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Automatic fish school classification for acoustic sensing of marine ecosystem

R. Lefort^{1,2}, R. Fablet², J.-M. Boucher², L. Berger¹, S. Bourguignon¹

¹ Ifremer/STH, Technopôle Brest Iroise, 29280 PLOUZANE, France

² Institut Telecom/Telecom Bretagne, UMR CNRS lab-STicc, UEB

Abstract

With the human demand for fish and the global warming effects, we know that marine populations are changing. Developing methods for observing and analyzing the spatio-temporal variations of marine ecosystems is then of primary importance. In this context, underwater acoustics remote sensing has a great potential. Operational systems mainly rely on expert interpretation of echograms acquired by sonar echosounders. In this work, we propose new algorithms for the analysis of acoustic survey regarding the inference of species mixing proportion. They rely on the definition and training of probabilistic school classification models from survey data.

1 Introduction

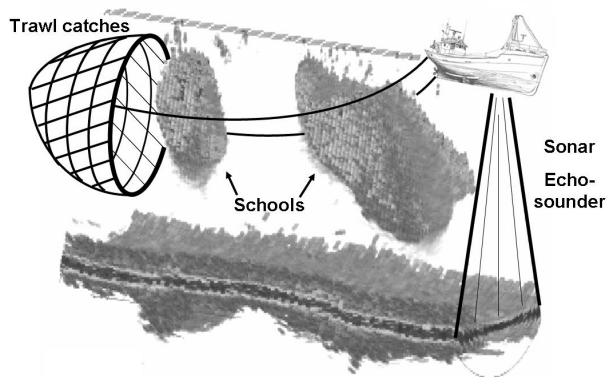


Figure 1. Weakly supervised learning: sonar echosounder provides a 3D image (echogram) composed of fish schools. Trawl catches the proportion of species mixture.

Sonar echosounders are commonly used to observe and analyse the spatio-temporal evolutions of marine ecosystems [1]. For instance, echosounders mounted on fishing vessels allow Scientifics to assess fish stock for pelagic species such as anchovy or herring [2]. It typically relies on

the interpretation of sonar echograms by experts to assign the backscattered acoustic energy to fish species biomass. All the aggregations in the water column are viewed by echosounders. The backscattering strength allows to build either a 3D picture (figure 1) when a multi beam sensor is considered or a 2D picture (figure 2) considering a single beam sensor. These echograms are analysed by experts to discriminate species when it is possible. Several studies have examined the responses of different fish species and the capability to be discriminated in terms of morphological and spatial features (figure 2) [2] [3] [4].

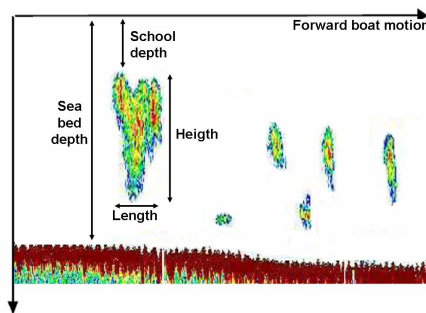


Figure 2. Geometric descriptors like the depth, the length and the height of the school are used. In the bidimensional echogram, six horse mackerel schools are observed.

The development of methods and algorithms automating or aiding this interpretation task would greatly contribute to improve the quality of expert estimation [5], as it should reduce the dependence on experts' subjectivity and provide better characterization of estimate uncertainties. Previous studies have been applied to automate the school classification [5] [6]. However, these methods are based on a supervised learning scheme that remains uncommon as representative labelled training sets are usually not available. The labelling is achieved by the correspondence between trawl catches data and associated echograms (figure 1). The trawl catches most frequently provide a mixture of species. So, one school can not be associated with a given species. The originality of our methods proceeds from the association between a mixture proportion coming from the trawl catches and the schools extracted from the echograms. It is a weakly supervised learning strategy (figure 1).

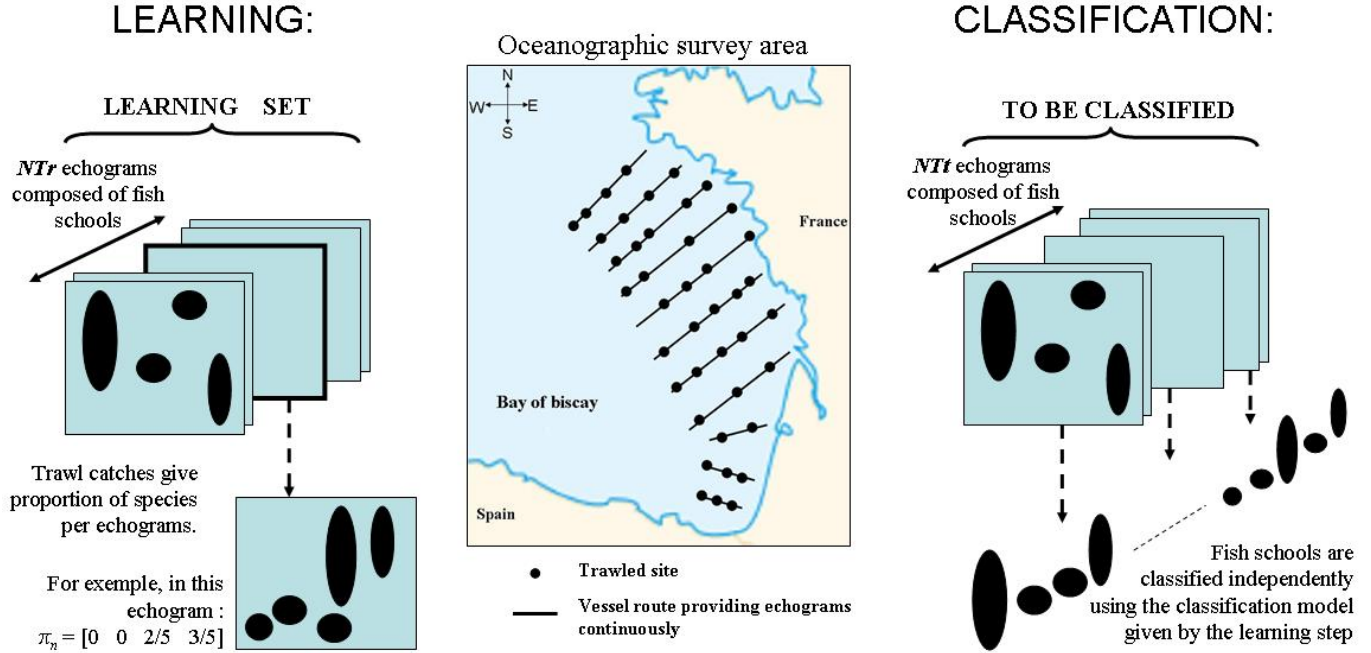


Figure 3. Example of an oceanographic vessel route in the bay of Biscay. The learning set is composed of echograms obtained at trawled sites. It provides labelled data necessary to evaluate the classification model. The oceanographic vessel route provides echograms continuously. All schools in these unlabelled echograms are classed.

The paper is organized as follows. Section 2 presents the methods and introduces the notations for the probabilistic model. In section 3 we present the two probabilistic models based on the conditional model and the Bayesian model. Performances of these models tested with real and synthetic data are presented in section 4. Finally, concluding remarks are given in section 5.

2 Global methods and notation

In this section the weakly supervised learning strategy and the notation of the probabilistic model are presented. An oceanographic survey provides two kinds of data set: NTr echograms associated with NTr trawls catches given the proportion π_n , $1 \leq n \leq NTr$ for each echogram and NTt echograms without trawl catch (figure 3). The first one is the training data set that allows us to build our probabilistic classification model (equation 1). All the non labelled schools of the second data set are classified independently using this model.

Considering a probabilistic school-based setting, we aim at evaluating the likelihood of observed school to be assigned to a given class. The term class refers to fish species or group of species. Let us denote by $X_{nj} \in \mathbb{R}^D$ the observation vector for the j^{th} school in the n^{th} echogram, where D is the number of descriptors per schools. For any

fish school, we used geometrics and energy descriptors (figure 2) [3] [4], but temporal or geographical descriptors [2] could be used too. Let us denote by $y_{nj k}$ the value indicating that the j^{th} school in image n belongs to the class k . $y_{nj k} = 1$ if the class is k . $y_{nj k} = 0$ if the class is different from k . Introducing in addition the global random variable π_n corresponding to class mixing proportion at the echogram level provided by the trawl catch, this leads to the definition of likelihood:

$$p(y_{nj k} | X_{nj}, \pi_n) \quad (1)$$

Note that for the training data set (i.e. for echograms associated to trawl catches) variable π_n is known. The first step of the method consists in estimating model parameters Θ (see the section 3 for details) from echograms for which π_n is known (i.e. echograms at trawled sites). In the second step, the trained model can be applied to any echograms.

To evaluate the performance of the proposed algorithms, datasets with known ground truth is built. Then, we compare the class found for each school with the real class. As there is a lack of mono specific trawl catch, it is hard to build the ground truth dataset. In practical terms, the method involves selection of haul having more than 90% of a determined species. Afterwards the mono specific set of fish schools is mixed according to the type of echograms

wanted. Then the composition and the species proportion of each echogram are known that allows us to test classification algorithms and compare classification results with real composition. Echograms comprising mixture with one, two, three, or four classes are simulated. Note that if there is one specie per echogram, it leads to the supervised case. As statistical variables must be evaluated from a mixing proportion, it is easy to understand that the higher is the number of species in echograms, the less the classification model is suitable.

In this paper, only 2D data are processed. Simulated echograms are built with four classes of data either coming out from the campaign (Sardina: 179 schools, Anchovy: 478 schools, Horse Mackerel: 1859 schools, Blue Whiting: 95 schools) or simulated with the acoustic fish school software OASIS [7] developed by the IFREMER institute (Anchovy: 1360 schools, Sardina: 1187 schools, Horse Mackerel: 1859 schools). While the fish school simulator provides big data base for any specie acoustic campaign does not. For instance, the statistical variables will not be correctly evaluated with the 95 Blue Whiting schools of the campaign. Once echograms are built, descriptors are extracted with a software [8]. 20 descriptors are used: the depth, the minimum depth, the relative altitude, the minimum altitude, the backscattering strength, the mean of acoustic echo, the maximum of acoustic echo, the standard deviation of acoustic echo, a coefficient describing the variation of echo, the maximum school height, the mean school height, the length, the area, the elongation, the fractal dimension, the circularity, the total energy, the mean energy, and the index of the amplitude dispersion. Note that these descriptors are not necessarily discriminative between them.

3 Models of classification

The two models of classification are presented in this section. The conditional model and the Bayesian model for weakly supervised learning have been considered and extended to our problem. Stated in [9] for binary labelling, an extension to mixing proportion data is considered.

- The conditional models can be viewed as a probabilistic setting of discriminative models. In the linear case, it consists in parametrizing a probabilistic decision from the signed distance to the decision hyperplane: $p(Y_{njk}|X_{nj}, \pi_n) \propto f(\langle W_k, X_{nj} \rangle + b_k)$, where $\langle W_k, X_{nj} \rangle + b_k = 0$ is the equation of the hyperplane separating the class k from the others and f is the exponential function. Exponential function weights the observation as a function of the distance to the hyperplan. Model parameters $\Theta = \{W, b\}$ are estimated from a gradient-based minimization of the

total proportion estimation error. An minimum error criterion is considered:

$$\hat{\Theta} = \arg \min_{\Theta} \sum_n D(\tilde{\pi}_n(\Theta), \pi_n) \quad (2)$$

where $\tilde{\pi}_n(\Theta)$ is the vector of the estimated priors of the acoustic energies relative to the different species classes: $\tilde{\pi}_n(\Theta) = \sum_j E_{nj} p(y_{nj}|x_{nj}, \Theta)$, E_{nj} equals one if these proportions are computed as relative object occurrences, and D a distance between the observed and estimated priors. Among the different distances between likelihood functions, the Battacharrya distance is chosen. An extension to non-linear models is proposed here using the kernel trick [10]. The non linear model consists in a projection of the original feature space in a new kernel space. Then a Principal Component Analysis is carried out.

- For the Bayesian model, we develop $p(y_{njk}|X_{nj}, \pi_n)$ according to Bayes relation:

$$p(y_{njk}|X_{nj}, \pi_n) = \frac{p(Y_{njk}|\pi_n)p(X_{nj}|Y_{njk}, \pi_n)}{\sum_l p(Y_{njl}|\pi_n)p(X_{nj}|Y_{njl}, \pi_n)}$$

where $p(Y_{njk}|\pi_n)$ is depending on the proportion π_n into the n^{th} echogram (the expression is given into [9]) and $p(X_{nj}|Y_{njk}, \pi_n)$ is a Normal M-mixture distribution of the form:

$$p(X_{njk}|Y_{njk}, \pi_n) = \sum_{m=1}^M \rho_{k,m} N(\mu_{k,m}, \Sigma_{k,m}) \quad (3)$$

Where $\rho_{k,m}$ is the mixing prior for class k , $\mu_{k,m}$ and $\Sigma_{k,m}$ are the Gaussian parameters. Models parameters $\Theta = \{\rho_{k,m}, \mu_{k,m}, \Sigma_{k,m}\}$ are estimated by an Expectation Maximization procedure [9]. A diagonal pooled variance-covariance matrix is chosen to avoid problems when the inverse matrix is calculated. This implicates that we suppose that there is no dependence between descriptors.

4 Results

Figure 4 shows the improvement brought by considering mixing proportion data for training compared to presence/absence data [9]. The presence/absence case considers that the proportion is unknown and replaces it by a binary value indicating 1 if the class is present in the echogram and 0 if the class is absent. The correct classification rate is

shown as a function of the complexity of the proportion in the echogram. A complexity value of zero means that one class is dominating in the echogram and a complexity of one means that the proportion is the same for all the classes. With a simulated database and for the three classification models, the classification rate of the proportion method is better compared with the presence/absence method.

Figure 5 shows algorithms performance for real and simulated data. The rate of correct classification is shown as a function of the complexity of the training dataset from mono specific echograms (i.e. in the supervised case) to three or four class mixture. This allows the behaviour changes of the methods to be evaluated. The implementation of the different proportion complexity is done with a random number computer selection on the mono specific database. A part of the data base is randomly selected for the training and the remaining part is used to evaluate the classification of the trained model. This procedure is carried out one hundred times and the mean of the correct classification rates gives the global rate of correct classification. The higher is the number of species, the less the results are suitable. Reported results show that the proposed conditional model outperforms the Bayesian model. The Bayesian model performance decreases faster when proportions are more complex. The difference between the linear and the non linear conditional model is difficult to evaluate and depends on the dataset but the non linear conditional model dominates.

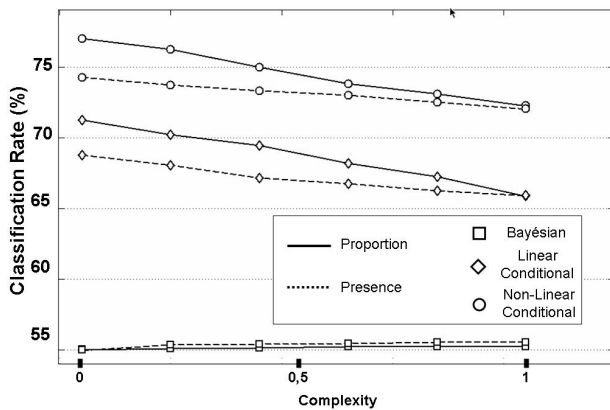


Figure 4. Correct classification rate for Simulated database as a function of the complexity of the class proportion in the training echogram. Comparison between the proportion case (dashed line) and the presence/absence case (solid line) for the three classification model (Bayesian, Linear conditional and non-linear conditional).

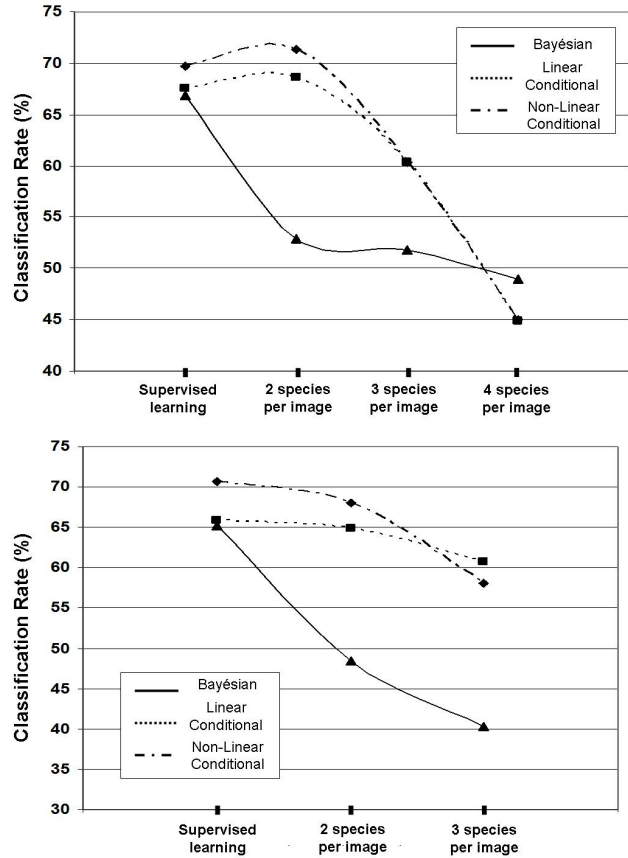


Figure 5. Classification performance for real fish school data (top) and simulated acoustic fish school data (bottom). The rate of correct classification is reported for the $M=5$ mixture Bayesian model (solid), the non-linear conditional model (dashed) with and the linear conditional Model (dotted).

Additional results also point out that correct classification rate depends on the number of descriptors used for the classification. Figure 6 presents the correct classification rate as a function of the complexity when four descriptors are considered. We picked out from the twenty descriptors those that are more discriminant. Results show that the Bayesian model is not robust. Indeed, performance decreases faster when proportions are more complex but the rate of correct classification dominates now (more than 10% for real data) compared with conditional model when the number of species per echogram is limited. We conclude that the Expectation Maximization algorithm doesn't converge with higher system dimension.

5 Conclusion

This paper considers an original algorithmic method for studying marine ecosystem. Previous works tried to clas-

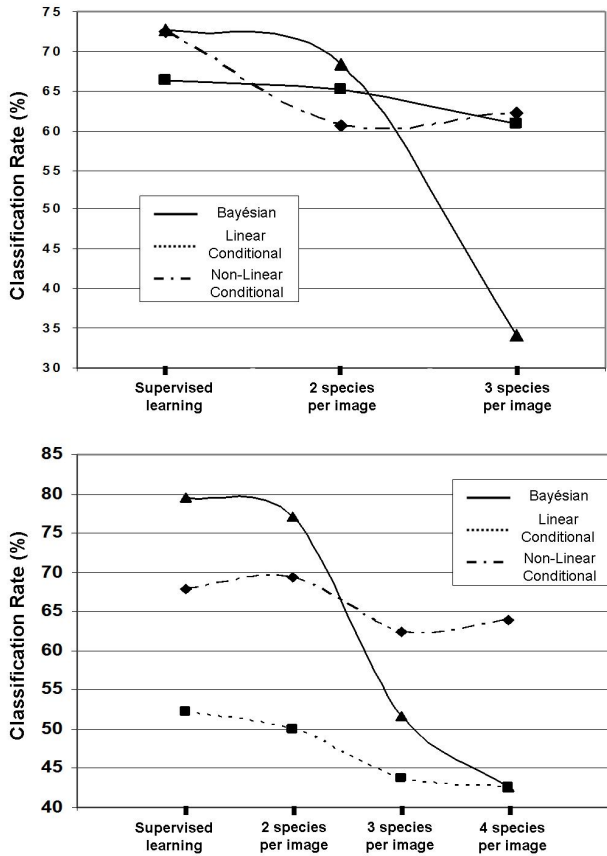


Figure 6. Classification performance for real (top) and simulated (bottom) fish school database using the four descriptors the most discriminant. The rate of correct classification is reported for the $M=5$ mixture Bayesian model (solid), the non-linear conditional model (dashed) and the linear conditional Model (dotted) as a function of the proportion complexity.

sify species using a supervised learning scheme that is not adapted to oceanographic survey. Our algorithm takes into account the observation labels coming from trawl catches give proportion information.

With regards to lack of ground truth, a procedure has been developed to test and evaluate the classification results. Before analyze the methods compartments we notice the result improvement when proportion label is considered compare to presence/absence label. Performance of the method depends on the classification model, the origin of database, and the number of parameters the methods have to estimate. Concerning the classification results and considering all the descriptors, non linear conditional model seems to be the more adapted to the weakly supervised method. Robustness and superiority of the model are deduced from the high level of correct classification and the regularity against the number of species complexity per echogram. Finally, we

observed that the Bayesian model is sensitive to the number of descriptors.

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