Abstract

This study examined links between the variability of coastal front features and composition of fisherylandings. Satellite-derived sea surface temperature data allowed the detection of thermal fronts and calculation of front metrics that account for gradient, persistency, and vicinity. Landings data were clustered by functional group (according to habitat use, size, morphology), and trophic level (TL). Three independent time series analyses, based on two different classes of statistical methodologies, were carried out: 1) correlation analysis performed on species aggregated by functional groups; 2) compositional analysis performed on the top-5 species landed and on species aggregated by trophic level. Analyses were carried out for the Moroccan coast of the Alboran Sea (western Mediterranean Sea). Results of the proposed type of application were discussed with respect to their potential for improving scientific knowledge and management of fisheries in data-poor areas. Pelagic landings were associated with front indicators in two-thirds of tested cases. The results demonstrated a markedly different association between landings and front features in the Nador fishing zone, relative to M'diq and Al Hoceima. Improved performance of the front gradient and persistence indicator was detected, with respect to the front gradient only for flatfish and demersal landings. Compositional data regression outlined a different role for *Sardina pilchardus* and *Trachurus trachurus* in the Al Hoceima and M'diq landings, and in the latter case the dominance of these two species in the landings seemed to respond to the front density indicator. A decreasing trend in TL>3.5 landings was detected with increasing front distance.

Introduction

Several recent works (Chassot et al., 2011; Stuart et al. 2011; Saitoh et al. 2011; Klemas, 2013) provided an overview of remote-sensing applications for data provisioning during implementation of ecosystem-based approaches to fishery management (EAF) (Garcia et al., 2003). Among those features that can be remotely tracked, marine and coastal fronts are of primary interest because of their characteristics. Frontal strength, extent, and persistence, can significantly influence the ecology of planktonic and pelagic organisms, while also having cascade effects on ecosystem as a whole (Mann and Lazier, 2006). For fisheries, these effects are not limited to pelagic species, since Alemany et al. (2014) showed a positive association between fronts and demersal fishing effort distribution. Moreover, potential applications of front detection from Earth Observation extend beyond fisheries to include, among others, definition of conservation objectives (Miller and Christodoulou, 2014 and references cited therein). Indeed, a study by Druon (2010) used satellite-derived front information to map bluefin tuna feeding and spawning habitats in the Mediterranean Sea.

Although several studies used space-explicit data on fishery efforts or fish abundance - e.g., Vessel Monitoring Systems data in Alemany et al. (2014), scientific campaigns, leisure and industrial fisheries in Druon (2010) and/or scientific fishery surveys by Ehrichet al. (2009) -, few studies have explored the contribution of front distribution and dynamics to the interpretation of "non-spatial" information such as landings data. Despite of the relevance of landings estimates to assess the health of fisheries remains unclear (Pauly et al., 2013), this type of data undoubtedly represents an important resource for the fishery community, and constitutes the only alternative for those regions where extensive fishery-independent surveys are unavailable. Even without spatialization, landings data can be ascribed to specific sea areas and at different spatial scales (Caddy and Carrocci, 1999; Watson et al., 2004; Pranovi et al., 2016). However, analyzing relationships among landings and relevant oceanographic features of areas to which they refer still represents a challenging task. To this end, calculation of indicators that can quantitatively synthesize front features (Miller and Christodoulou, 2014; Miller et al., 2015) could serve as an interesting resource, since they allow to synthesize the information originally available in a 2-dimensional space, for its use in non-spatial applications.

This work presents an application investigating the association of landings with fronts, using remote sensing as a proxy for the latter. Two specific aspects were examined, with the aim of providing examples of how the approach could be used for improving scientific knowledge about the relationship among environment and fisheries: i) differences in the level of association of specific front features (strength; persistence; vicinity) with landings quantity and quality (functional groups; trophic level proportion; top five species landed); and ii) changes in the patterns of these associations in different sub-portions of the investigated area.

We focused on three major Mediterranean Moroccan harbors on the Alboran Sea coast (western Mediterranean Sea): M'diq, Al Hoceima and Nador. The goal is of interest in the framework of EAF implementation, and is also foreseen as a priority within the United Nations Environmental Programme Mediterranean Action Plan (UNEP-MAP) Ecological Approach, which is currently being implemented in the Mediterranean (UNEP/MAP/PAP, 2008).

Materials and Methods

Landings data and front indicators that were used in the analysis are presented in Table 1. Three independent time series analyses were performed that were based on two different classes of statistical methodologies: 1) a correlation analysis performed on species aggregated by functional groups; and 2) a compositionalanalysis performed on both species aggregated by trophic level and the top 5 species landed.

This methodological section describes first the study area, therefore focusing on: i) data pre-treatment and calculation of front-activity indicators; ii) statistical methodologies used in the time-series analysis.

Study area

This study focused on the Moroccan coast of the Alboran Sea (Fig. 1), which is within the western Mediterranean Sea and is an area that features water exchanges between the Atlantic and the Mediterranean. The main frontal structure of the Alboran Sea is located along the Almeria (Spain)-Oran (Algeria) axis (Tintoré et al., 1988). This region experiences water inflow from the Atlantic and is characterized by high phytoplankton standing-stock (Videau et al., 1994) that is transferred to higher trophic levels by primary consumers (Thibault et al., 1994). Two anticyclonic gyres (Baldacci et al., 2001; Renault et al., 2012) are located along the southern Alboran Sea coast, between Morocco and Algeria (Fig. 1). These features render this region a dynamic area for fishing activities, which along the southern Alboran Sea coast include exploitation of both pelagic and demersal resources by small-scale fisheries (IUCN, 2012). Fleets operating in this area include different *métiers,* namely bottom and mid-water trawling, purse seine, longline, or trammel nets (INRH, 1999; IUCN, 2012). The fishing grounds of the different fleets have been estimated in terms of potentially exploited zones, and these fleets are mainly composed of boats that are less than 24 m length overall (LOA) with a limited range of action such that they mainly exploit the coastal fringe and move in areas close to their port of origin.

Landings data

Three time series of landings data were provided by the Moroccan fishery authority through the Institut National de Recherche Halieutique (INRH)-Nador. Data were aggregated on a monthly basis and covered a 7-year period (2007-2013) in Nador (NA) and M'Diq (MD), and 4 years (2010-2013) in Al Hoceima (HA). Fishery landings data were aggregated to monthly fields by summating all records within a calendar month using the landing dates. Some information on fishing effort was recently made available by CopeMed II (2015) reporting comparable numbers for seiners and small-scale artisanal boats in the area, but not indicating biases among the main harbors. To our knowledge, there is no similar specific information for demersal fisheries. Therefore, for the purposes of this analysis we assumed that the three harbors behaved similarly in terms of effort and fleet composition. Functional groups were defined on the basis of habitat use, size, and morphology. The functional groups are: demersals, flatfish, large pelagics, small pelagics, and sardines (distinguished from small pelagics as this species is over-dominant). In the subsequent step of the analysis, specieswere aggregated based on trophic level (TL), and grouped as $TL<3.0$; $3.0<TL<3.5$; $TL>3.5$. We assigned TL to species according to Pranovi et al. (2014), and, where possible, integrating information specific for the area of study (e.g. *Sparus aurata*). The complete list of species for each port, assigned TL, and functional group is presented in Table A1, while the time series of landings per area (MD, HA, NA) and functional group are presented in Figure A1 (Appendix A).

Detection of thermal fronts and front metrics calculation

Daily sea surface temperature (SST) data gathered between 2007 and 2013 at a resolution of 2 km were obtained from the European Space Agency (ESA) Medspiration project, and were based on an optimal merging of infrared data (1 km resolution but obscured by clouds) and microwave data (25 km resolution but can pass through clouds) (http://cersat.ifremer.fr/thematic-portals/projects/medspiration, Robinson et al., 2012). Algorithms have been previously developed to enable oceanic fronts to be located accurately and objectively on SST maps: the composite front map technique combines the location, gradient, persistence, and proximity of all fronts observed over a given period into a single map (Miller, 2009). This approach often produces a synoptic view from a sequence of partially cloud-covered scenes without blurring dynamic fronts, which is an inherent problem in conventional time-averaging methods. Fronts were detected on every daily SST map and averaged into monthly composite front maps, from which three front indicators were derived (according to the methodology described in Miller et al., 2015) (Fig. 2). Front gradient density (FGD) was calculated by applying a Gaussian smoothing filter (sigma = 5 pixels) to a map of the mean front gradient magnitude values. FGD is designed to provide a local neighborhood average of the frontal gradient and avoids the discrete nature of individually detected front contours. Meanwhile, front density (FDE) incorporates the gradient with front persistence to give a combined metric that describes the front strength. Finally, front distance (FDI) quantifies the distance from any location in the study area to the closest major front, and is determined using a simplification algorithm. Monthly statistics for the selected indicators, including mean, median, standard deviation, minimum and maximum values, were calculated for each fishery zone represented in Figure 1.

Correlation and compositional analyses

For each fishing area we calculated the pairwise correlation coefficients between the mean values of the three indicators of front activity and the 5 functional groups of landings (weight in kg). The selected variables (front indicators and landings) did not follow a normal distribution and thus the Spearman correlation coefficient was computed to verify the association strength.The Spearman correlation coefficient was calculated at 3 different temporal lags from the same month in which landings data were recorded (lag 0) and up to 2 months before (lag 2). A compositional data regression technique (Aitchison 1982; Egozcue 2003; see details in Appendix B) was used to analyze variations in the composition of landings with respect to front indicators, in terms of trophic level and the top 5 species landed. An analysis of variance (ANOVA) was applied to the compositional data regression to assess whether the front indicators had a significant effect on the landings compositions.

Results

Significant correlations among front indicators and quantities landed per functional group (including the single species group "sardines") are summarized in Table 2. Sardine landings are associated with all the front indicators considered, at multiple time lags (0, 1, 2), and in all areas. Both sardine and large pelagic landings responded positively to increasing front gradient and persistence (FGD, FDE), while are negatively correlated to the distance between nearest fronts (FDI). The correlation pattern was consistent between M'diq and Al Hoceima, and the analysis showed higher significance at these two harbors, with respect to Nador (p-values are reported in Tab. 2 caption). In Nador, sardines landings presented correlations of opposite sign at 0 and 2 month lags with FGD and FDE indicators. With respect to small pelagic landings, highly significant correlations ($p<0.001$) were detected only in M'diq at 0 month lag. As for demersal and flatfish association of landings with fronts was weaker: in 5 out of 6 cases correlations were detected in Nador, at a low level of significance ($p<0.05$). For flatfish, correlations between landings and FDE and FDI were negative at different time lags, while demersal landings were positively correlated with the front distance indicator (FDI).

In terms of composition, the analysis outlined a different role for *Sardina pilchardus* and *Trachurus trachurus* in the makeup of Al Hoceima and M'diq landings (Fig. 3). For M'diq the dominance of these two species in the landings responded to the FDE indicator, while in Al Hoceima *S. pilchardus* was always dominant in landings. Yet for Nador, the only significant relationship was the increase of *Octopus* spp. with increasing front distance FDI ($p<0.05$). Notably, lower trophic levels (TLs<3, Fig. 4, green color) dominated in landings at the Al Hoceima harbor, while at Nador and M'diq TLs>3.5 (pink color) were the most common. In Al Hoceima and M'diq the proportion of lower trophic levels in landings, decreased slightly with increasing front density and intensity (FGD, FDE), and, conversely, increased with distance between fronts (FDI). The decrease in TL<3 was accompanied by an increase of both TL 3-3.5 and TL>3.5. It is worth noting that the compositional regression performed on TL groups was significant at a level of $p<0.01$ only for FDI in Nador (ANOVA p-values are reported in Fig. 4).

Discussion

Being based on landings data relative to wide geographic areas, the present application marks some differences with respect to previous works focusing on the relationship among front dynamics and fisheries, which included fishing position data (e.g. Zainuddin et al., 2008; Alemany et al., 2014; Polovina et al., 2001). Due to this inherent data limitation, it was not possible to base our analysis on the interpretation of maps co-locating fronts and catches, and the information on fronts, originally available at a resolution of 2 km, had to be aggregated by extracting spatial statistics. The subsequent analysis, which focused on the degree of association of the features characterizing fronts (strength, persistence, and vicinity) with those characterizing landings (quantity and composition), allowed to identify the patterns of these associations for the different groups of landings, and in different sub-portions of the investigated area. The correlation analysis indicated that all the functional groups in the three harbors responded to the different indicators of front activity that were considered, with a notable exception being the absence of any correlation between demersals/flatfish and front gradient density (FGD), which is a measure of average front strength in a given area. The Front Density (FDE) incorporates both gradient and persistency, and was correlated with demersals and flatfish in Nador. Although FGD and FDE are correlated, the different behavior reported above for Nador suggested the opportunity to include both indicators in the analysis. Taking into consideration all the harbors and functional groups, the FDE indicator appeared to show the best performance, being correlated in 9 of 15 cases (lags not considered in this count). Nonetheless, the level of significance of correlations showed differences among the three harbors, with highly significant correlations detected in M'diq and Al Hoceima (all the p values < 0.001), and weaker ones in Nador (p values <0.05). As expected, pelagic groups provided the clearest response, and their landings were related to front density, intensity, and proximity (18 over 27 correlations significant - lags not considered in this count). Interestingly, the correlation pattern showed an inverted signal among sardines and small pelagics (dominated by the Atlantic horse mackerel, *Trachurus trachurus*). This result was also consistent with the compositional analysis performed on the top 5 species landed. This feature was clearly visible in M'diq and Al Hoceima, where a shift towards a higher percentage of sardine in landings was detected with an increasing front density/intensity. Further research along this line should investigate if, and to which extent, the environmental conditions can drive the fishery choices of target location and target species – which was mentioned by Kada (2011) as a potential mechanism affecting landings in the area.

In general, these results suggest the possibility of using aggregated indicators for exploring the association between pelagic landings quantity and composition and fronts characteristics by operating in two ways: 1) studying differences in these associations over different sub-portions of the investigated domain; 2) identifying temporalchanges in this association, by ranking the most significant correlations and performing the compositional regression in different windows of time. In both cases, the analysis could support scientific inference on how the environment influences the behavior of landed species in the area of interest. Indeed, this represents a key element of knowledge for managing fisheries. Also, in a phase of global warming, understanding fishing strategies and their dependence on environmental factors could substantially help fisheries management (Woodson & Litvin, 2015). Nonetheless, attempts to manage fisheries on a single or multi-species level, taking into account only population dynamics have failed systematically, pointing out the need for a deeper understanding of the role played by trophic interactions (Pikitch et al., 2004). Analyzing the relationship between landings trophic levels (TLs) composition, and front indicators could represents a movement in this direction, since for higher trophic levels organism behavior is expected to become increasingly important in defining the level of spatial association with fronts (Woodson and McManus, 2007). Our results showed a decreasing trend in TL>3.5 landings with increasing front distance (FDI). This negative trend was associated with a positive trend for 3.0>TL>3.5. Major representatives of TL>3.5 were *T. trachurus* and *Octopus* spp. (Table A1 and Fig. 3). Replication of the compositional regression on TLs should considered some caveats, since significant results were found only in 1 case over 9 (FDI in Nador). This suggests that the analysis could provide better results when performed with a limited number of relevant species in the TL groups, which was also corroborated by the results of the analysis performed on the top 5 species landed. Also, in accordance with Chassot et al. (2011), in order to improve the robustness of the results we underline the need for extending the present analysis, by including an evaluation of the sensitivity of outputs to the uncertainty in input parameters, and by comparing results obtained in presence of different type of fronts, such as estuarine fronts, shelf fronts, shelf break fronts, coastal upwelling fronts.

With respect to the results obtained in the specific area studied in the present application, the analysis was carried out uniquely on the 2007-2013 time window, and thus the comparison among time windows suggested at point 2) above was not possible, and is foreseen as a potential future extension of this study. However, results allowed to focus on different sub-portions of the investigated area (point 1). Correlations among pelagic landings and indicators were more evident in M'Diq and Al Hoceima relative to Nador. In the case of Nador the association was less clear for pelagic landings, but was detected also for demersals and flatfish. Correlations were characterized by: i) less evident patterns, with an inversion of sign between lag 0 and lag 2 for sardines; and ii) a positive association with front distance (FDI) for both sardines and demersals, which is an opposite behavior from that observed in Al Hoceima and M'Diq. This latter aspect was also highlighted by the positive trend detected for *Octopus* spp. in a compositional analysis of the top 5 species landed. All of these features, and in particular the correlation with demersals and flatfish, suggest a completely different role of fronts in shaping the trophic characteristics in the Nador area relative to Al Hoceima and M'diq. If interpreted in this view, a possible explanation of the different behavior seen for M'diq and Al Hoceima could be related to a diverse food chain mechanism - e.g. based on the prevalence of advected exogenous production and/or on a detrital pathway (Belgrano et al., 2005). These aspects could be further studied by using models that describe the functioning of the food web in the area, such as an extension of the one recently developed by Bocci et al. (2016) for the Nador lagoon.

Conclusions

This work presented an application investigating the relationships among the features of coastal front structures, and the quantity and composition of landings. We believe that a comparison of the result obtained by repeating this approach over different windows of time and in different sub-portions of the study domain could be used for improving scientific knowledge about the relationship among environment and fisheries, providing information to management in data-poor conditions. With respect to the application presented, in two thirds of the tested cases, front indicators considered were associated to pelagic landings quantities (small, large, sardines). A markedly different association between landings and front features was detected in the Nador fishing zone, relative to M'diq and Al Hoceima. Compositional data regression outlined a different role for *Sardina pilchardus* and *Trachurus trachurus* in the Al Hoceima and M'diq landings, and a decreasing trend in TL>3.5 landings was detected with increasing front distance in Nador. In general, the association with the measure of overall spatial coverage of fronts (FDI), was more clearly visible in the compositional regression analysis that was performed on the top 5 species and on TL groups.

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References

Aitchison, J. (1982). The statistical analysis of compositional data. *Journal of the RoyalStatistical Society. Series B (Methodological)*, 44, 139-177.

Aitchison, J. (1986). *The statistical analysis of compositional data*. Chapman and Hall London.

Aitchison, J. (1999). Logratios and natural laws in compositional data analysis. *Mathematical Geology*, 31, 563-580.

Alemany, D., Acha, E.M., Iribarne, O.O. (2014). Marine fronts are important fishing areas for demersal species at the Argentine Sea (Southwest Atlantic Ocean). *Journal of Sea Research*, 87, 56-67.

Baldacci, A., Corsini, G., Grasso, R., Manzella, G., Allen, J.T., Cipollini, P., Guymer, T.H. & Snaith, H.M. (2001). A study of the Alboran sea mesoscale system by means of empirical orthogonal function decomposition of satellite data. *Journal of Marine Systems*, 29(1-4), 293-311.

Belgrano, A., Scharler, U.M., Dunne, J., Ulanowicz, R.E., 2005. *Aquatic Food Webs: An Ecosystem Approach*. Oxford University Press, Oxford.

Bishop, R.L., & Neff, H. (1989). *Compositional data analysis in archaeology*. Archaeological chemistry IV. American Chemical Society, 57-86.

Bocci, M., Brigolin, D., Pranovi, F., Najih, M., Nachite, D., Pastres, R. (2016). An Ecosystem Approach for understanding lagoonal status and change: application of food web models and ecosystem indices to the Nador lagoon (Morocco). *Estuarine Coastal and Shelf Science*, 171, 133-143.

Buccianti, A., & Pawlowsky-Glahn, V. (2005). New perspectives on water chemistry and compositional data analysis. *Mathematical Geology*, 37, 703-727.

Caddy, J.F., & Carocci, F. (1999). The spatial allocation of fishing intensity by port-based inshore fleets: a GIS application. *ICES Journal of Marine Science*, 56, 388-403.

Chassot, E., Bonhommeau, S., Reygondeau, G., Nieto, K., Polovina, J.J., Huret, M., Dulvy, N.K., Demarcq, H. (2011). Satellite remote sensing for an ecosystem approach to fisheries management. *ICES Journal of Marine Science*, 68, 651–666.

CopeMed II. (2015). Report of the 5th Meeting of CopeMed II Study Group on stock assessment of small pelagic species of interest to Algeria, Morocco and Spain in the Alboran Sea (GSAs 01, 02, 03 and 04). Malaga, Spain 6-7 October 2015. CopeMed II Technical Documents Nº39 (GCP/INT/028/SPA - GCP/INT/006/EC). Málaga, 2015. 45 pp.

Druon, J-N. (2010). Habitat mapping of the Atlantic bluefin tuna derived from satellite data: Its potential as a tool for the sustainable management of pelagic fisheries. *Marine Policy*, 34, 293-297.

Egozcue, J.J., Pawlowsky-Glahn, V., Mateu-Figueras, G., Barceló-Vidal, C. (2003). Isometric logratio transformations for compositional data analysis. *Mathematical Geology*, 35, 279-300.

Ehrich, S., Stelzenmüller, V., Alderstein, S. (2009). Linking spatial pattern of bottom fish assemblages with water masses in the North Sea. *Fisheries Oceanography*, 18, 36-50.

Garcia, S. M., Zerbi, A., Do Chi, T., and Lasserre, G. (2003). The ecosystem approach to fisheries. Issues, terminology, principles, institutional foundations, implementation and outlook. FAO Fisheries Technical Paper, 443. 81 pp.

Klemas, V. (2013). Fisheries applications of remote sensing: An overview. *Fisheries Research*, 148, 124-136

INRH (1999). Situation actuelle de la peche artisanale en Mediterranee Marocaine. Resultat de l'enquete efectuee en Decembre 1998. Institut National de Recherche Halieutique - Centre Régional de Nador, 25 pp.

IUCN (2012). Propuesta de una red representativa de áreas marinas protegidas en el mar de Alborán / Vers un réseau représentatif d'aires marines protégées dans la mer d'Alboran. Gland, Suiza y Málaga, España: UICN. 124 pp.

Kada, O., 2011. Etude biologique et écologique des anchois de la Méditerranée marocaine et caractérisation des populations lagunaires (Lagune de Nador). Doctoral thesis, University Abdelmalek Essaadi, Tetouan Faculty of Sciences, 143 pp (in French).

Mann, K.H., & Lazier, J.R.N. (2006). Dynamics of marine ecosystems. Biological-physical interactions in the oceans. 3rd edition. Blackwell publishing.

Miller, P.I. (2009). Composite front maps for improved visibility of dynamic sea-surface features on cloudy SeaWiFS and AVHRR data. *Journal of Marine Systems*, 78, 327–336.

Miller, P.I., & Christodoulou, S. (2014). Frequent locations of oceanic fronts as an indicator of pelagic diversity: Application to marine protected areas and renewable. *Marine Policy*, 45, 318-329.

Miller, P.I., Scales, K.L., Ingram, S.N., Southall, E.J. & Sims, D.W. (2015) Basking sharks and oceanographic fronts: quantifying associations in the north-east Atlantic. *Functional Ecology*, 29(8), 1099-1109.

Pauly, D., Hilborn, R., Branch, T.A. (2013). Fisheries: Does catch reflect abundance? *Nature*, 494, 303-306.

Pikitch, E.K., Santora, C., Babcock, E.A., Bakun, A.,Bonfil, R., Conover, D.O., Dayton, P.K., Doukakis, P., Fluharty, D., Heneman, B., Houde, E.D., Link, J., Livingston, P.A., Mangel, M., McAllister, M.K., Pope, J.G. and Sainsbury, K.J. (2004). Ecosystem-based fishery management. *Science*, 305, 346-347.

Polovina, J.J., Howell, E., Kobayashi, D.R., Seki, M.P., 2001. The transition zone chlorophyll front, a dynamic global feature defining migration and forage habitat for marine resources. *Progress in Oceanography*, 49, 469-483.

Pranovi, F., Libralato, S., Zucchetta, M., Link, J.S. (2014). Biomass accumulation across trophic level: analysis of landings for the Mediterranean Sea. *Marine Ecology Progress Series*, 512, 201 216.

Pranovi, F., Anelli Monti, M., Brigolin, D., Zucchetta, M. (2016). The Influence of the Spatial Scale on the Fishery Landings-SST Relationship. *Frontiers in Marine Science*, 3, 143. DOI: 10.3389/fmars.2016.00143.

Renault, L., Oguz, T., Pascual, A., Vizoso, G. & Tintore, J. (2012) Surface circulation in the Alboran Sea (western Mediterranean) inferred from remotely sensed data. *Journal of Geophysical Research-Oceans*, 117, C08009. doi:10.1029/2011JC007659

Robinson, I., Piolle, J.F., LeBorgne, P., Poulter, D., Donlon, C. & Arino, O. (2012) Widening the application of AATSR SST data to operational tasks through the Medspiration Service. *Remote Sensing of Environment*, 116, 126-139.

Saitoh, S.-I., Mugo, R., Radiarta, I.N., Asaga, S., Takahashi, F., Hirawake, T., Ishikawa, Y., Awaji, T., In, T., Shima, S. (2011). Some operational uses of satellite remote sensing and marine GIS for sustainable fisheries and aquaculture. *ICES Journal of Marine Science*, 68, 687-695.

Stuart, V., Platt, T., Sathyendranath, S. (2011). The future of fisheries science in management: a remote-sensing perspective. *ICES Journal of Marine Science* 68, 644-650.

Thibault, D., Gaudy, R., Le Fèvre, J. (1994). Zooplankton biomass, feeding and metabolism in a geostrophic frontal area (Almeria-Oran Front, western Mediterranean). Significance to pelagic food webs. *Journal of Marine Systems*, 5, 297-311.

Tintoré, J., La Violette, P.E., Blade, I. and Cruzado, A. (1988). A study of an intense density front in the eastern Alboran Sea: the Almeria-Oran Front. *Journal of Physical Oceanography*, 18, 1384-1397.

Videau, C., Sournia, A., Prieur, L. and Fiala, M. (1994). Phytoplankton and primary production characteristics at selected sites in the geostrophic Almeria-Oran front system (SW Mediterranean Sea). *Journal of Marine Systems*, 5, 235-250.

Wang, H., Shangguan, L., Wu, J., Guan, R. (2013). Multiple linear regression modeling for compositional data. *Neurocomputing* 122, 490-500.

Watson, R., Kitchingman, A., Gelchu, A., Pauly, D. (2004). Mapping global fisheries: sharpening our focus. *Fish and Fisheries*, 5, 168-177.

Woodson, C.B., McManus, M.A. (2007). Foraging behavior can influence dispersal of marine organisms. *Limnology and Oceanography*, 52, 2701–2709.

Woodson, C.B., Litvin, S.Y., 2015. Ocean fronts drive marine fishery production and biogeochemical cycling. *Proceedings of the National Academy of Sciences of the United States of America*, 112, 1710-1715.

Zainuddin, M., Saitoh, K., Saitoh, S.-I., 2008 Albacore (*Thunnus alalunga*) fishing ground inrelation to oceanographic conditions in the western North Pacific Ocean using remotely sensed satellite data. *Fisheries Oceanography*, 17:2, 61-73.

Table 1. Summary of data used in the analysis. *Front metrics refer to those for 2007-2013.

Landings	**Front metrics***
- Periodicity: monthly - Time interval: 2007-2013 - Data aggregation: as functional groups (demersals, flatfish, large pelagics, small pelagics, sardines); based on trophic level (TL<3.0; 3.0<TL<3.5; TL>3.5).	- Front density (FDE): strength of detected fronts (combination of their thermal gradient and persistence); - Front gradient density (FGD): the gradient magnitude of detected fronts; - Front distance (FDI): distance between nearest fronts.

Table 2. Correlation analysis results showing significant pairwise spearman correlation coefficients at different time lags (0,1,2) between fishing landing and front indicators (FGD, FDE, FDI) by functional groups. Levels of significance (*p<0.05, **p<0.01, ***p<0.001).

Indicator		**Demersal**			**Flatfish**			**Large pelagic**			**Small pelagic**			**Sardines**		
	Lag	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**	**0**	**1**	**2**
M'diq	FGD							0.39 ***			-0.36 **			0.42 ***	0.33 **	
	FDE							0.41 ***			-0.42 ***			0.44 ***	0.40 ***	
	FDI							-0.34 **			0.47 ***			-0.42 ***	-0.37 **	
Al Hoceima	FGD						0.39 **	0.46 ***						0.62 ***	0.53 ***	
	FDE							0.5 ***						0.54 ***	0.56 ***	
	FDI													-0.53 ***	-0.45 **	
Nador	FGD					-0.25 *								0.25 *		-0.38 ***
	FDE		-0.24 *			-0.25 *	-0.24 *				-0.22 *			0.24 *		-0.33 **
	FDI		0.23 *												0.31 **	0.45 ***

Description: Figure_1.tif

Figure 1. Layout of the three fishing grounds studied (each zone name was assigned according to the harbor of reference: left M'diq; center: Al Hoceima; right: Nador). Zones intersected by anticyclonic gyres and the Almeria-Oran front are shown. Points 1-6 indicate locations where mesozooplankton observations made by Thibault et al. (1994) were collected.

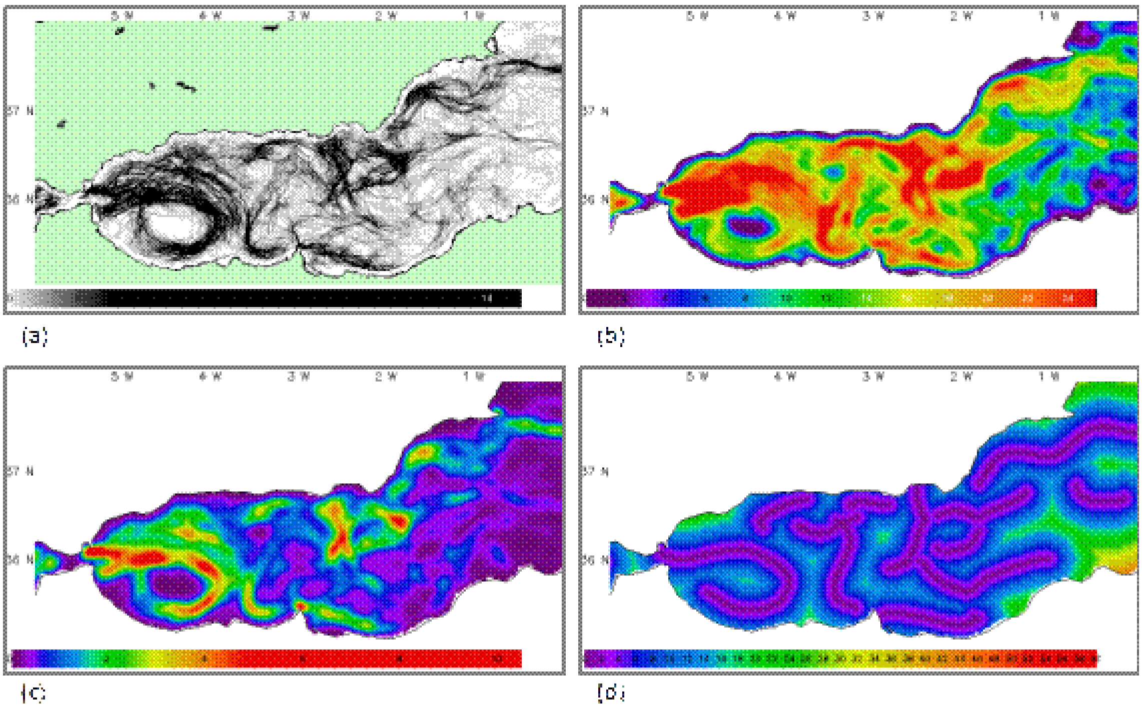

Figure 2: Thermal front metrics for a representative month, June 2007: (a) Composite front map; (b) Front gradient density (FGD) showing thermal gradient magnitude; (c) Front density (FDE), a combined measure of gradient and persistence; (d) Front distance (FDI), the distance to the closest major front.

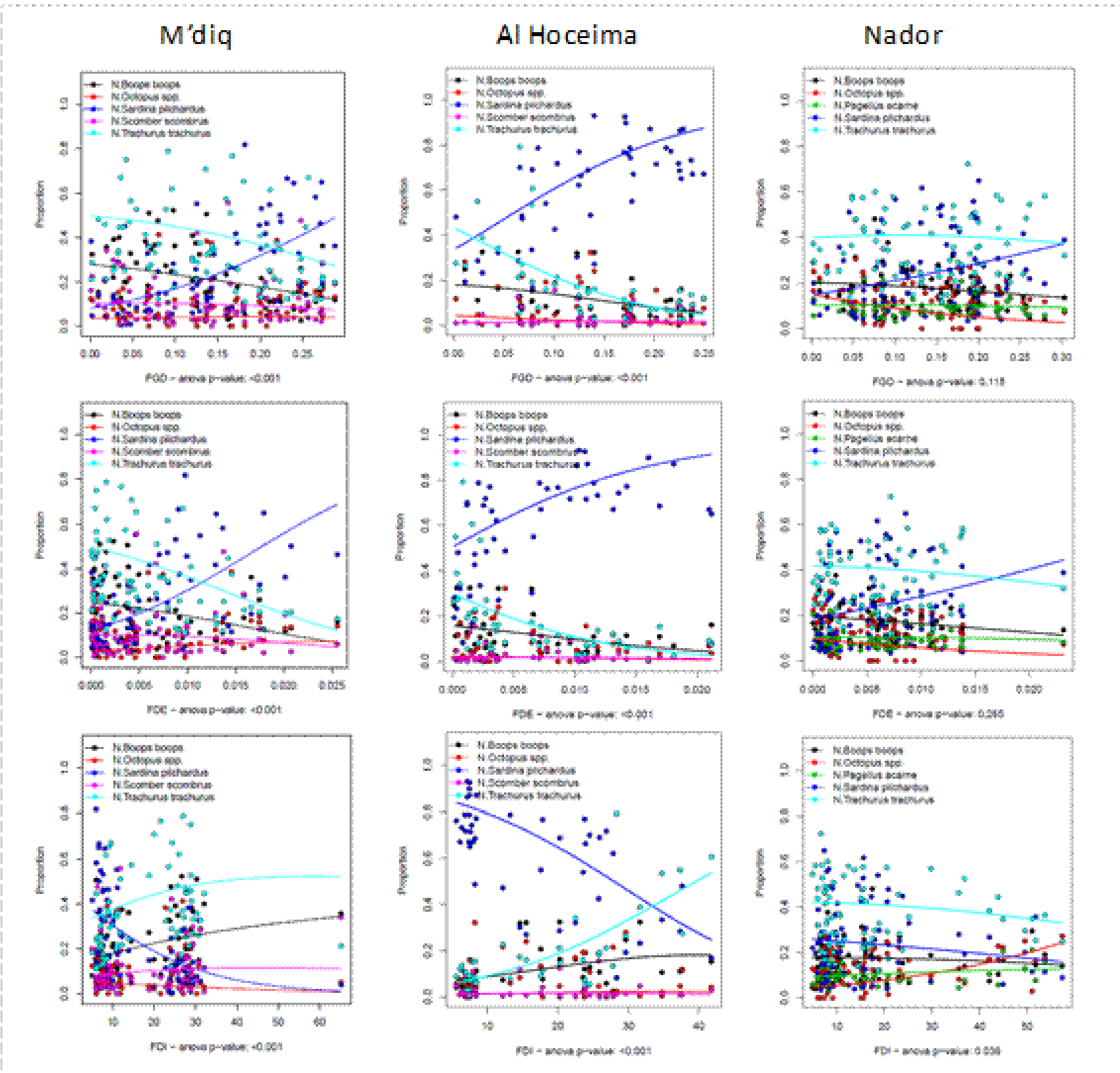

Figure 3. Compositional analysis of the top 5 species landed with ANOVA results for each regression. Left column: M'diq; central column: Al Hoceima; right column: Nador.

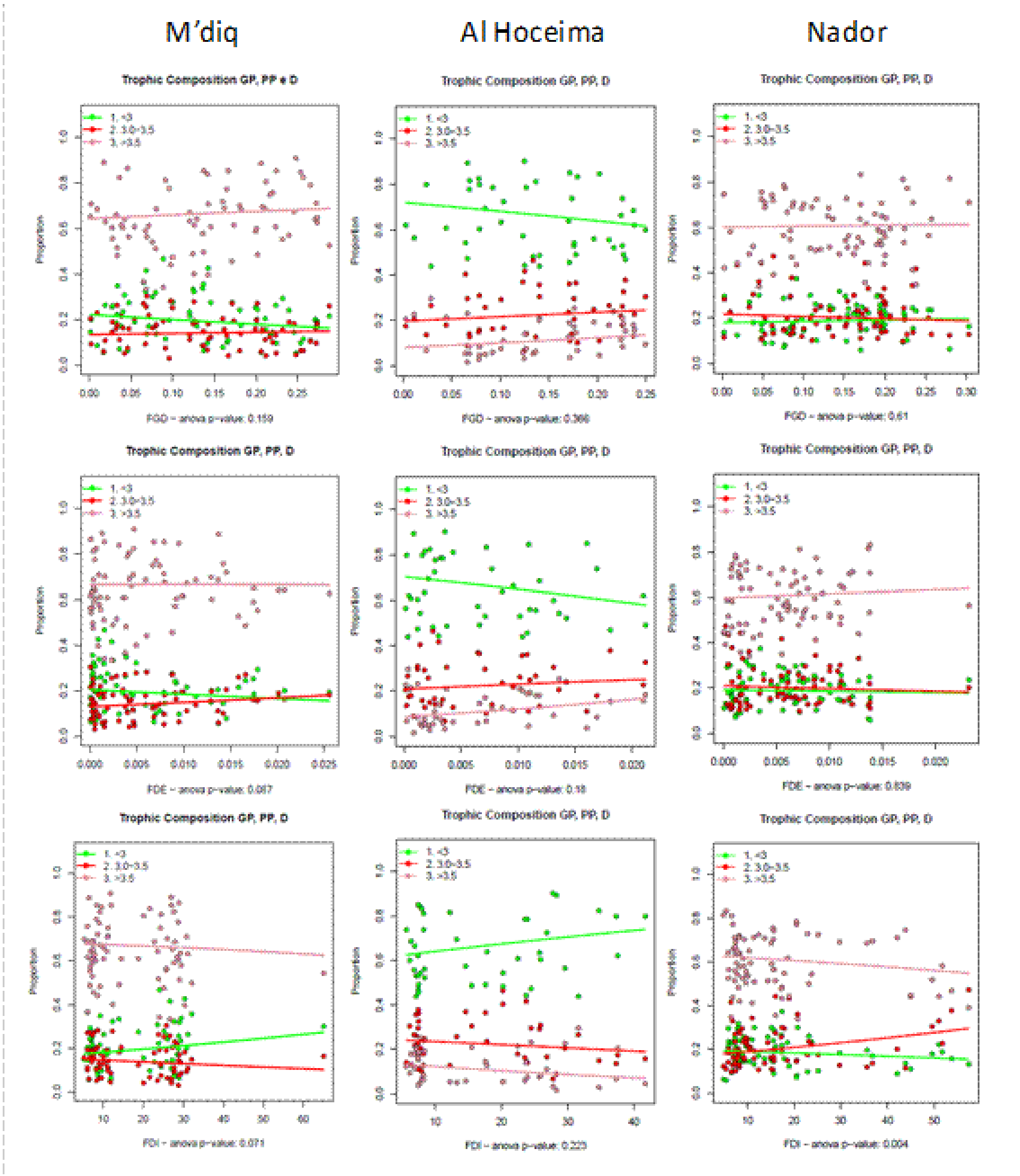

Figure 4. Compositional analysis showing proportion of TL groups (y-axis) and the different front activity indicators (x-axis) with ANOVA results for each regression – demersals (D), flatfish (FF), large pelagic (GP), small pelagic (PP), and sardines (S).