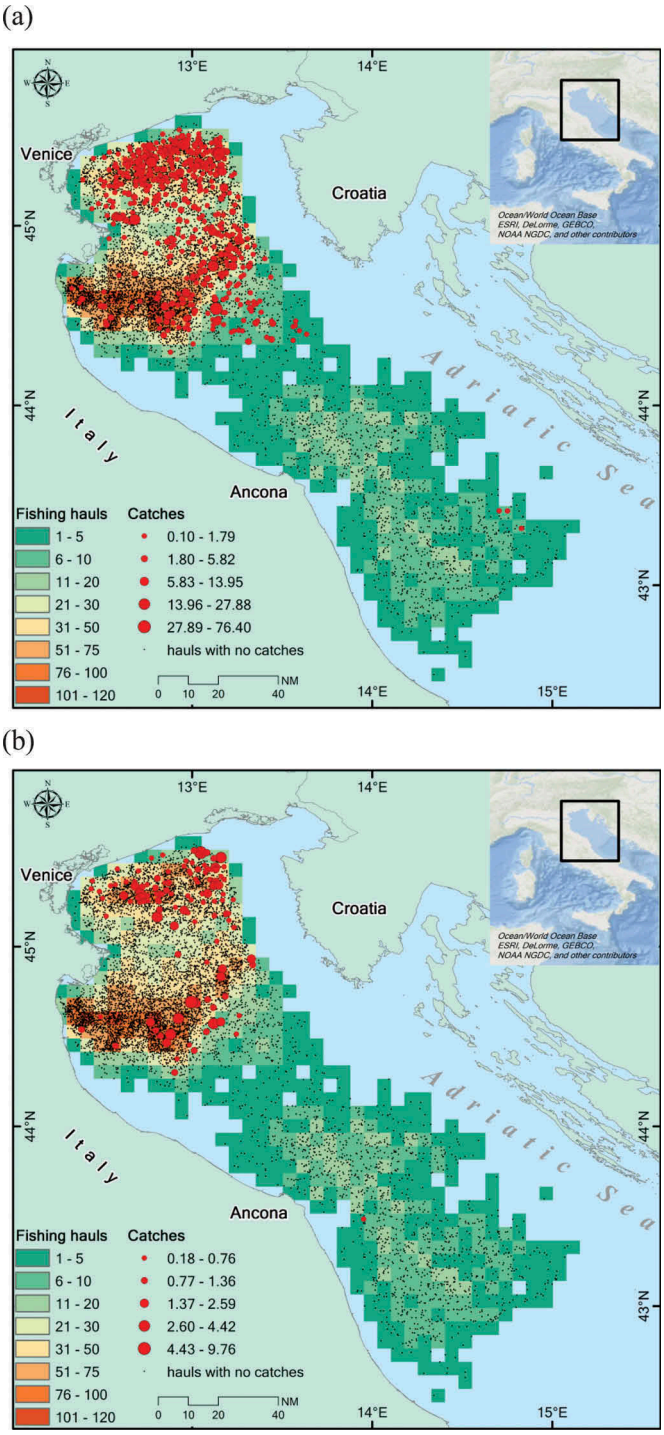


FIGURE 1. Map of the study area in the north-central Adriatic Sea, showing the spatial distribution of fishing effort and catches (CPUE, number of individuals per 10^6 m^3) of **(a)** Common Eagle Rays and **(b)** Bull Rays during 2006–2012.

stations; nevertheless, some hauls were sporadically made at the same locations. Although the vessels worked throughout the year, the nets were only hauled out during daylight. Haul data, such as vessel and trawl net configuration, date, haul duration, vessel speed, and geographic coordinates, were recorded. From those data, we obtained spatial (haul location), temporal (month, season, and year), and operational (net vertical opening, haul duration, and vessel speed) descriptors.

Potentially relevant environmental factors were selected by considering some of the ecological traits of Common Eagle Rays and Bull Rays. Each of these rays is a thermophilic species that mainly occurs in tropical to warm-temperate coastal waters and sometimes enters brackish environments, such as semienclosed bays and lagoons (El Kamel et al. 2009; Zogaris and Dussling 2010). These habits prompted us to investigate the influence of four environmental variables: sea surface temperature, sea surface salinity, bottom depth, and primary production (chlorophyll concentration). Sea surface temperature, sea surface salinity, and chlorophyll concentration data for the study area over the study period were obtained from satellite-based and *in situ* observations developed over a mesh grid at a 0.0625° resolution from two European Union-funded projects, MyOcean and MyOcean2 (marine.copernicus.eu). Monthly average values were used for these variables.

Each haul was correlated to the sea surface salinity, sea surface temperature, chlorophyll concentration, and bathymetry based on the haul's exact date and coordinates. The CPUE, expressed as the number of fish caught divided by the swept volume (area of the trawl net opening multiplied by the distance towed), provided an estimate of fish abundance.

Statistical analysis and modeling.—The GAM techniques were used to evaluate the influences of a suite of spatiotemporal, environmental, and operational variables on the presence/abundance of Common Eagle Rays and Bull Rays. The use of GAMs can be justified when there are suspected nonlinear relationships between multiple predictors and the response variable (Hastie and Tibshirani 1986). In GAM analyses, the expected value of the response variable Y_i is related to the predictor Z_{mi} according to the following general formulation:

$$f(E[Y_f]) = LP_i = c + \sum_{mi}^{p} s_m(Z_{mi}), \quad (1)$$

where f is the link function, LP is the linear predictor, c is the intercept, s_m is the one-dimensional smooth function of covariate Z_m, and Z_{mi} is the value of covariate m for the ith observation (Wood 2006).

The distribution of Common Eagle Ray and Bull Ray catches was skewed and included a large proportion of zero observations because these species were not specifically targeted by the midwater pair trawlers operating in the study area. Given the nature of the data, we applied the delta modeling procedure (Maunder and Punt 2004), which allowed us to model the probability of species presence and catch rates (CPUEs) separately. Models of presence/absence data were obtained by using a binary response variable (coded 0 or 1) with a binomial error distribution and logit link. Abundance data were modeled by using CPUE as the response

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variable. Akaike's information criterion (AIC; Akaike 1973; Burnham and Anderson 2002) was used to select the best underlying error distribution (gamma, Gaussian, negative binomial, or Poisson) and link function. All models were fitted using thin-plate regression splines estimated by penalized iterative least squares, and the optimum degree of smoothing was defined by generalized cross validation (GCV; Wood 2006). To check for autocorrelation in the model residuals, Moran's *I*-statistic (Moran 1948) was computed by means of a specific tool in ArcGIS version 10.2 (ESRI, Redlands, California).

To partially address the spatial autocorrelation observed in the residuals of the presence/absence models, the effect of location was evaluated by using a bivariate smoothed predictor (i.e., the interaction between longitude and latitude; Table 1; Hollowed et al. 2012). Furthermore, α was set at 0.01 to compensate for potential overestimation of the significance level of the covariates.

Model fitting was accomplished by using the mgcv package (Wood 2006) in R version 3.0.2 (R Development Core Team 2013). Eleven predictor variables or covariates were considered for inclusion in the final models for each species: haul position (defined by latitude and longitude), year, season, month, bottom depth, sea surface temperature, sea surface salinity, chlorophyll concentration, net vertical opening, haul duration, and vessel speed. Applying a forward stepwise model building procedure, 1–11 covariates were added to each of the initial models (i.e., the null models, consisting only of the overall mean for each species). Removal of covariates followed the criteria proposed by Wood (2001). Finally, reduction in the GCV score was taken into account to select the "best" models (Wood 2006) for Common Eagle Rays and Bull Rays.

The significance of each term in the final models was assessed by use of an ANOVA *F*-ratio test. Prior to running the analyses, catch data were split into training and test sets: data collected between 2006 and 2012 were used for training, whereas those collected in 2013 were used for model validation. Model performance was evaluated according to the procedure described by La Mesa et al. (2015). The predictive accuracy of the presence/absence models was evaluated with a threshold-independent receiver operating characteristic (ROC) plot (Fielding and Bell 1997; Guisan and Zimmermann 2000) and by estimating the area under the ROC curve (AUC) via the PresenceAbsence package in R (Freeman and Moisen 2008).

RESULTS

During 8 years of monitoring, fishing data were collected from 11,014 hauls, which were unevenly distributed over the study area (Figure 1). The number of hauls per year ranged between 584 and 2,038 (Table 2). The proportion of successful hauls (i.e., hauls in which rays were caught) was 5.8% for Common Eagle Rays and 1.3% for Bull Rays, accounting for a total of 1,857 and 215 individuals, respectively. Yearly CPUEs ranged between 0.024 and 0.151 individuals/10^6 m^3 for Common Eagle Rays and between 0.002 and 0.021 individuals/10^6 m^3 for Bull Rays (Table 2).

Modeling of Species Occurrence (Presence/Absence Models)

The final model for the presence/absence of Common Eagle Rays in the catch encompassed 4 of the 11 main effects or covariates and took the following form: presence (link = logit) ~ *s*(longitude, latitude) + *s*(month) + *s*(year) + *s*(depth). The final model for the presence/absence of Bull Rays included 3 of the 11 covariates: presence (link = logit) ~ *s*(longitude, latitude) + *s*(year) + *s*(month). Temperature, salinity, and all of the operational factors were dropped based on the covariate removal criteria suggested by Wood (2006). Results from the forward stepwise GAM-fitting process are summarized in Table 3, along with results for the variability explained by the factors that were sequentially added to the models. The model for Common Eagle Rays explained 21.4% of the total deviance, and the ANOVA *F*-ratio test indicated that all terms were significant (Table 3). Haul position was the most important factor in terms of relative contribution to the total deviance explained (77.1%), followed by month (15.4%) and year (6.6%; Table 3). The spatial pattern of catches indicated that the most important area of Common Eagle Ray aggregation was located in the northern Adriatic Sea, namely between 44.5°N and 45.5°N and between 12.5°E and 13.5°E (Figure 2). An area of lesser aggregation was observed in the southeastern-most part of the investigated area (between 43.0°N and 43.5°N and between 14.5°E and 15.0°E; Figure 2). The probability of Common Eagle Ray presence was very low during winter and reached its maximum values between late spring and early autumn. At larger temporal scale, an increasing trend in catches was observed from 2009 onward (Figure 2). The lowest contribution to the total deviance

TABLE 1. Spatial autocorrelation in model residuals, as estimated by Moran's *I*-statistic, for the models of Common Eagle Ray and Bull Ray presence/absence and abundance. Values of Moran's *I* were transformed to *z*-scores, with values ≥ 1.96 or ≤ 1.96 indicating significant spatial autocorrelation ($P \leq 0.05$).

Species	Model	Moran's *I*	*z*-score	*P*-value
Common Eagle Ray	Presence/absence	0.005	9.90	<0.0000001
	Abundance	–0.014	–1.31	0.19
Bull Ray	Presence/absence	0.017	31.57	<0.0000001
	Abundance	–0.008	–0.49	0.62

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TABLE 2. Summary of midwater pair-trawling effort (number of hauls), the geographic range of hauls, and the catches of Common Eagle Rays and Bull Rays in the north-central Adriatic Sea during 2006–2013 (CPUE = number of individuals caught per 10^6 m^3).

Year	Number of hauls	Latitudinal range (°N)	Longitudinal range (°E)	Number of hauls with ray catches		Number of rays caught		CPUE	
				Common Eagle Ray	Bull Ray	Common Eagle Ray	Bull Ray	Common Eagle Ray	Bull Ray
2006	649	42.79–45.53	12.34–14.65	68	5	115	5	0.151	0.007
2007	835	42.80–45.41	12.34–14.86	22	19	28	25	0.024	0.021
2008	1,656	42.50–45.55	12.32–15.08	52	64	122	115	0.042	0.039
2009	584	42.85–45.34	12.31–14.96	14	6	22	8	0.024	0.009
2010	1,962	42.75–45.53	12.29–14.98	86	17	357	30	0.072	0.006
2011	1,685	42.74–45.57	12.27–14.86	115	8	303	11	0.044	0.002
2012	2,038	42.79–45.53	12.27–15.00	157	12	636	13	0.086	0.002
2013	1,605	43.24–45.51	12.30–14.29	122	8	274	8	0.078	0.002
Total	11,014	42.50–45.57	12.27–15.08	636	139	1,857	215	0.065	0.007

(0.9%) was accounted for by depth. The probability of encountering Common Eagle Rays remained fairly constant in waters of 10–65 m depth, declining sharply on deeper grounds (Figure 2).

The model for Bull Ray presence/absence explained 27.7% of the total deviance, and all terms had significant effects (Table 3). Haul position again showed the highest explanatory power (64.3% of the total deviance explained), followed by year (26.3%) and month (9.4%; Table 3). The spatial pattern of Bull Ray catches allowed us to identify a primary aggregation area, which was located in the northern part of the Adriatic Sea (between 44.5°N and 45.5°N and between 12.5°E and 13.5°E; Figure 3). The probability of encountering Bull Rays changed significantly at the monthly level (with two peaks in May–June and September–October) and across years (with one peak during 2007–2008; Figure 3).

Modeling of Species Abundance (Positive-Catch Models)

Evaluation of AIC scores to compare abundance models assuming different error distributions indicated that a gamma distribution with a log link function provided the best performance (Table 4). The final model for the abundance (i.e., positive catch) of Common Eagle Rays included five covariates and took the following form: $\log_2(\text{CPUE} + 1) \sim s(\text{longitude, latitude}) + s(\text{net vertical opening}) + s(\text{haul duration}) + s(\text{season}) + s(\text{depth})$. The final abundance model for Bull Rays included four covariates: $\log_2(\text{CPUE} + 1) \sim s(\text{longitude, latitude}) + s(\text{net vertical opening}) + s(\text{haul duration}) + s(\text{month})$.

Table 5 provides information on the GAM-fitting process, the deviance explained, and ANOVA results. The final abundance model for Common Eagle Rays accounted for 34.6% of the total deviance, and all terms were significant (Table 5). The highest contributions to the total deviance explained were provided by haul position (36.7%), haul

TABLE 3. Results of generalized additive model building for factors affecting the presence of Common Eagle Rays and Bull Rays in the north-central Adriatic Sea during 2006–2013. The *F*-values and *P*-values are results from an ANOVA *F*-ratio test between the model in the given row and the model in the previous row (GCV = generalized cross validation).

Model structure (terms added)	Residual deviance	Cumulative deviance explained (%)	GCV score	*F*	*P*-value	% of total deviance explained
Common Eagle Ray presence						
Null	3,988.0		0.424			
Longitude, latitude	3,328.7	16.5	0.356	68.7	$<2.2 \times 10^{-16}$	77.1
Month	3,196.6	19.8	0.343	44.4	$<2.2 \times 10^{-16}$	15.4
Year	3,144.3	21.2	0.337	35.8	$<2.2 \times 10^{-16}$	6.6
Depth	3,132.6	21.4	0.336	6.1	3.2×10^{-6}	0.9
Bull Ray presence						
Null	1,380.0		0.147			
Longitude, latitude	1,135.0	17.8	0.121	81.4	$<2.2 \times 10^{-16}$	64.3
Year	1,034.0	25.1	0.111	183.4	$<2.2 \times 10^{-16}$	26.3
Month	997.3	27.7	0.107	39.9	$<2.2 \times 10^{-16}$	9.4

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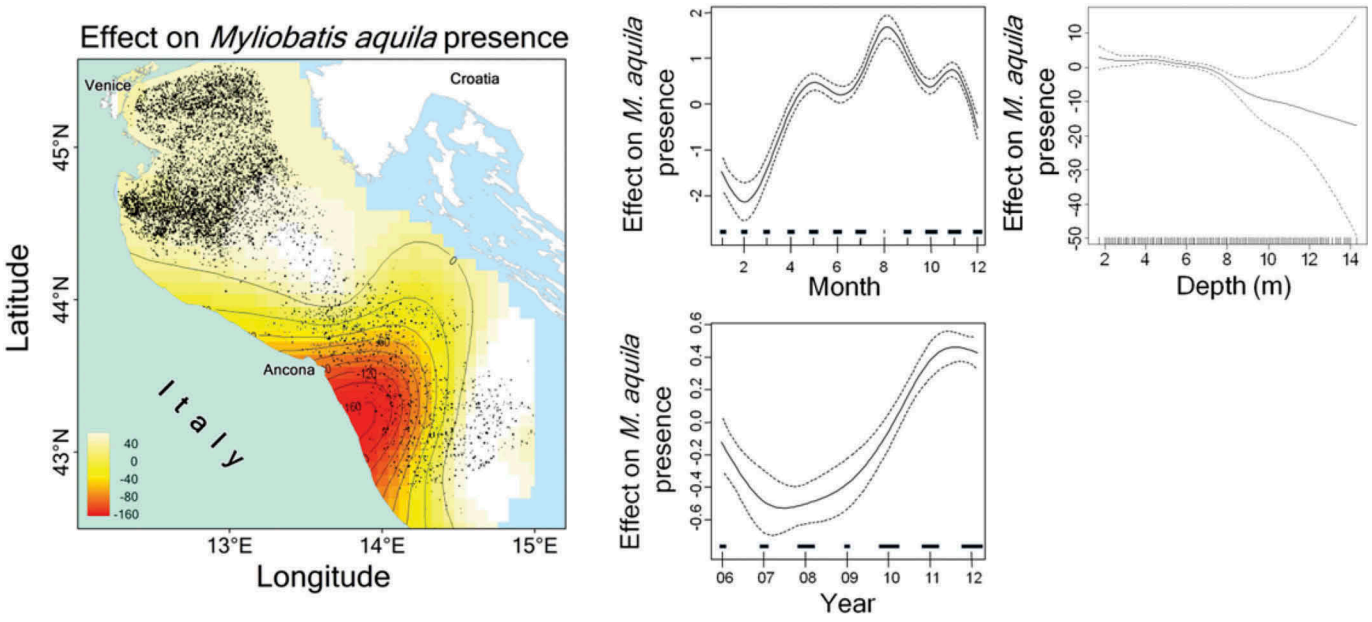


FIGURE 2. Generalized additive model-derived effects of covariates used to model the presence of Common Eagle Rays in the north-central Adriatic Sea during 2006–2013. In the bivariate predictor map, the solid line is the estimate of the smooth function, and the black dots indicate haul locations. In the univariate predictor plots, the solid line is the estimate of the smooth function, the dashed lines indicate 95% confidence bands, and the "rug" or bars on the *x*-axis show the relative density of data points.

duration (28.3%), and net vertical opening (21.7%). The plot illustrating the effect of haul position revealed that Common Eagle Rays were mostly abundant in the northern portion of the Adriatic Sea (between 44.5°N and 45.4°N and between 12.7°E and 13.5°E; Figure 4). The CPUE of Common Eagle Rays declined significantly with haul duration and was also negatively affected by the net vertical opening (Figure 4). Minor contributions to the model were provided by season (8.1%) and depth (5.2%; Table 5). Minimum CPUE values were observed in winter, and maximum CPUEs were observed in summer. The CPUE did not significantly vary within the bathymetric range (i.e., 20–50 m) preferred by Common Eagle Rays, whereas the reduced density of data points below 50-m depth led to very large SEs (Figure 4).

The final abundance model developed for Bull Rays explained 56% of the total deviance, and all terms were significant (Table 5). Haul position (34.3% of the total deviance explained) and haul duration (38.8%) were the most important covariates, followed by net vertical opening (17.9%) and month (9.1%). The spatial pattern of CPUEs indicated that Bull Rays were especially abundant in the northern portion of the investigated area (between 44.5°N and 45.5°N), with an eastward decreasing trend (Figure 5). A sharp decline in Bull Ray CPUE was observed over the entire ranges of haul duration and net vertical opening. The CPUE of Bull Rays also showed significant monthly fluctuations, reaching maximum values between June and September and in December (Figure 5).

Model Validation

The estimated values of AUC in the ROC plots were 0.84 for Common Eagle Rays and 0.78 for Bull Rays, indicating good predictive performance of the presence/absence models (Figure 6). The optimum probability threshold for model performance—occurring when sensitivity (percentage of true positives that are correctly predicted) equals specificity (percentage of true negatives that are correctly predicted)—was 0.10 for Common Eagle Rays and 0.01 for Bull Rays. Setting the probability threshold at these values, 75% of Common Eagle Ray samples and 71% of Bull Ray samples were correctly classified.

The model that was developed from the positive catches of Common Eagle Rays showed a moderate predictive power; the best-fitting regression line explained about 30% of the variability (r^2 = 0.29). The model overpredicted small values of abundance and underpredicted large values, as suggested by the slope (0.27) and intercept (0.75; Figure 7a). Mismatch between the observed and predicted abundances of Common Eagle Rays was mostly located in the northernmost section (beyond latitude 45.3°N) of the study area (Figure 8). In contrast, the predictive ability of the abundance model for Bull Rays was very high, as suggested by the amount of variability (97%) explained by the regression line (r^2 = 0.97; Figure 7b).

DISCUSSION

To identify the most important environmental and operational factors explaining the spatiotemporal pattern of Common Eagle

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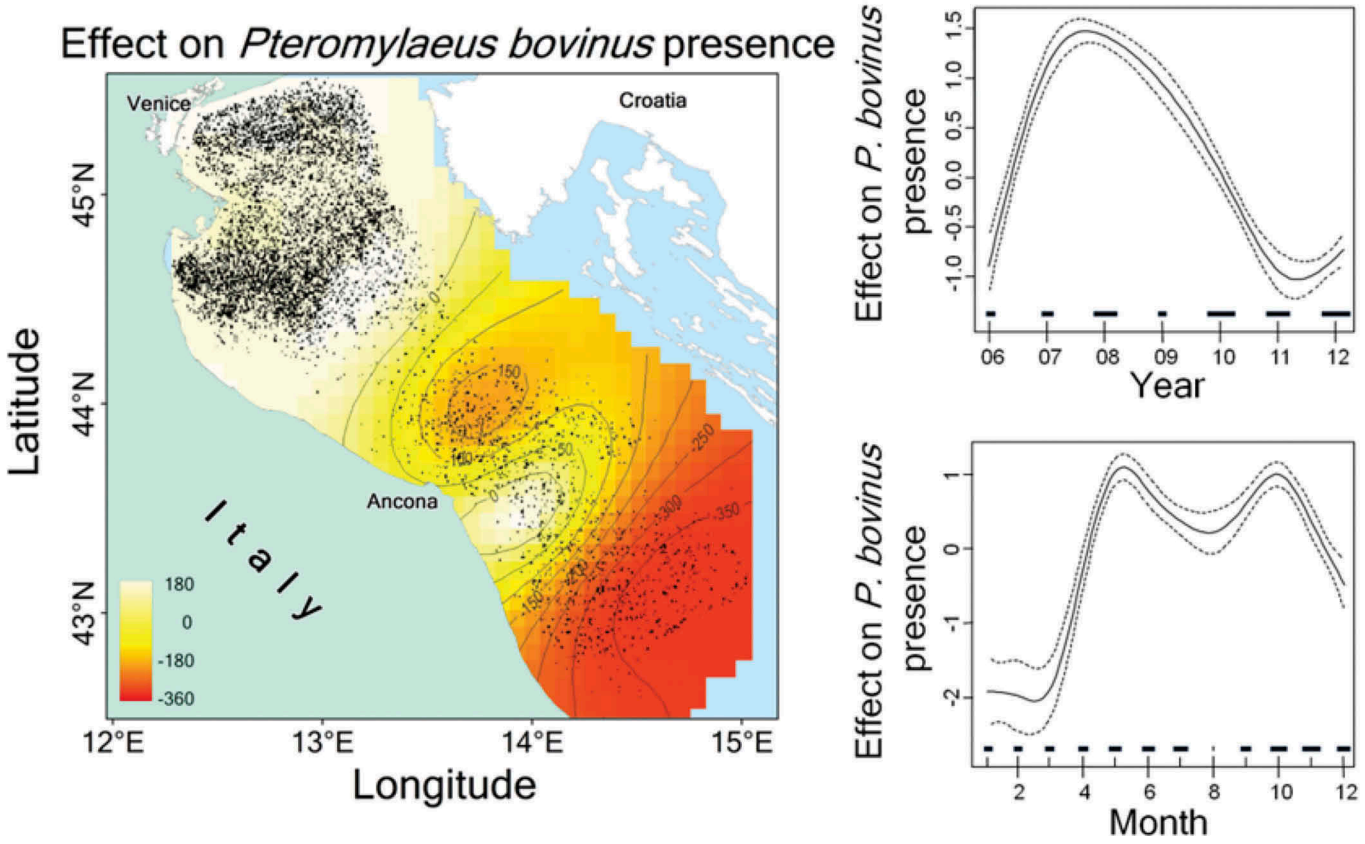


FIGURE 3. Generalized additive model-derived effects of covariates used to model the presence of Bull Rays in the north-central Adriatic Sea during 2006–2013. In the bivariate predictor map, the solid line is the estimate of the smooth function, and the black dots indicate haul locations. In the univariate predictor plots, the solid line is the estimate of the smooth function, the dashed lines indicate 95% confidence bands, and the "rug" or bars on the *x*-axis show the relative density of data points.

Ray and Bull Ray catches in the north-central Adriatic Sea, we analyzed fishery-dependent data by separately modeling the probability of species presence and the positive catch rates. Fishery-dependent data can be intrinsically biased by an unbalanced spatial distribution of effort and changes in gear configuration. Despite this, fishery-dependent data have often been used as a surrogate for species density and to explore the relationship between fish distribution and spatial, temporal, and environmental variables (Walsh and Kleiber 2001; Damalas et al. 2007; Megalofonou et al. 2009; Damalas and Megalofonou 2010).

TABLE 4. Results comparing the use of different underlying error distributions for full generalized additive models (i.e., those including all predictors) of Common Eagle Ray and Bull Ray abundance (i.e., positive catches) in the north-central Adriatic Sea during 2006–2013. Models were compared by using Akaike's information criterion (AIC) scores.

	AIC	
Error distribution	Common Eagle Ray	Bull Ray
Gamma	786.0	56.7
Gaussian	1,153.5	143.3
Negative binomial	1,275.8	292.7
Poisson	2,244.9	317.3

The final models developed by GAM analyses for the presence/absence and abundance (CPUE) of Common Eagle Rays and Bull Rays included different sets of covariates. The explanatory power of the species abundance models was two-fold higher than that of the presence/absence models. Spatial factors (i.e., those representing the geographic location of the hauls) and temporal factors played the predominant role in the presence/absence models, whereas environmental features were of minor importance. Higher occurrences of Common Eagle Rays and Bull Rays were observed in the upper Adriatic Sea off the estuaries of three main river systems in northern Italy (the Po, Adige, and Brenta rivers). This zone is extremely productive due to the riverine input of nutrients and specific oceanographic regimes; it is characterized by a great abundance of benthic (mollusks and crustaceans) and pelagic (anchovies) consumers (Pranovi and Link 2009), which are preferred prey for Common Eagle Rays and Bull Rays (Jardas et al. 2004; Dulčić et al. 2008). In the eastern Mediterranean Sea, Megalofonou et al. (2009) reported a northward increase in catches of Blue Sharks *Prionace glauca*, and

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TABLE 5. Results of generalized additive model building for factors affecting the abundance (log_2[CPUE + 1]) of Common Eagle Rays and Bull Rays in the north-central Adriatic Sea during 2006–2013. The *F*-values and *P*-values are results from an ANOVA *F*-ratio test between the model in the given row and the model in the previous row (GCV = generalized cross validation).

Model structure (terms added)	Residual deviance	Cumulative deviance explained (%)	GCV score	*F*	*P*-value	% of total deviance explained
Common Eagle Ray abundance						
Null	192.2		0.375			
Longitude, latitude	167.7	12.7	0.348	6.1	4.4×10^{-16}	36.7
Net vertical opening	153.4	20.2	0.325	11.7	3.3×10^{-10}	21.7
Haul duration	134.5	30.0	0.286	57.7	3.5×10^{-16}	28.3
Season	129.2	32.8	0.278	6.3	2.2×10^{-4}	8.1
Depth	125.6	34.6	0.276	2.9	0.009	5.2
Bull Ray abundance						
Null	34.1		0.264			
Longitude, latitude	27.6	19.2	0.234	9.2	5.4×10^{-8}	34.3
Net vertical opening	24.2	29.2	0.205	135.4	5.5×10^{-8}	17.8
Haul duration	16.7	50.9	0.143	217.9	4.3×10^{-13}	38.8
Month	15.0	56.0	0.138	3.1	0.009	9.1

those authors hypothesized a positive effect of productivity on the observed pattern.

Common Eagle Rays were also present—but to a lesser extent—in the southeastern-most portion of the investigated area, where they only occurred during autumn and winter months. The most striking effect of season on the spatial patterns in Common Eagle Ray and Bull Ray catches was the southward shift during the winter. Shelf water temperatures in the northern Adriatic Sea during winter are lower than temperatures in the rest of the basin, mainly due to the Po River outflow (Böhm et al. 2003), reaching values (9–10°C) that presumably act as a limiting factor for the presence of Common Eagle Rays and Bull Rays. A similar temporal pattern of distribution was reported by Manfredi et al. (2010), who analyzed catch data on Common Eagle Rays collected from 2001 to 2007 during experimental bottom trawl surveys.

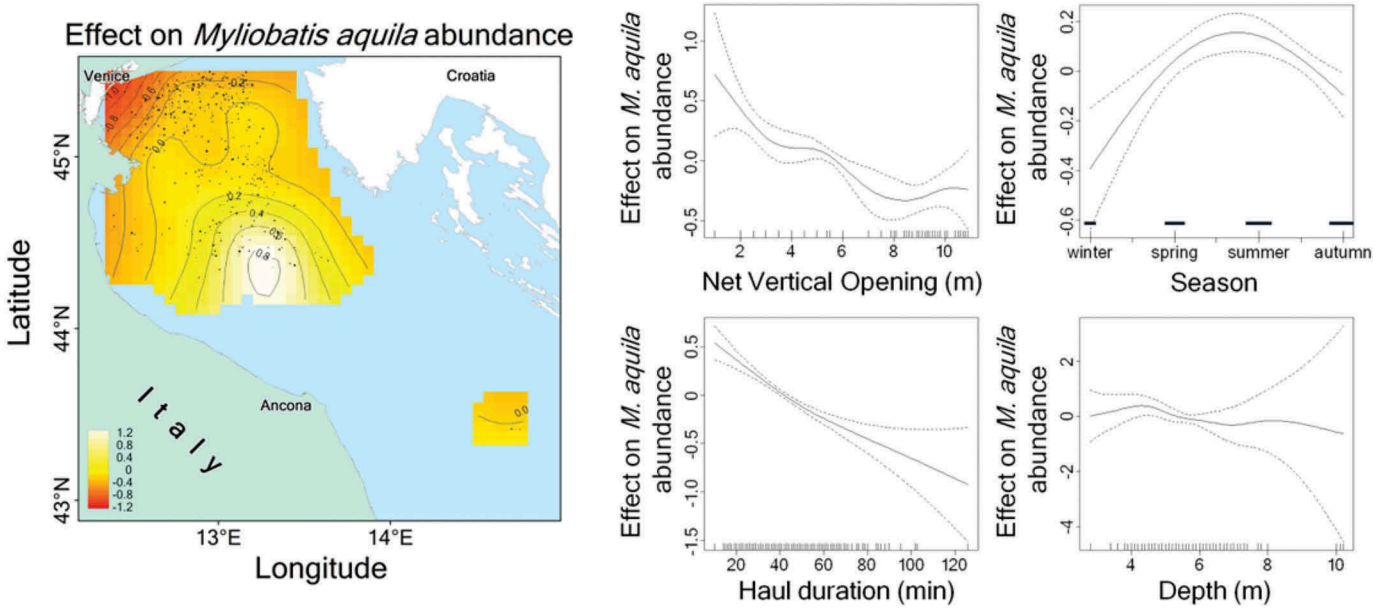


FIGURE 4. Generalized additive model-derived effects of covariates used to model the abundance (log_2[CPUE + 1]) of Common Eagle Rays in the north-central Adriatic Sea during 2006–2013. In the bivariate predictor map, the solid line is the estimate of the smooth function, and the black dots indicate haul locations. In the univariate predictor plots, the solid line is the estimate of the smooth function, the dashed lines indicate 95% confidence bands, and the "rug" or bars on the *x*-axis show the relative density of data points.

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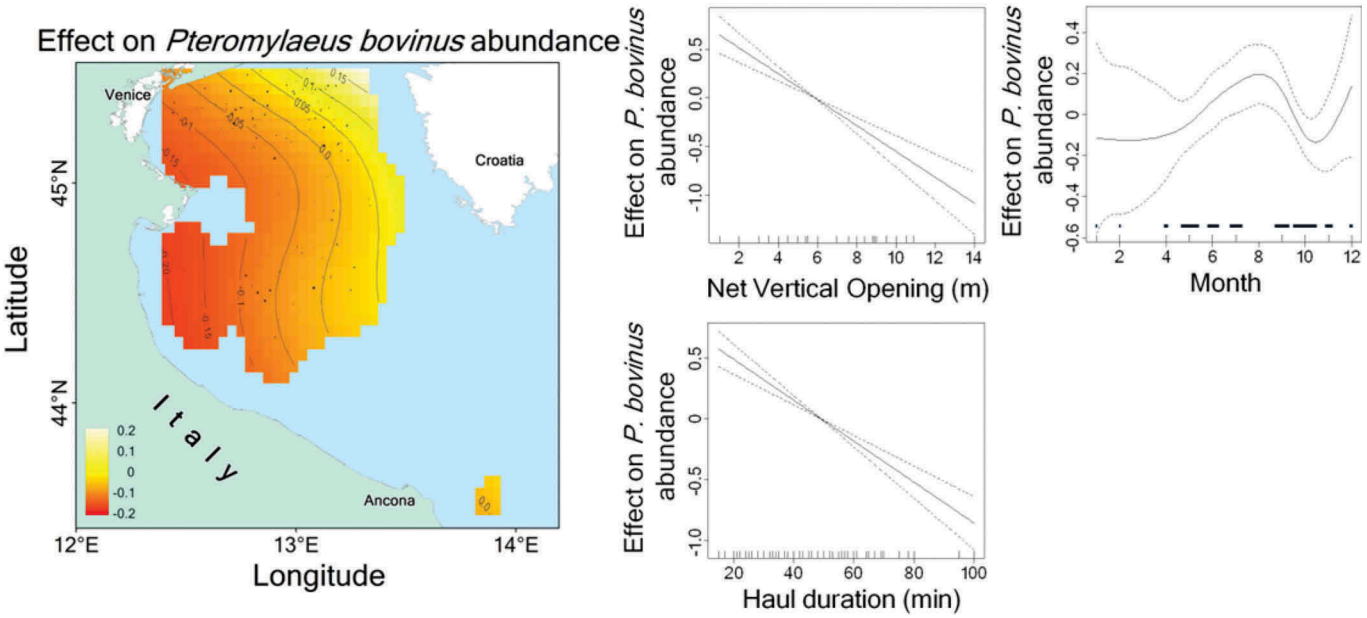


FIGURE 5. Generalized additive model-derived effects of covariates used to model the abundance ($\log_2$[CPUE + 1]) of Bull Rays in the north-central Adriatic Sea during 2006–2013. In the bivariate predictor map, the solid line is the estimate of the smooth function, and the black dots indicate haul locations. In the univariate predictor plots, the solid line is the estimate of the smooth function, the dashed lines indicate 95% confidence bands, and the "rug" or bars on the *x*-axis show the relative density of data points.

In the summer, catches of Common Eagle Rays were limited to the northeastern Adriatic Sea, whereas they also extended to the central portion of the Adriatic Sea during autumn (Manfredi et al. 2010). In other Mediterranean areas (Languedoc, France; and Izmir Bay, Turkey), Common Eagle Rays were also principally caught during summer and autumn (Capapé et al. 2007; Gurbet et al. 2013).

The presence of Common Eagle Rays and Bull Rays in midwater pair-trawl catches showed significant variation at a yearly scale, although the two species exhibited opposing patterns. The occurrence of Common Eagle Rays reached its minimum value in the 2008 survey, whereas the occurrence of Bull Rays attained its maximum during that year. In the subsequent years of monitoring, there was an increasing trend in Common Eagle Ray catches, whereas the occurrence of Bull Rays declined progressively. Very few studies examining medium- to long-term changes in elasmobranch catch rates from commercial fisheries have reported data on Common Eagle Rays. Aldebert (1997) listed the Common Eagle Ray as being among the species that have declined continuously in the Gulf of Lion since 1970. Damalas and Vassilopoulou (2011) documented the presence of Common Eagle Rays in the Aegean Sea during bottom trawl surveys in 1995–2000 but not during the subsequent period of monitoring (2003–2006). Given the reported general decline of Common Eagle Ray populations in these other areas, the increasing occurrence of this species in the northern Adriatic Sea in more recent years would seem unexpected. On the other hand, we cannot ascertain whether the temporal patterns of Common Eagle Ray and Bull Ray presence observed during this relatively short monitoring period should be interpreted in terms of cyclic fluctuations or as part of long-term trends.

The effects of spatial and temporal descriptors on Common Eagle Ray and Bull Ray abundances closely resembled those identified for the species' occurrence. Among the investigated environmental predictors, only depth had a significant effect on the presence and abundance of Common Eagle Rays. In the study area, this species was recorded in waters of 10–110-m depth but was found most often in waters down to 60-m depth, corresponding with the results of previous investigations (Jardas 1984; Manfredi et al. 2010). The most striking differences between the presence/absence models and the abundance models stemmed from the operational factors, which had a significant influence only on species abundances. The observed decline in Common Eagle Ray and Bull Ray CPUEs with increases in haul duration and net vertical opening was likely determined by the rarity of the species, which contributed to the low likelihood of catching more than 1–3 individuals/haul. Consequently, an increase in haul duration or net size resulted in little to no influence on the number of individuals caught but generated a substantial increase in the swept volume, thereby negatively affecting the fishing yield (CPUE). Though apparently ineffective for reducing the bycatch of Common Eagle Rays and Bull Rays, limiting the midwater trawl fishing effort in terms of haul duration and net size could still be beneficial. In fact, the shortening of haul duration would greatly enhance the viability of fish that are caught and, in turn, their chance of survival after being

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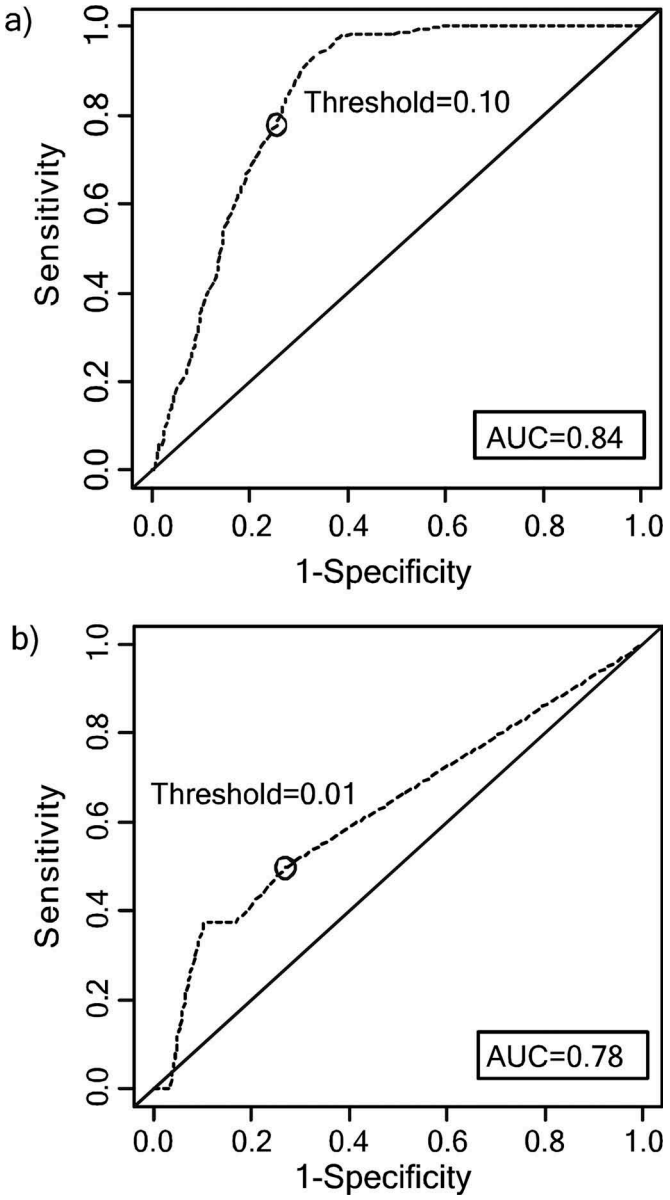


FIGURE 6. Predictive performance of the presence/absence models for **(a)** Common Eagle Rays and **(b)** Bull Rays in the north-central Adriatic Sea, as measured by the receiver operating characteristic (ROC) plot and the area under the ROC curve (AUC). The point on the curve where sensitivity equals specificity (circle) and the relative threshold value are indicated.

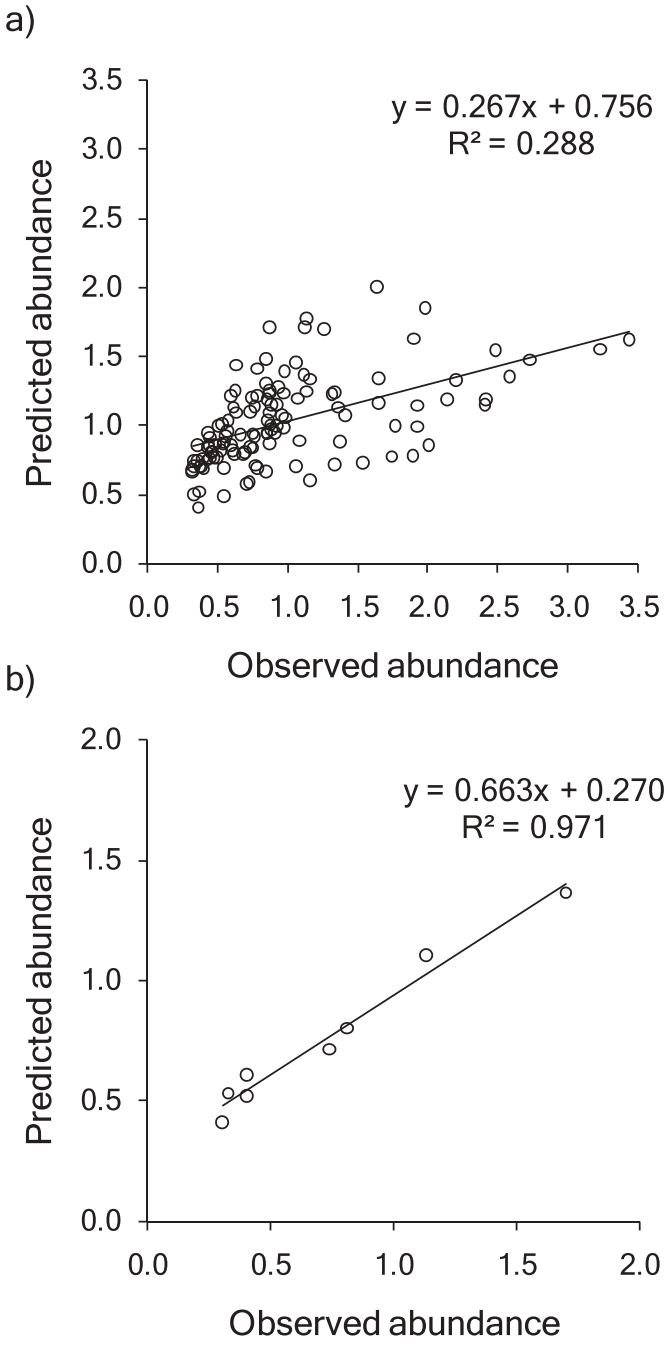


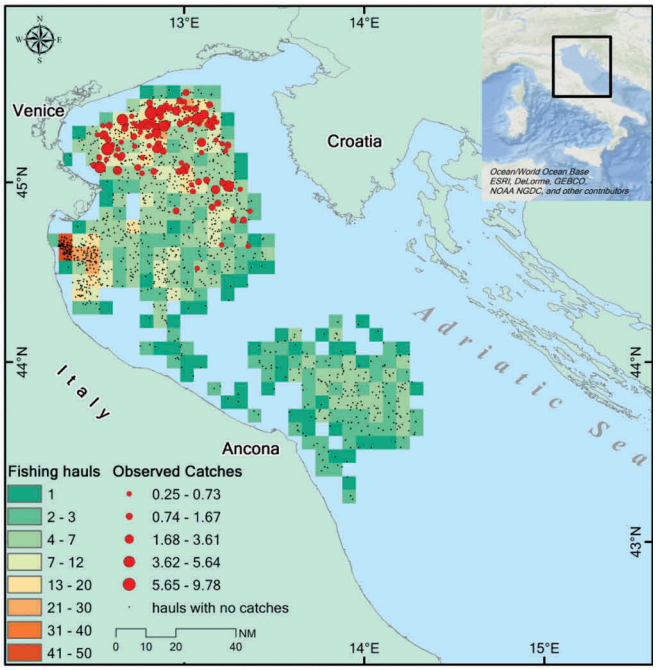
FIGURE 7. Relationship between predicted and observed abundances ($\log_2$ [CPUE + 1]) for **(a)** Common Eagle Rays and **(b)** Bull Rays in the north-central Adriatic Sea.

discarded at sea. The release of these and other elasmobranch species soon after their capture is a common practice in many Mediterranean commercial fisheries (Capapé et al. 2008; Dulčić et al. 2008; Fortuna et al. 2010; Gurbet et al. 2013) and should be further encouraged by implementing activities that increase awareness of the "best practices" for mitigating the impact of bycatch on threatened species.

In this study, the model-fitting stage was followed by a validation procedure, which indicated that the presence/absence models for Common Eagle Rays and Bull Rays yielded good predictive accuracy. The model for Common Eagle Ray abundance data can also be considered reliable, although it leads to the overestimation of low abundance values. This is demonstrated by the correlation between the observed and predicted values. The abundance model for Bull Rays showed even better performance, but it should be tested again by using a larger validation data set to adequately assess

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(a)



(b)

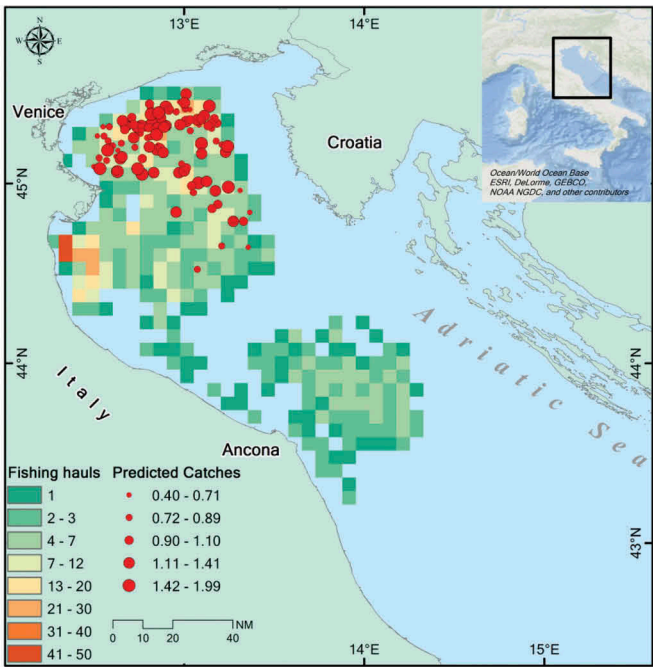


FIGURE 8. Map of the study area in the north-central Adriatic Sea, depicting the spatial distribution of midwater pair-trawl fishing effort in relation to the **(a)** observed and **(b)** predicted abundances (CPUE, number of individuals per 10^6 m^3) of Common Eagle Rays in the catch during 2013.

its predictive ability. To develop models with higher predictive power and to extrapolate results to a wider spatial scale, further catch data should be obtained from other areas and other fishing gears. In addition, an effort should be made to test other factors that may potentially affect the distribution of Common Eagle Rays and Bull Rays, such as the presence and abundance of their preferred prey. In this manner, the predictive ability of the models can be improved.

The incidence of Common Eagle Ray and Bull Ray bycatch in midwater pair-trawling fisheries of the Adriatic Sea still remains unassessed since updated knowledge of the actual population abundances at this and larger geographic scales is lacking. However, the precautionary approach suggests the use of coordinated long-term monitoring and research programs to accurately quantify the impacts of fishing activity on Common Eagle Rays and Bull Rays in the Adriatic Sea and elsewhere in the Mediterranean Sea. In addition to species-specific fisheries-related data, further ecological information (e.g., fish age and growth, movement patterns, and potential nursery areas) will be crucial for the development of conservation targets and indicators. Research, monitoring, and information exchange should be undertaken through the involvement of scientific networks and in cooperation with relevant fisheries organizations.

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