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PP	Restricted to other programme participants (including the Commission Services)	
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Contribution to project objectives – with this deliverable, the project has contributed to the achievement of the following objectives (from Annex I / DOW, Section B1.1.):

N.º	Objective	Yes	No
1	Reduce uncertainties in our knowledge of the functioning of Tropical Atlantic (TA) climate, particularly climate-related ocean processes (including stratification) and dynamics, coupled ocean, atmosphere, and land interactions; and internal and externally forced climate variability.		x
2	Better understand the impact of model systematic error and its reduction on seasonal-to-decadal climate predictions and on climate change projections.		x
3	Improve the simulation and prediction TA climate on seasonal and longer time scales, and contribute to better quantification of climate change impacts in the region.		x
4	Improve understanding of the cumulative effects of the multiple stressors of climate variability, greenhouse-gas induced climate change (including warming and deoxygenation), and fisheries on marine ecosystems, functional diversity, and ecosystem services (e.g., fisheries) in the TA.	x	
5	Assess the socio-economic vulnerabilities and evaluate the resilience of the welfare of West African fishing communities to climate-driven ecosystem shifts and global markets.	x	

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Deviation from planned efforts for this deliverable: none to our best knowledge.

Executive Summary:

This report covers the main aspects of the WP 12 analysis of Yellowfin tuna (YFT) dynamics with regards to temporal trends and spatial distribution of catches around Cape Verde (CV) and covers a first analysis of size classes of forage fish. Results on tuna stable isotope analysis are not included, since they were not fully analysed.

Tagging results indicated that YFT, in line with literature results, mainly occupy the epipelagic layer of the ocean, only occasionally extending dives beyond 150 m.

Catch-per-unit-effort trends as indicators of YFT abundance in the CV region indicated a strong effect of subtropical wind stirring with a subsequent cooling of the surface layer, which led to an increase in abundance, evidenced in negative correlations to NTA and NAO. NTA is a tropical index, whereas NAO addresses effects related to the subtropics. The wind effects are interpreted as conditions of enhanced ecosystem productivity, with subsequent attraction and aggregation of this migratory species.

Spatially significant factors extending the center of gravity of catches were positive SST anomalies (with regards to longitude) and positive NAO and NAO with a lag of 1 year (with regards to latitude).

Positive NAO is linked to less wind stirring in the CV region, so that the ocean surface layer is not cooled down. This is in line with published results, indicating that YFT did not show any range contraction.

The epipelagic swimming characteristics of YFT augment the interpretation of surface features associated with wind stirring and surface cooling which were indicated as significant factors in the analysis of CPUE and spatial distribution of catches.

The analysis of forage fish size distributions indicated that YFT habitat suitability has not declined, given that the relative abundance of fishes in the preferred size range for diet has increased in the subtropical and tropical North Atlantic.

Scenario analysis in collaboration with WP11 is not undertaken at this stage. The analysis of stock dynamics is subject of the work in PREFACE WP 12.1. The reference area considered is waters around the Cape Verde Islands. The results indicate the potential of Yellowfin tuna for the fisheries in Cape Verde, not distinguishing between artisanal and industrial fisheries. In PREFACE WP 13, catches and landings in Cape Verde artisanal fisheries are considered, indicating the relevant factors for utilizing the resource for a specific fleet.

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YFT in the Atlantic

Yellowfin tuna (YFT) is a tropical and subtropical species distributed mainly in the epipelagic oceanic waters of the three oceans. The sizes exploited range from 30 cm to over 170 cm; maturity occurs at about 100 cm..

YFT – climate relationships: State-of-the-art

In an analysis of tuna habitat requirements at global scale, Arrizabalaga et al. (2015) showed that YFT had very specific habitat needs with a preference for warm surface waters > 24°C. . Highest catch rates of YFT in the tropical Atlantic are linked to water temperatures of 24-25°C. For the North Atlantic, Lan et al. (2011) analysed a short time series 1998-2007 based on Taiwanese long-line fisheries data in relation to the North Atlantic Tropical index (NTA), sea surface temperature (SST), subsurface temperature, chlorophyll a concentration, net primary productivity, and wind speed. For the fleet considered, subsurface temperature was an important determinant of YFT catch rates and a positive relationship to NTA was postulated, but the influence of NTA on the cpue of YFT seemed to be insignificant.

YFT state-of-the-stock in the tropical Atlantic

Fisheries informations

YFT long line (LL) fishery dates from 50s and gained popularity in the 60s along the Atlantic Ocean according to Lan. et al, 2011. In contrast to the increasing catches of YFT in other oceans, there has been a steady decline in overall Atlantic catches, with an overall decline of 45% since the peak catches of 1990 (Anonymous, 2011). The catches from surface fisheries in the Atlantic Ocean decreased between 2001 and 2004, whereas LL catches increased. After 2006, the catches of the LL fishery declined, although some surface fisheries increased in the eastern Atlantic.

YFT migrate seasonally avoiding areas of lower sea surface temperature (SST). In the first quarter of the year, as long as the spread of the coastal upwelling influences waters at the Cape Verde Frontal Zone, catches in Cape Verde are low. In quarters 2,3, and 4, catches increase in Cape Verde, while the stock retreats from the eastern tropical Atlantic and the Gulf of Guinea and moves west of 20°W. In the first two quarters of the year, YFT mainly aggregate in the equatorial Atlantic and extend their range into the Gulf of Guinea.

Assessments

Assessments indicate that YFT total stock abundance has decreased from a very high level in the 1960's. The stock encompasses all Atlantic YFT, not only the part accessible in Cape Verde waters.

At present, biomass appears to be at maximum sustainable yield-level (MSY), offering good prospects for future fisheries (Fig. 1).

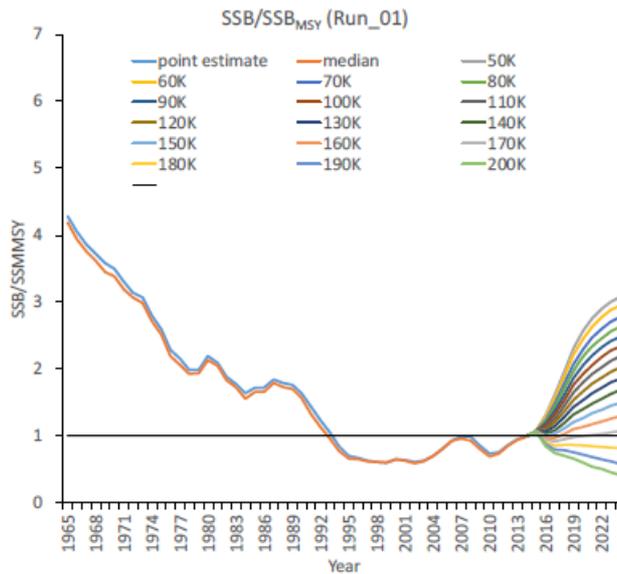


Figure 1: Stock assessment and stock projections under different management options (Anonymous, 2016). Catches in ktons. Catches at < 170 K per year would be sustainable according to the MSY concept.

Data sources

YFT stock indices

Japanese LL stock index:

This standardized index has been further explored and revised to satisfy the ICCAT YFT Species Group requests. Its advantages are: Long time series, extensive spatial coverage.

Disadvantages are: There is a noted shift in targeting from YFT before 1975, to BET after 1976. This change in targeting was likely accompanied by changes in gear configuration and/or fishing operations, but data describing gear configuration are not available to directly quantify the change in targeting. The ICCAT assessment group recommends to include this index in all stock assessment models 1976-2014 (Anonymous, 2016).

Index4 series

In 2011, combined indexes were calculated for assessment purposes using a GLM approach with the following model formulation, where each source was weighted so that total weight added up to 1 (Anonymous, 2011):

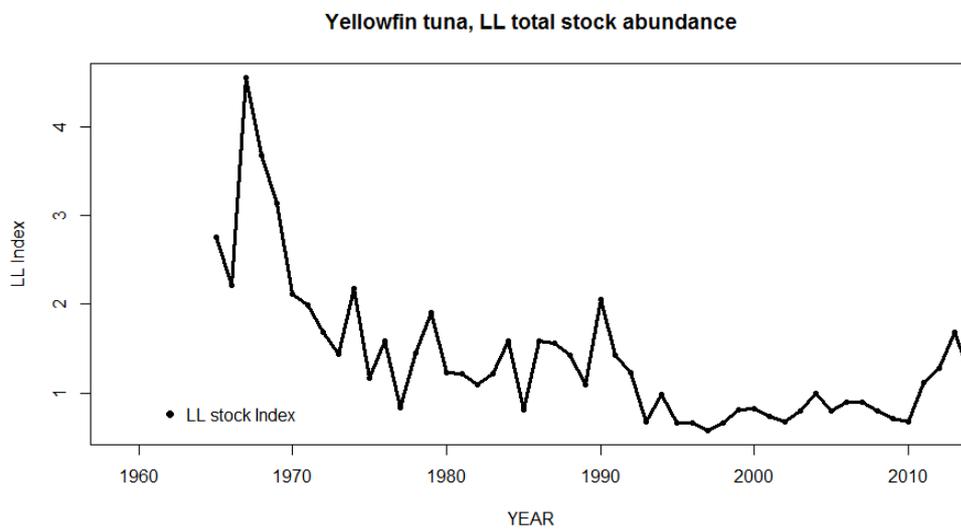
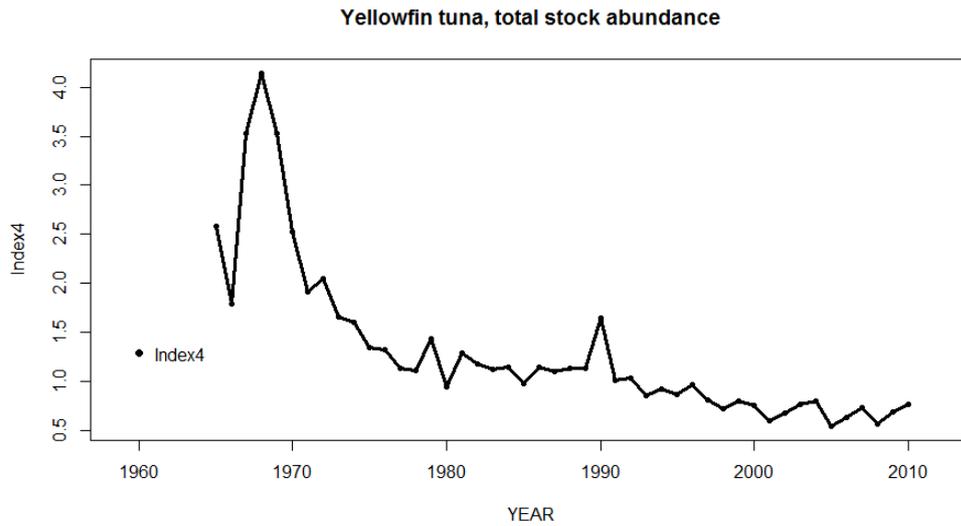


Figure 2: YFT stock indices

$$\text{Log}(\text{index}) = \text{Year} + \text{Source} + \varepsilon$$

The so-called index 4 combined different fleets from different countries, i.e. purse seine fisheries data, catches obtained at Fish-Attracting-Devices, and long line fisheries data.

Both indices differ from each other, in particular when considering recent trends. The Index4 (Fig. 3 lower panel) is characterized by a steep decline from the late 1960's on with a relatively weak tendency to recover from 2000 onward. The LL index shows significant variability from 1975 to 1995 (Fig. 4 lower panel). Further, the LL index is able to depict the recent upward trend in the stock also visible in YFT stock assessments (Fig. 2).

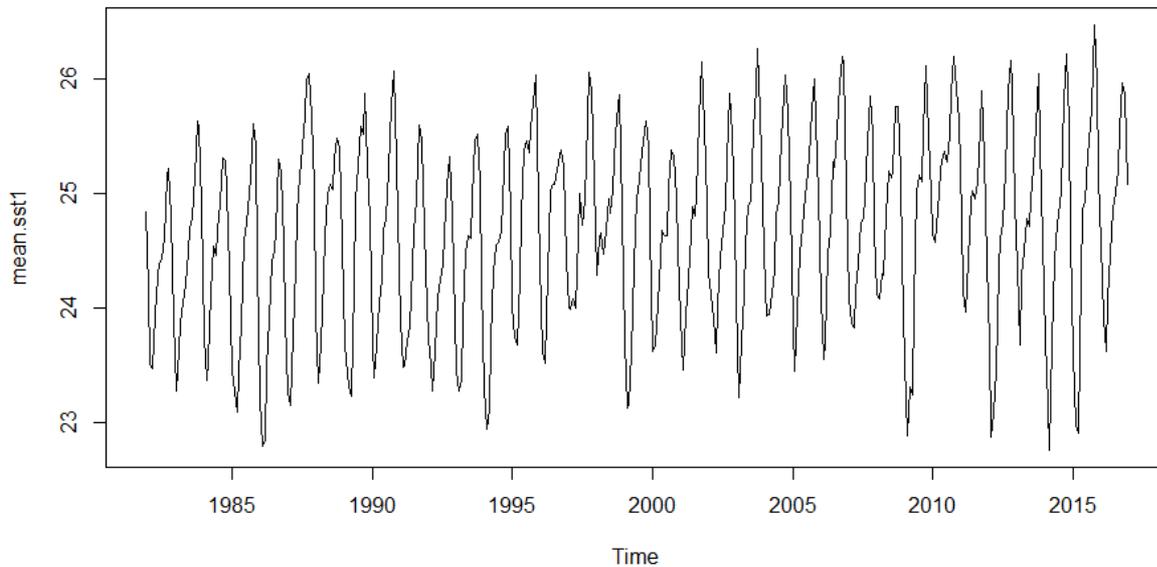


Fig. 3: SST trends for the Cape Verde region 1982-2016

YFT CPUE data types

Two different CPUE indices were applied, of which the shorter time series does not have the extension to model the initial decline of the stock.

The area considered was 10-20°N latitude and 10-30°W longitude to represent the catching opportunities in the Cape Verde region.

CPUE.nr

The regional CPUE estimates were calculated from the ICCAT "t2ce" data base. Reporting format in the early years was fish by numbers caught. CPUE for numbers were calculated for gear type "LL", i.e. long-lining, from 1965 to present. Effort is expressed in terms of number of hooks, although other effort parameters such as gear soak time could be more informative but are not available in the data base (Watson and Kerstetter, 2006).

CPUE.kg

Catches by weight-data are only available since 1995.

Environmental data

Tuna are migratory fish. Therefore, we apply both local data and regional climate indices. Whereas local data directly indicate local conditions, the application of climate indices by definition reduces complex space and time variability into simple measures, 'packages of weather'. The disadvantages of using global climate indices are all related to the fact that another level of problems are added to the ecology-climate interface, namely the link between global climate indices and local climate (Stenseth *et al.*, 2003). Climate indices were available from www.esrl.noaa.gov/psd/data/climateindices

SST

Sea surface temperature data were averaged over a region from 0°N to 30°N and 0°W to 30°W (Fig. 3). The data were monthly resolved NOAA Optimum Interpolation (OI) SST V2 data. The new climatology was built from the 1 degree SST climatology for the period 1982-2000.

Climate indices

NTA – Time series of SST anomalies averaged over 60W to 20W, 6N to 18N and 20W to 10W, and 6N to 10N map. Data is obtained from the ERSST V3b dataset. Anomalies were calculated relative to the 1981-2010 climatology, smoothed by three months running mean procedure and projected onto 20 leading EOFs.

TNA – Anomaly of the average of the monthly SST from 5.5N to 23.5N and 15W to 57.5W. HadISST and NOAA OI 1x1 datasets are used to create index. Climatology is 1971-2000. TSA was also included in the analysis, but proved to be not informative.

ENSO – The El Niño Southern Oscillation (ENSO) affects weather and climate variability worldwide (Stenseth *et al.*, 2003). The Bivariate EnSo Time series (BEST) index was applied as long time period ENSO index for research purposes. Nino 3.4 has traditionally been used as a measure of ENSO strength in the tropical Pacific. However, its use alone neglects explicit atmospheric processes. By adding the SOI or Southern Oscillation Index (the pressure difference between Tahiti and Darwin), these processes are more directly included. In addition, older SST values are at least partially reconstructed and not explicitly measured. By including the SOI, which is better measured historically, the effect of biases in the SST data introduced by the reconstruction technique are reduced. Based on 1871-2001 SST and SOI indices.

NAO – The North Atlantic Oscillation (NAO) represents the dominant climate pattern in the North Atlantic region (Stenseth *et al.*, 2003). Negative NAO-phases in the subtropical Atlantic are characterized by an increased CO₂ uptake in this region by intensified cooling associated with changes in both enhanced wind stirring and reduced surface heat input (Friedrich *et al.*, 2006), resulting in a negative correlation to SST (Ruiz-Barradas *et al.*, 2000). However, the NAO has no direct link to the tropical-equatorial Atlantic (Ruiz-Barradas *et al.*, 2000). The index is calculated for the months D-J-F.

PDO – The Pacific Decadal Oscillation has significant effects on western Atlantic ecosystems (Gherardi *et al.*, 2010). During warm PDO phases, Atlantic SST anomalies in the northern tropical zone are linked to ENSO variability, so that PDO is seen to modify ENSO effects in the Atlantic. Other authors have suggested that PDO and AMO belong to the same atmospheric oscillation pattern (d'Orgeville and Peltier, 2007). Calculated for months O-N-D-J-F-M.

Analysis of YFT CPUE in the Cape Verde region

Tuna production and distribution can be affected by large-scale environmental and climatological variability. YFT prefer warm waters and the distribution may be affected by sea surface temperature (SST), subsurface temperature, and the depth of the thermocline as reflected by climate indices.

The purpose of this study is to investigate the relationship between catch data and climate using catch data from Cabo Verde region. Catch-per-unit-effort is treated as a function of stock size, N , and environmental factors, E_i :

$$\text{CPUE} \sim f(N) + f(E_i)$$

CPUE calculations and model selection

We analyse catch-per-unit-effort (CPUE) data from Japanese longline fisheries to have a consistent data set for several decades. CPUE is commonly used as an index to estimate relative abundance and is then applied within stock assessments. For that purpose, CPUE must be treated as unbiased indicator of stock size with both successful and unsuccessful fishing effort indicated.

This does not apply to an opportunistic fisheries such as pelagic longlining, so that CPUE must be treated as fishery-dependent data while directedly pursuing the migratory target species (Watson and Kerstetter, 2006). Pelagic longlining is operated at high technological standards with a significant level of fleet communication, utilization of satellite imagery to detect fronts and other electronic devices to minimize the risk of unsuccessful fishing effort.

The concept of concentration profiles in turn allows to analyse the distribution and abundance of fish in area under the premise, that fishermen opportunistically will go to the best area first and extract all the fish in the area before moving on. Tuna, here skipjack tuna, apply in general a type III concentration profile (Hilborn and Walters, 1992, p. 190), i.e. the stock is not evenly distributed but concentrated in certain areas. Type III fish behaviour together with the capability of the fishermen to target these areas due to high technological standards leads to hyperdepletion of stocks, while the apparent stability of catch rates in the hot spots indicates hyperstability, i.e. false stability of the stock.

(A) H1 model				
Formula = cpue.nr ~ apr + lagnao1 + nao + ENSO_ann + pdo + LLindextotStock				
	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	6.198e-04	2.863e-04	2.165	0.03601 *
apr	-5.270e-04	3.591e-04	-1.468	0.14949
lagnao1	-2.492e-04	1.933e-04	-1.289	0.20413
nao	-5.561e-04	2.036e-04	-2.732	0.00911 **
ENSO_ann	1.393e-05	1.816e-05	0.767	0.44714
pdo	4.214e-04	2.176e-04	1.936	0.05942 .
LLindextotStock	1.011e-03	1.916e-04	5.277	4.07e-06 ***

Adjusted R-squared: 0.5723 , p-value: 7.706e-08				
(B) H1 only significant terms				
Formula = cpue.nr ~ nao + LLindextotStock				
	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	0.0005680	0.0002899	1.959	0.0560 .
nao	-0.0005155	0.0001954	-2.639	0.0112 *
LLindextotStock	0.0010810	0.0001878	5.757	6.27e-07 ***

Adjusted R-squared: 0.5097 , p-value: 1.998e-08				
(C) GAM with H1 terms				
Formula:				
cpue.nr ~ s(apr) + s(lagnao1) + s(nao) + s(pdo) + s(ENSO_ann) + s(LLindextotStock)				
Approximate significance of smooth terms:				
	edf	Ref.df	F	p-value
s(apr)	3.3846	4.210	2.211	0.07258 .
s(lagnao1)	0.9553	2.000	1.881	0.03440 *
s(nao)	3.1680	3.863	4.091	0.00851 **
s(pdo)	1.8124	2.000	4.603	0.00851 **
s(ENSO_ann)	1.0000	1.000	0.566	0.45687
s(LLindextotStock)	3.6151	4.417	8.458	3.38e-05 ***

R-sq.(adj) = 0.708				

Table 1 CPUE.nr model results

According to Hilborn and Walters (1992, eq. 5.4.6), this can be solved as stratified analysis, with the different catch units as strata instead of spatial units, since the spatial unity would not have been chosen randomly but rather reflect aggregated fishing activity. Therefore, we apply a catch-weighted analysis of CPUE, hence a weighted average

$$N = \frac{1}{q} \sum_l n_l \frac{C_l}{E_l}$$

(A) H1 model				
Formula = cpue.kg ~ lagnao1 + feb + LLindextotStock				
	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	0.02997	0.05249	0.571	0.576
lagnao1	-0.02324	0.01913	-1.215	0.242
feb	-0.09953	0.04089	-2.434	0.027 *
LLindextotStock	0.07893	0.05446	1.449	0.167

Adjusted R-squared: 0.2652 , p-value: 0.04805				
(B) H1 only significant terms				
Formula = cpue.kg ~ feb				
Coefficients:				
	Estimate	Std. Error	t value	Pr(> t)
(Intercept)	0.1036	0.0181	5.722	1.63e-05 ***
feb	-0.1010	0.0399	-2.532	0.0203 *

Adjusted R-squared: 0.213 , p-value: 0.02031				
(C) GAM with H1 terms				
Formula: cpue.kg ~ s(lagnao1) + s(feb) + s(LLindextotStock)				
Approximate significance of smooth terms:				
	edf	Ref.df	F	p-value
s(lagnao1)	1.5031	2	1.607	0.1403
s(feb)	0.9516	2	2.781	0.0186 *
s(LLindextotStock)	0.8170	2	1.413	0.0652 .

R-sq.(adj) = 0.368				

Table 2 CPUE.kg model results

where N is the stock abundance, q is a conversion factor, and C , E and n is catch, effort and weighting factor in terms of catch units n , which sum up to l . Since q is unknown, we assume

$$N \propto \frac{1}{l} \sum_l n_l \frac{C_l}{E_l}$$

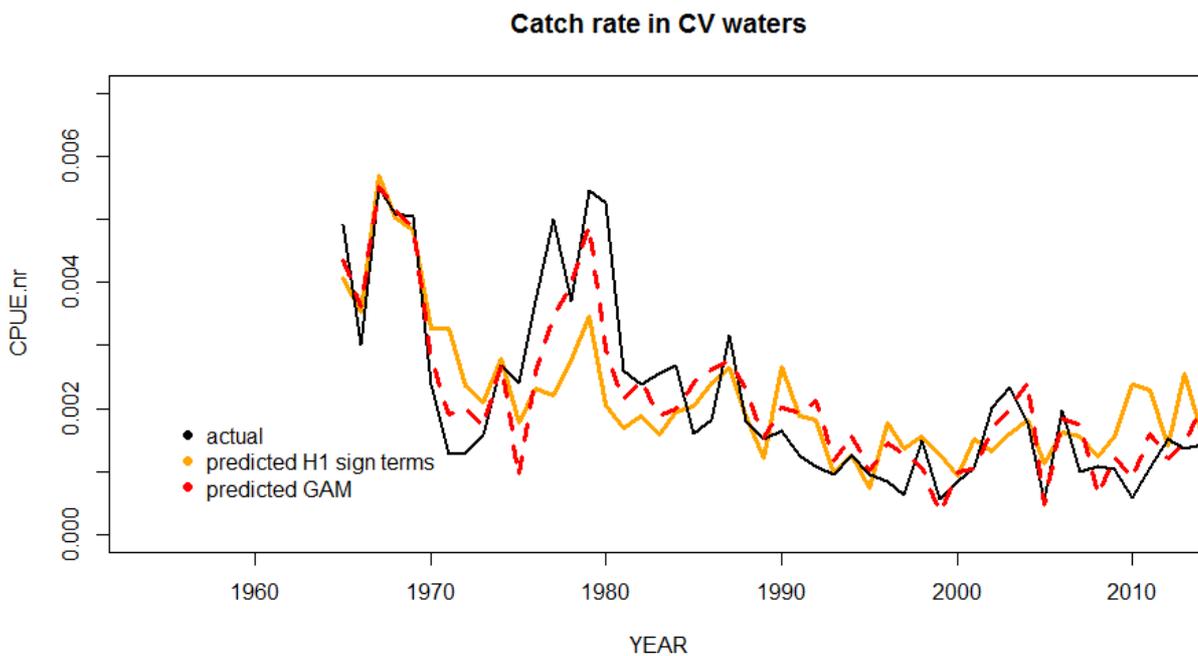
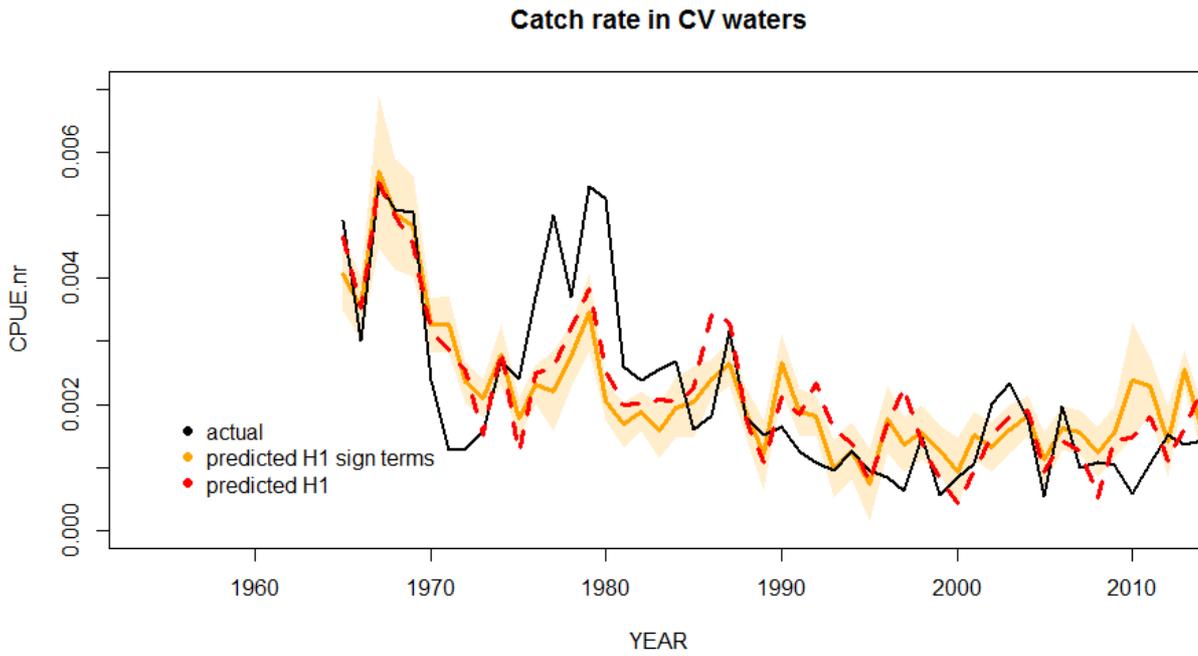


Figure 5: CPUE.nr model results. Confidence interval for H1 model with significant terms shaded.

The workflow for model selection (1) applies a linear model, analysed with the `stepAIC()` function in R. This information theoretic approach applies the AIC criterion to select a model H_1 from a suite of alternative models H_2, \dots, H_n , and provides the most parsimonious solution given the data available (Burnham *et al.*, 2011). It is not yet a "true" model, and therefore this model is (2) further evaluated

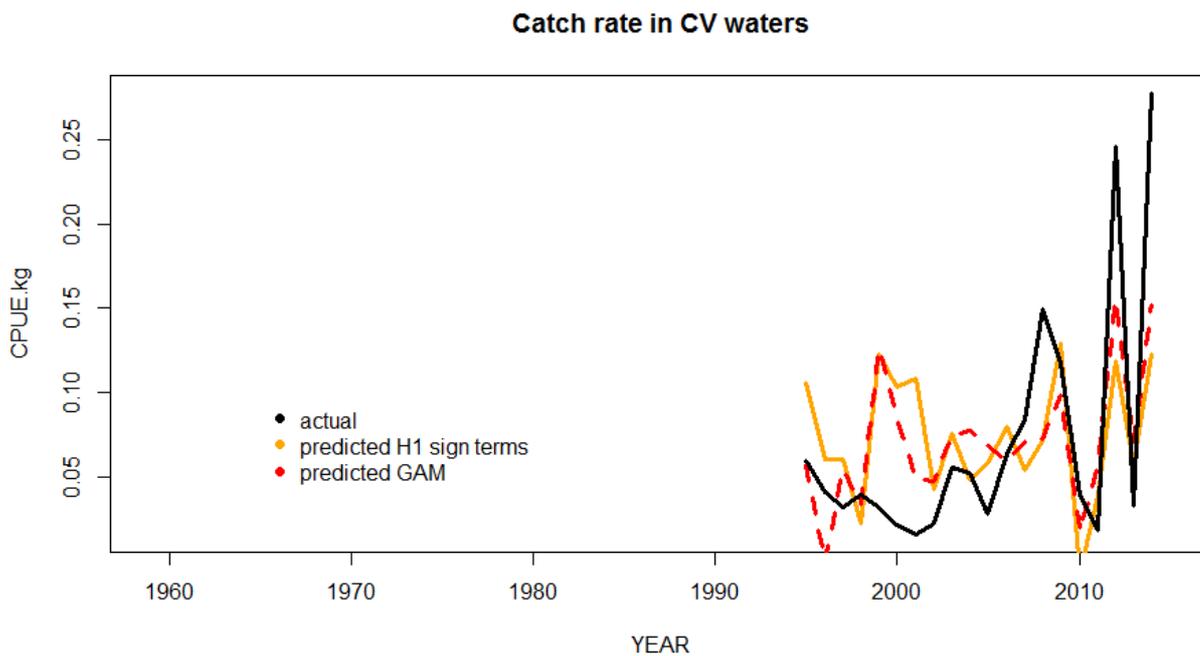
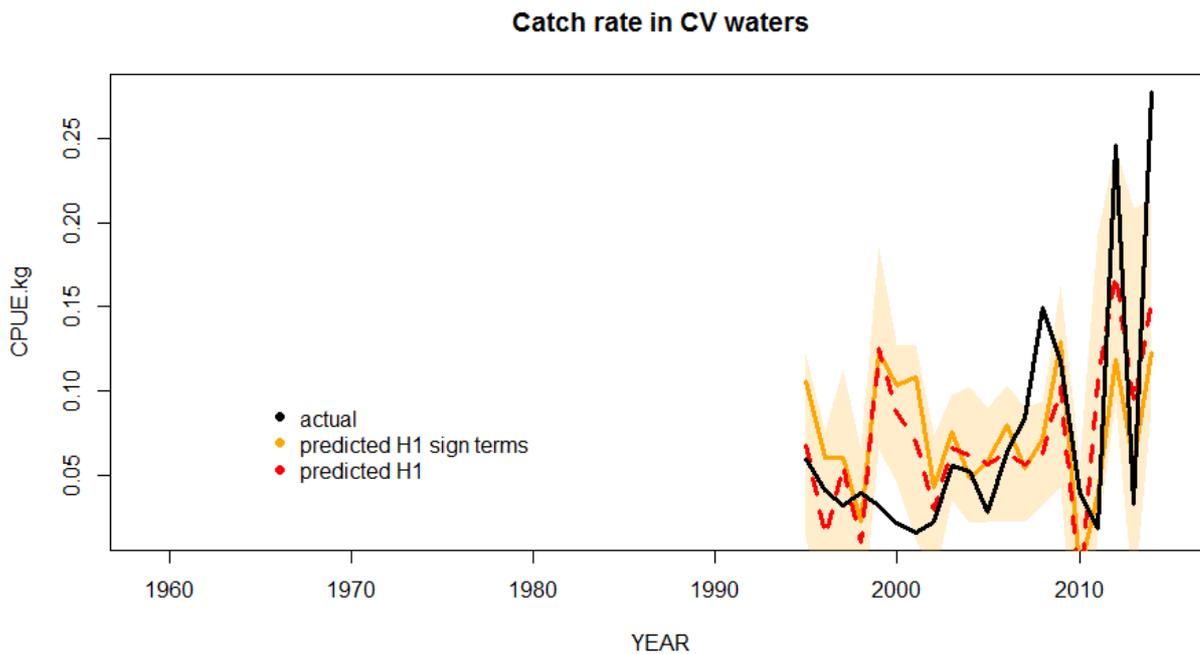


Figure 6: CPUE.kg model results. Confidence interval for H1 model with significant terms shaded.

for its significant terms. The application of a linear model allows a more straightforward interpretation of relationships in terms of correlation. In a third step, (3) a generalized additive model (GAM) is applied to the model parameters defined under H_1 . The smoothing function in GAM for each parameter allows for non-linear relationships and applies very effective fitting. Accordingly, model fit in GAMs is better, but interpretation of parameters could be difficult as standalone tool.

Results

In both analyses for CPUE.nr and CPUE.kg, a relationship to the LL index was indicated but not to Index4.

Analysis for CPUE by number (CPUE.nr)

In terms of stock indices, the LL index proved to be significant (Table 1, H1). SST and TNA were not included in the model. NTA month April was included, as well as PDO, NAO, lagNAO (1 yr) and ENSO. Adjusted r^2 for the H1 model is 0.57, and drops to 0.51 if only significant terms ($p < 0.05$) are considered.

The H1 model with only significant terms was reduced to a two parameter model, comprising effects for NAO and stock size.

In the GAM model, NTA April, lagNAO and NAO and PDO are significant, whereas ENSO appears to be insignificant. As matter of fitting, the adjusted r^2 is high, 0.85.

The coefficients for NAO, lagNAO, NTA apr in either analysis are all negative, although the latter is insignificant in both H1 and the GAM model. This however indicates an overall significant wind driven effect in the subtropical region at time scales of 12 to 24 months. In the tropics, increased wind stress would also lead to cooling by means of increased equatorial upwelling, Both effects, i.e. wind stirring and equatorial upwelling, can be understood to enhance ecosystem productivity. The ENSO effect is considered insignificant, and the PDO effect is weak, i.e. not significant in the linear model, but significant after non-linear fitting in the GAM model.

The linear models are in particular good in showing the decline phase 1965-1975, 1980-1990 and the period 1998-2009 (Fig. 5). In particular the recovery of the stock after 2009 is overestimated by the linear models. The GAM model is in particular good at reflecting variability in the period 1975-1980. The variability in CPUE.nr from 1975 onward resembles very much the variability in the LL reference index, as opposed to the trend of stock index Index4.

Analysis for CPUE by weight (CPUE.kg)

The CPUE.kg data set is much shorter than the series for CPUE.kg. It has already been noted, that the CPUE.kg index resembles the most recent increase of the stock after 2010. The H1 model indicates a non-significant relationship to stock size by means of the LL index, but a significantly negative relationship to NTA feb anomalies (Table 2). In the GAM model, only NTA feb appears to be significant. Similar to the models for CPUE.nr, coefficients for NTA feb and lagNAO are negative. The insignificant effect of the stock index indicates, that at low stock sizes environmental aspects are more important.

All models are in particular good at showing the increase in CPUE.kg after 2002, in line with the increase of the LL stock index (Fig. 6).

Analysis of spatial distribution of catches

Shifts in in ranges and range contractions have been indicated for overexploited stocks (Worm and Tittensor, 2011) They state, that reductions in the abundance of exploited predators have led to significant range contractions for those species. This pattern can be formalized as the range–abundance relationship, a general macroecological pattern that has important implications for the conservation of threatened species.

We further formalize this relationship as shift in center of gravity of catches, which is correlated to the contraction of ranges. For YFT, a range contraction was not observed (Worm and Tittensor, 2011), in turn, a minute expansion was observed.

The shift in the center of gravity is investigated in relationship to environmental factors.

Calculation of center of gravity of fisheries

The center of gravity was calculated by year as weighted Lon/Lat mean of catches.

Results and Discussion

Annual SST was not significant. Instead, for weighted longitude a relationship to NTA SST anomalies for the months August to October appeared, of which the relationship to month September had the best correlation (Fig. 7).

Weighted latitude was related to NAO and lag1 NAO, indicating a positive relationship.

Both relationships can be understood as temperature dependent effects. With warmer than average summer and autumn values, the longitudinal center moves further west. This probably is linked to the annual cycle of migration, when YFT migrate westwards during summer.

Whereas negative NAO was linked to increased wind stirring, a positive relationship indicates a link to less wind stirring in subtropical latitudes. However, a positive signal to temperature and SST anomalies was not indicated.

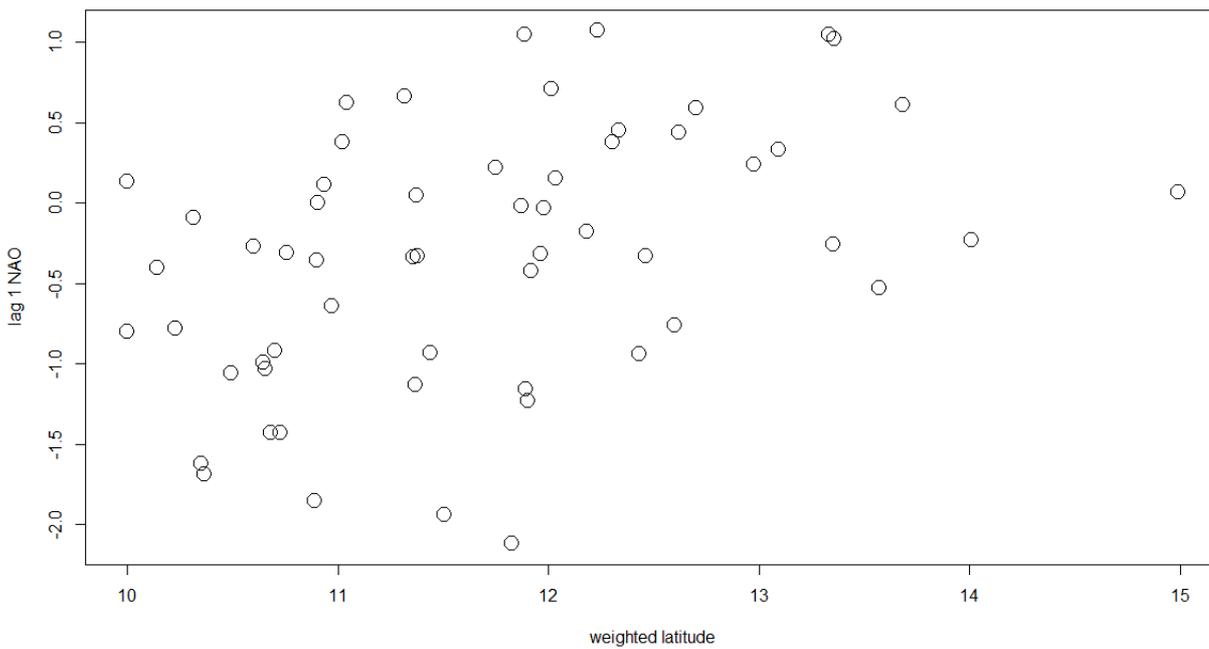
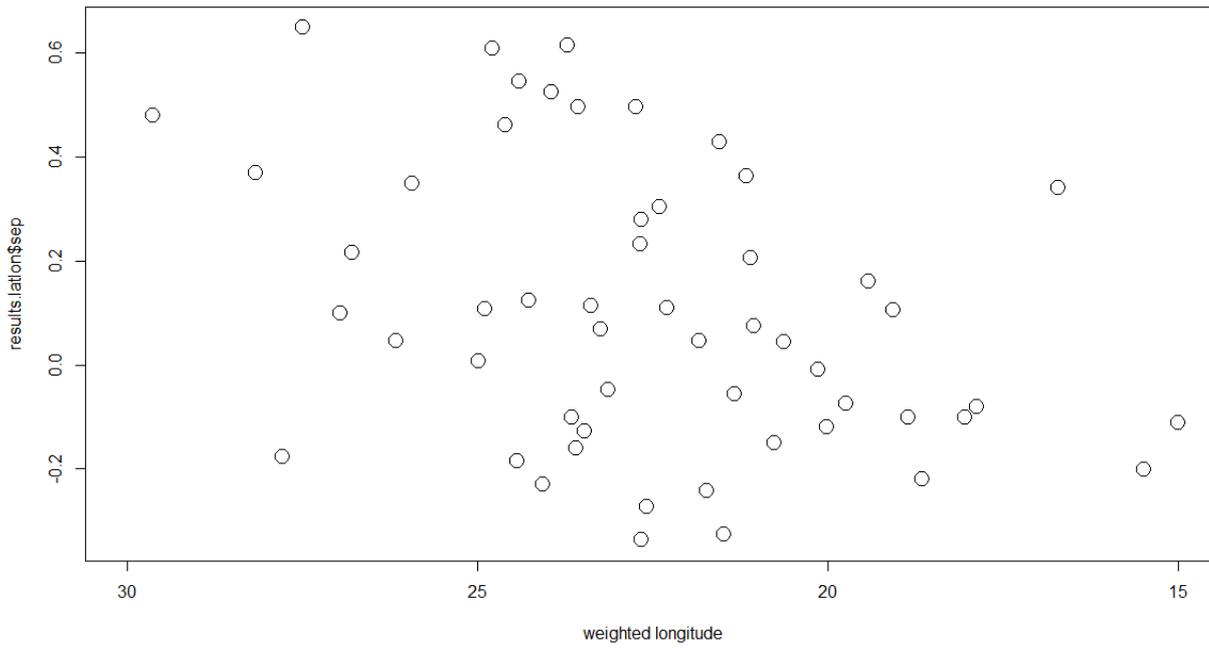


Fig. 7. Significant relationships for weighted longitude and weighted latitude for (upper panel) NTA sep anomalies and (lower panel) NAO and lagNAO

Dynamics of forage fish

The main sizes of YFT in the commercial catches are below 1 m body length. This indicates, that age group 0 constitutes most of the catch. Diet for YFT < 100 cm consists mainly of small mesopelagic fishes/micronekton such as *Vinciguerria* spp. , myctophids etc. (Ménard *et al.*, 2000; Ménard and

Marchal, 2003; Varela *et al.*, 2017) so that knowledge on the changes in size composition of forage fishes is crucial in understanding potential shifts in YFT distribution.

Catchability aspects

Net sampling in deep sea fishes is indispensable for analysis of long-term changes of community composition, growth and reproduction at species level. However, fisheries samples taken with different trawls can be affected by net effects in several ways (Fock *et al.*, 2002; Heino *et al.*, 2012): area of net opening (width, height), ease of avoidance of net, retention through mesh selection, escapement from net, trawling operation, and herding effect. For midwater trawling, the possession of light organs in many deep-sea fishes may have further implications for the sampling, i.e. induced bioluminescence may lead to either a further herding effect, or attraction in terms of "baited-can-effect" for predators, or enhanced avoidance (Harrison, 1967; Jamieson *et al.*, 2006). Pearcy (1983) showed that catchability changes significantly with time of day with lower catches during daytime (after taking account of vertical migration effects), so that reaction distance also depends on visibility conditions. Significant trawl avoidance behavior was shown for myctophids (Kaartvedt *et al.*, 2012), while in other cases large predators were apparently attracted and 'accidentally' caught even from outside of plankton nets (Harrison, 1967).

As a consequence, biomass estimations of deep sea fishes depend on the methodologies chosen (Fock and Ehrich, 2010; Irigoien *et al.*, 2014). Inter-calibration studies between gears normally sample from the same fauna or stock, and obtain catchability comparisons by analyzing catch rates in terms of log-linear models (Heino *et al.*, 2012; Laretta *et al.*, 2013) or ANOVA (Antacli *et al.*, 2010), or in terms of length spectra and biological indices (Trenkel *et al.*, 2004). The application of length spectra also as community metric to indicate environmental change or as input for length-based modelling (e.g. (Shin *et al.*, 2005; Duplisea and Castonguay, 2006)) underpins the clear need of understanding catchability effects when different gears are applied.

Body size and behavior are important traits to understand the catchability of deep sea fishes (Harrison, 1967), in turn, differential treatment of traits in community analysis can be applied to disentangle gear and temporal effects (e.g. (Fock *et al.*, 2002)). Larger specimens are relatively faster and thus are less likely to be caught with smaller nets (Harrison, 1967; Pearcy, 1983). This result fueled the discussion on the value of larger and often non-closing nets in the study of deep sea fishes (Krefft, 1976; Gjoesaeter and Kawaguchi, 1980) while certain disadvantages pertain to this net type, i.e. contamination with specimens from shallower depths and unclear volumes of filtered seawater (Pearcy, 1983; Hulley and Krefft, 1985; Fock *et al.*, 2004). In terms of behavioural traits, optical investigations indicate that many mesopelagic species, in particular elongated species, have a 45° to vertical orientation in the water column which depends on their predatory behavior. For horizontally towed nets, the presumed escape angle would easily lead the animals out of the path of a horizontally towed net (Harrison, 1967).

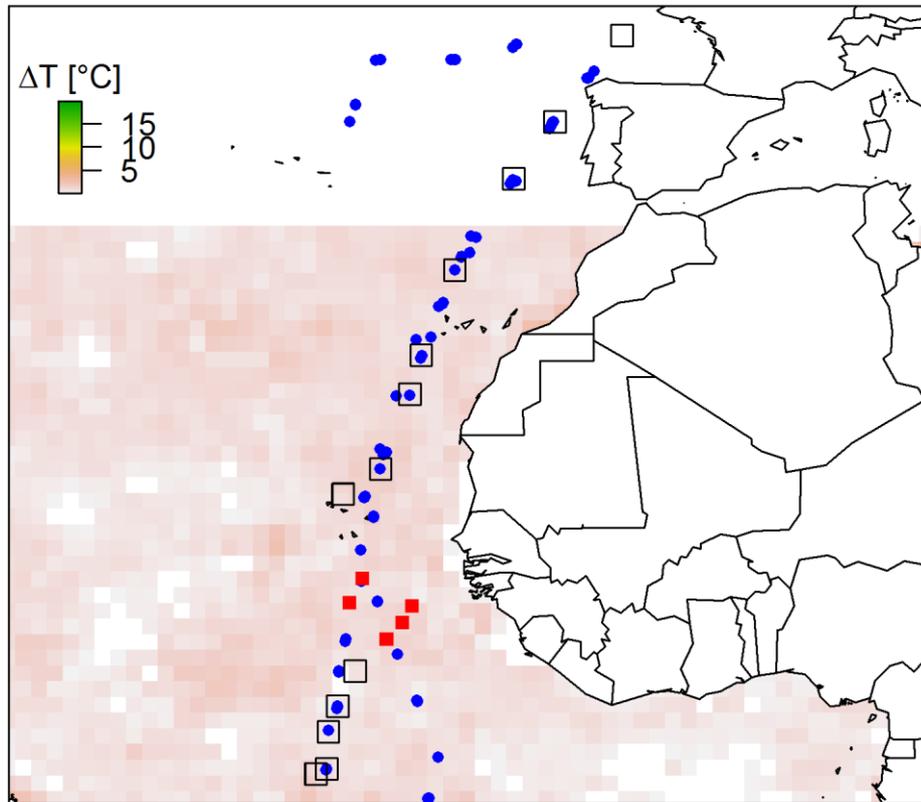


Figure 8: Changes in water temperature 1965/74 to 2005/12 and sampling stations 1966-71, 1979 and 2015.

Blue – sampling 1966-71 and 1979 (stations west of Bay of Biscay), black – sampling stations in 2015, red – OMZ stations 2015. Changes in water temperature calculated from World Ocean Atlas data for the upper 100 m (<https://www.nodc.noaa.gov/OC5/woa13/>).

In this study we compare samples from two periods, i.e. 1966-1979 and 2015. Although aligning fishing locations in 2015 to historical sampling locations (Fig. 8) and applying a similar gear, the samples nevertheless differ in terms of gear, month of sampling, changes in the environment, and trawling operations. The basic rationale for this study is that a systematic sampling bias in terms of catchability would be evident by means of correlated changes between size parameters and gear. In turn, environmental changes between periods would cause correlated changes with other factors but gear, and in relation to the environmental gradient. On community level, body-shape and swimming behavior as traits are applied in 3 regions in the eastern Atlantic, i.e. tropical, subtropical and temperate. At species level, an analysis of size ranges and cohort structure is undertaken in 2 regions due to data availability, i.e. tropics and subtropics. Whereas sizes depend on growth and thus

could depend on the time of sampling, cohort structure is assumed to present a qualitative measure of population structure less sensitive to time of sampling. The potential bias in terms of behavioural traits is investigated in that patterns are analysed by partially excluding groups for which Harrison (1967) predicted that they would be proportionally caught in higher numbers in the upward cast of double oblique hauls as compared to horizontal tows, i.e. stomiids, paralepidids, and anguilliform species. Stomiidae and Anguilliformes entangle easily in the forenet and could not be assigned to catching depths in the 2015 survey, while were collected and assigned to the catch in 1966-79.

To investigate changes along an environmental gradient, a further regional comparison is undertaken for the tropical region and the East Atlantic oxygen minimum zone (OMZ), which was also sampled in 2015 during the same cruise. Size ranges obtained with a smaller trawl from the same year and almost the same Atlantic region are acquired to see whether the chosen methodology responds to changes in gear size (see (Olivar *et al.*, 2017)).

Changes in the environment are evident in terms of an increase in sea temperature of the upper 100 m layer (Fig. 1), and an increase of the oxygen minimum zone in connection with the coastal upwelling in the eastern Tropical Atlantic (Stramma *et al.*, 2008). In our study, minimum oxygen concentrations of ca 40 μmol per litre were measured (0.9 ml/l), which according to Ekau *et al.* (2010) meet criteria for hypoxic conditions of <60 μmol . Theory predicts that warming will negatively affect growth by constrained uptake of oxygen (see(Pörtner and Peck, 2010; Cheung *et al.*, 2012)), so that OMZ conditions and climate change should yield similar effects. Warming in the sea is enhanced at higher latitudes visible by means of a northerly shift in surface isotherms since 1960, although variability is the range of the last 150 years ((Hobson *et al.*, 2008), Fig 3b in (Keenlyside and Latif, 2008)). This long-term variability is linked to multidecadal variability (MDV) in the Atlantic with a period length of 50-80 yrs (Keenlyside and Latif, 2008; Polyakov *et al.*, 2010). During the present positive MDV phase trade winds were enhanced (Polyakov *et al.*, 2010) with likely effects on the coastal wind-driven upwelling systems. The global trend for ocean warming even may have accelerated since 2000 (Hausfather *et al.*, 2017). Increased SST could have a confounding effect on the analysis of size ranges, which is discussed.

Material and Methods

Sampling with large pelagic trawls

Two data sets were employed, comprising 18266 length records from 1966-1979 and 15500 records from 2015 for an area from the equator to the Bay of Biscay and delimited by 25.96 °W longitude. Historical survey design and the application of large commercial trawls were mimicked in 2015 (Fig.7). The 1966-1979 samples were collected from January to May during trans-Atlantic cruises of the FRV "Walther Herwig", while the 2015 sampling was undertaken in March and April with FRV "Walther Herwig III". In 1966-79, a commercial Engel MT 1600 trawl was deployed (Table 3). Gjoesaeter and Kawaguchi (1980) assume that this net has an effective mouth opening of 300 m², given that fishes are able to escape through the large meshes in the forenet. To avoid contamination, nets were retrieved very speedily (Krefft, 1976). Usually, vessel speed was reduced to 1.5 kn during retrieval (Krefft, 1967). Sampling was carried out as double oblique haul. According to fishing protocols, for a mesopelagic haul (500 m catching depth) lowering and retrieval time took each up to

Gear feature	1966 - 1979	2015
Type of net	Engel Midwater trawl	Engel 'Aal'-trawl
Size at front	1600 meshes by 20 cm stretched mesh size	260 meshes by 180 cm stretched mesh size
Opening	20*30 m (height depending on trawling speed, ~15 m trawled at 4-4.5 kn)	20*30 m
Operation	Double oblique tows	Horizontal tows when used with multiple opening-closing device
Codend mesh size	10 mm	20 mm
Length	120 m	150 m with multiple opening-closing device*
Rigging	2 doors, frontweights and headline floats	2 doors, frontweights and headline floats, additional floats at multiple opening-closing device
Headrope/Bottomline	70 m / 78 m	73.8 m / 73.8 m
Trawling speed	2.5-3.5 kn	2.8 – 3.3 kn

* (Engås *et al.*, 1997)

Table 3 : Gear characteristics

20 and 40 min. After retrieval, the forenet area was carefully sampled by hand. Sampling duration at designated depth was 30 minutes.

In 2015, a so-called "Aal"-trawl was deployed, equipped with a multiple closing device. with 3 net bags. Additionally, a 1 m catch retainer was inserted with a mesh size of 1.8 mm (see British Columbia midwater trawl modification (Harrison, 1967)). The gear was lowered to the respective designated depth with open codend before a net bag was opened for 30 minutes. Tows were done horizontally. Specimens from the forenet were collected on deck, but not assigned to one of the 3 net samples.

In accordance with an analysis of fish larvae from the 2015 cruise (Dove, 2017), data were assigned to 3 broader biogeographical regions, i.e. tropics (Eq. - 12°N to avoid mixture with OMZ region), subtropics (19° - 40°N) and temperate (>40°N). All samples within a geographical region were pooled (see Olivar *et al.* (2017)). For historical sampling, only samples shallower than 800 m were included in the analysis.

OMZ data

Additional data comprising 5380 length measurements from 2015 sampled in OMZ locations (Fig. 7) were analysed separately from the tropical data because of the significant change in OMZ conditions since the 1960's (see (Stramma *et al.*, 2008)).

Processing of length data

Length data were binned to 5 mm length classes. Five types of length measurements in historical and 2015 data sets were applied, all adjusted to standard length (SL, in mm): 'fd' (frequency distribution), 'min-max' (minimum and maximum sizes indicated), 'rge' (unmeasured specimens for which numbers need to be raised to either 'fd' or 'min-max' distributions), 'unm' (unmeasured), 'fix' (single measurements). To analyse length distributions at species level, raised 'fd'- were combined with 'fix'- measurements, comprising 15577 and 12933 records for these two categories in 1966-79 and 2015 resp. In the historical data set, the following numbers were available by month and year: 1966 (May: 2439), 1968 (January: 5205, February: 1450,) 1971 (April: 4078), 1979 (May: 2405). To analyse length frequency distributions at community level, raised fd, fix, and raised min-max and unm-records were applied. For min-max measurements, the range between minimum and maximum was evenly split into 10 length values. This uniform distribution was raised by a factor corresponding to the number of 'rge' specimens for this species. For 'unm' specimens, average abundance weighted mean length by species was applied, in the first place from the respective period and regional outline. With no match, both periods were pooled and further historical data set records from the entire North Atlantic were acquired to obtain mean lengths.

In the data records, 'unm' applied in particular to species groups that were originally measured and determined but subsequently redetermined without remeasuring lengths or indicating which individuals were taken out of the sample, for instance in some cases of melamphids or the myctophid congeners *Hygophum macrochir*/*H. taaningii* and *Ceratoscopelus warmingii*/*C. maderensis*.

Association tests

Changes in maximum size, minimum size and in cohort structure (changes in dominance for certain cohorts) were analysed in terms of their association with significant changes in length frequency distributions, time period (historical or 2015), region or in combination. Further, the effect of month of sampling was investigated for two reference periods in the historical sampling, i.e. months February and April (Feb-Apr) versus months January to May (Jan-May), in relation to the 2015 sampling. Association was tested with the χ^2 measure of association for one factor cases or Fisher's exact test for contingency tables. Fisher's exact test accepts zero cell frequencies (Zar, 1996). The null hypothesis H_0 was uniform probability.

For analysis at species level, historical data from 1966-71 are applied, whereas for community level analysis, further data from 1979 are used, which only refer to the temperate zone.

Testing for differences in species length frequency distributions

The Cramer-von Mises two-sample test is one of the best-known distribution-free two-sample tests and more accurate than the Kolmogorov-Smirnov test (Anderson, 1962). The test is based on the difference between two empirical distributions function (EDF) $F(\cdot)$ and $G(\cdot)$ of two samples N, M :

$$\omega^2 = \sum_i (F_N(x_i) - G_M(x_i))^2$$

The Cramer-von Mises test (CvM) is as EDF test insensitive to changes in abundance in N, M but not to change in distribution parameters. The frequency distributions of the test static is obtained by means of a permutation test (Syrjala, 2010), in this study based on 500 permutations on bootstrap samples, each consisting of 200 draws, i.e. 100 for either category N, M , and sampled with replacement. A minimum of 20 original records for either N, M was considered sufficient to run the test.

Differences in community length frequency distributions

Following the rationale of Heino et al. (2012), catchability q at length class l between two sampling groups i, j can be described as :

$$C_{i,l} = q_l C_{j,l}$$

Assuming log-normal errors and standardising to catch proportions x in terms of abundance shows that the log difference is related to the Aitchison distance statistic d_A for proportions. The Aitchison static d_A is the average of the sum of n elements of length class l applying the log-ratio transformation (Aitchison et al., 2000):

$$d_A = \frac{1}{n} \sum_n (\log \frac{x_{i,l}}{g(x_i)} - \log \frac{x_{j,l}}{g(x_j)})^2)^{\frac{1}{2}},$$

where $g(\cdot)$ is the geometric mean for the distribution of proportions. The log ratio transformation is preferable over the Euclidean distance in that it is invariant in terms of scale (proportions, percentage), selection of subsets and permutation. Opposite to the Aitchison distance, the log difference indicates the direction of change by means of its sign.

Results and Discussion

Species level length frequency distributions

The list of species analysed accounted for 56 % and 28 % of total abundance in 2015 and 1966-1979, resp (Appendix Table 4). Significant changes in length frequency distributions (LFD) between 1966-71 (1979-data not used for this analysis) and 2015 appeared for 18 out of 22 tested combinations considering reference period Feb-Apr of the historical records, and in 20 out 28 cases considering reference period Jan-May (Appendix Table 5, H1a,b). The differences in LFDs between reference

periods Feb-Apr and Jan-May were significantly associated (Appendix, Table 5, H2). There was no regional effect, i.e. no association between regional affiliation (tropics, subtropics) and significant changes in LFDs (Table 5, H3-H4). There was no clear relationship between changes in LFDs and changes in maximum or minimum sizes (Table 5, H5-H8). Changes in cohort structure between 1966-71 and 2015 were not significant (Table 5, H9). In 9 species, younger cohorts increased in dominance, while in 9 cases older cohorts increased. In 2 species, a shift in modal length was observed. For the sternoptychid *Argyropelecus hemigymnus* (subtropics), the myctophid *C. warmingii*, and the phosichthyid *Vinciguerria nimbaria*, younger additional cohorts were found, whereas for *Diretmoides pauciradiatus* considerably larger specimens were indicated (increase of maximum size from 72 to 118 mm). However, a significant association was indicated between region and cohort structure, with the increase in younger cohorts linked to the subtropical region (Table 5, H10).

When considering the OMZ and the tropics in 2015, significant changes along this gradient were evident for LFDs and maximum sizes (Table 5, H11-H12). In 11 out of 14 cases a significant change in LFD was indicated. All species available for the comparison between tropics and OMZ (Appendix Table 6) had a smaller maximum size inside the OMZ. *Ceratoscopelus warmingii* had a maximum size of 69.2 mm in the OMZ as compared to 73 mm in the subtropics and 75.9 mm in the tropics, with a small shift in modal size from 42.5 mm to 37.5 in the OMZ. Although minute differences appeared for some species (i.e. *Lepidophanes guentheri*, 78 mm compared to 77.2 mm), it is noteworthy, that no species showed an increase in maximum size.

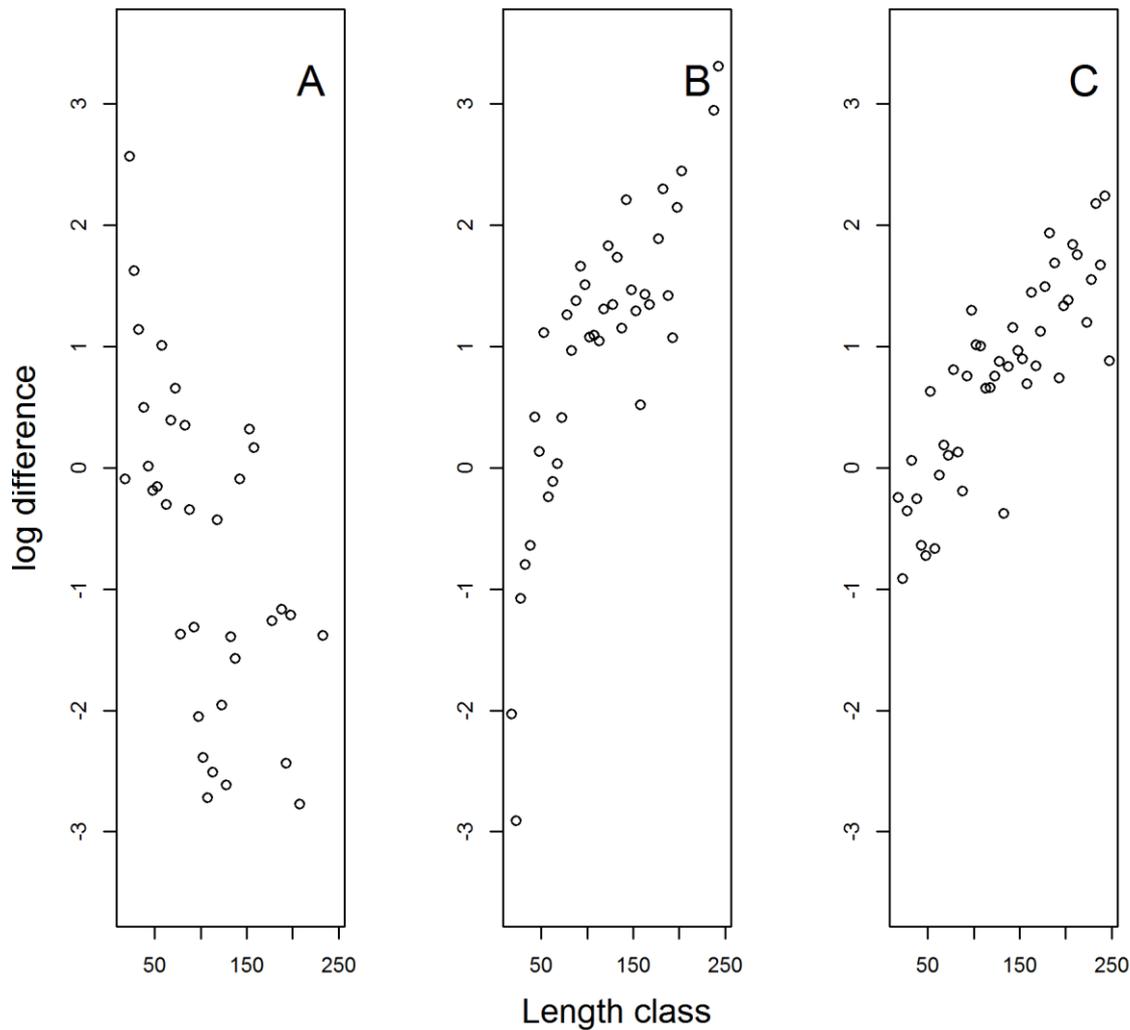


Figure 9: Log difference 1966-71 to 2015 of LFD proportions by length class. A – temperate region (including data from 1979), B- subtropics, C – tropics. Negative difference – proportion in 2015 greater than in 1966-71.

Community level length frequency distributions

Log difference plots for the three regions (Fig. 9) were consistent with patterns after excluding taxa to account for sampling and behavioural bias (Stomiidae, Paralepididae and Anguilliformes). For the subtropics and tropics, it is indicated that smaller length classes increased in relative abundances in 2015, leading to negative log differences. The opposite is indicated for the temperate region, with relative abundances at smaller length classes were smaller in 2015. The high negative log difference values for the subtropics for smaller size classes correspond to the significant change in cohort structure for the subtropics (Table 5, H10). Overall, the distance statistics d_A increases from 0.64 in the tropics to 1.6 in the temperate region, indicating an increase in LFD differences along this gradient (Fig. 10).

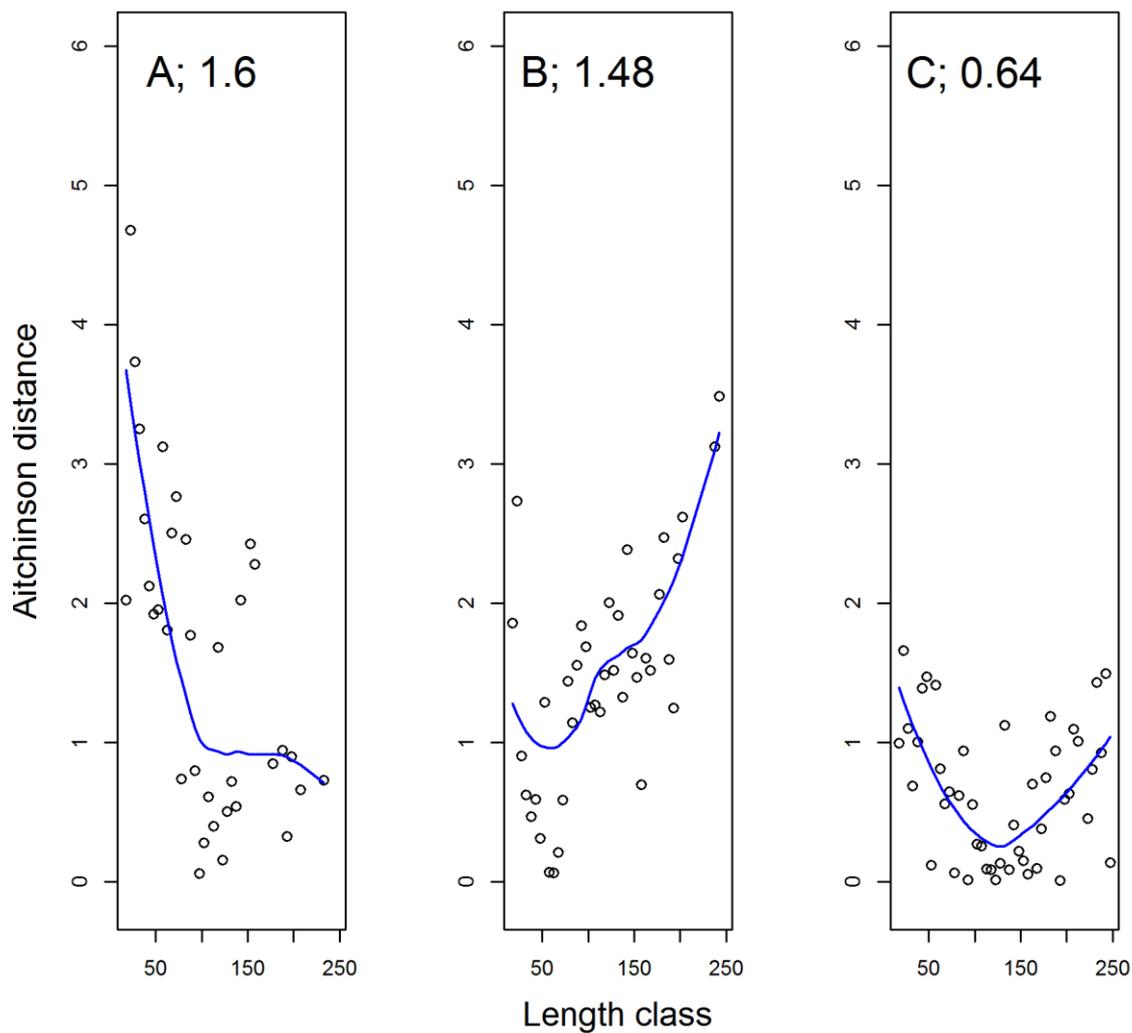


Figure 10: Aitchison difference of LFD proportions by length class and total, indicated by number. A – temperate region (including data from 1979), B- subtropics, C – tropics. Loess fit added.

The comparison with OMZ data by means of the negative slope in the log differences in particular between the 90 mm and 220 mm length class indicates that in the OMZ relative abundances of smaller specimens were higher than in the corresponding tropics. The corresponding d_A was 0.72.

Methological aspects

The main point is whether the chosen approach allows for a sufficient evaluation of changes in catchability. In this study, a paired approach with quasi-synoptic sampling of several gears (Heino *et al.*, 2012) or complementary population modelling (Fraser *et al.*, 2007) was not possible to assess catchability differences. In turn, we developed a complementary framework based on compositional data to account for changes in abundance due to environmental changes.

Significant changes in LFDs and maximum sizes at species level from the tropics towards the OMZ show, that the method is capable of indicating change along an environmental gradient. Comparing with published data further corroborates the chosen methodology (Table 4, column 'Range "Mesopelagos" 2015'). In 12 out of 15 cases maximum sizes in the "Mesopelagos" samples were smaller than in the "Aal"-trawl samples from this study ($\chi^2=5.4$, $df=1$, $p=.02$). It is noteworthy, that "Mesopelagos" samples were pooled including greater depths down to 1000 m than in our study, and further including sub-equatorial habitats. For many mesopelagic species, bigger specimens live in deeper waters (Harrison, 1967). Hence the increases in maximum size for the myctophids *Ceratoscopelus warmingii*, *Myctophum affine* and *Lepidophanes gaussi* could be affected from this area and depth effect. Differences further appear in terms of cohort structure. For *C. warmingii* a significant change was indicated for the tropical region in our study, with an additional younger cohort indicated at length class 22.5 mm SL, and 42.5 mm as the dominating length class in the subtropics. This corresponds to the LFD modal structure for *C. warmingii* in Olivar et al.(2017), where modes were indicated at 19 mm and 40 mm (see Table 3). However, in this study we identified a cohort at 57.5 mm SL in the subtropics, which was not indicated in the "Mesopelagos" catches. Accordingly, modes for *Lepidophanes guentheri* at 52 mm and *Diaphus rafinesquii* at 35 and 55 mm were indicated both in the "Aal"-trawl and "Mesopleagos" samples. In turn, the modes in "Mesopelagos" samples for *Bonapartia pedaliota* at 43 mm and *L. guentheri* at 19 mm could not be found in our study, whereas for *B. pedaliota* a larger mode at 62.5 mm from our study was not indicated in the "Mesopelagos" samples. Despite the fact, that surface migrators and certain small species (e.g. myctophids *Diogenichthys atlanticus*, *Notolychnus valdiviae*, *Gonichthys cocco*) are not well represented in Engel trawls (Hulley and Krefft, 1985), for smaller species not included in the table maximum sizes differed only very little between the "Mesopelagos" and the "Aal"-trawl catches, e.g. *Diogenichthys atlanticus* (24 to 24.3 mm SL), *Benthoosema suborbitale* (Myctophidae, 34 to 33.4 mm SL).

Analysis of potential catchability changes

The framework addressed different sources of uncertainty, i.e. changes in gear, time of sampling, environmental changes and gear operations. Presumed changes in catchability at species level between periods were analyzed in terms of LFDs, size ranges and cohort structure. Cohort structure was analysed by Linkowski (1987) for the myctophid *Electrona risso* in the temperate North Atlantic. Cohort structure was dependent on time of sampling, larger cohorts were missing in daytime catches and nighttime samples were similar with each other. Overall, a significant change in LFDs was indicated for 20 out of 28 combinations (Table 4, reference period Jan-May), but no association was indicated between changes in size ranges and changes in LFDs for either reference period (Table 5, H5-H8). Only for a decrease in maximum size for the reference period Feb-Apr, a marginal value $p=0.07$ was obtained. This value is dependent on a much smaller sample size in the historical reference period Feb-Apr with only 35 % of data records available for analysis from the historical period. Maximum reported sizes for the species considered differ in most cases only little from the maximum sizes indicated in this study for the respective regions (Table 4), indicating that an almost representative size range is sampled in both reference periods and in 2015, so that further considering H2 and H3-H8 (Table 5) the effect of reference periods is considered to be weak.

With regards to gear operations, trawling speed and type of tow must be considered. The probability of capture is positively linked to trawling speed (Pearcy, 1983), but no difference in average trawling speed between 1966-79 and 2015 is indicated (Table 3). In the case of double oblique in the historical period and horizontal tows in 2015, patterns were analyzed at community level with respect to different groups of species subsequently being excluded from the analysis to take account of the hypothesis that behavioral traits could confound the analysis of differently operated trawls (see discussion on swimming behavior in Harrison (1967) and Gjoesaeter and Kawaguchi (1980)). The patterns did not change with the exclusion of vertically orientated species, indicating that the patterns in the size range analysed (20 – 250 mm) were likely not biased from vertically orientated species.

At community level, patterns in the log difference figures were opposite in direction between temperate region and tropics/subtropics, which would not be expected under the assumption of systematic catchability bias between historical and 2015 sampling.

Hence, differences between 1966-79 and 2015 are likely linked to environmental changes rather than to changes in catchability, given that the method is well able to indicate gear and environmental effects as discussed before. This improved knowledge of changes in size structure in mesopelagic ecosystems could be important for ecosystem models based on hydroacoustic data (e.g. (Proud *et al.*, 2017)).

Interpretation of environmental influences

Haedrich (1986) showed that an increase in ocean primary production was correlated with a shift in the biomass size spectrum of mesopelagic fishes, leading to an increase in the number of smaller specimens. In a comparative study on LFDs of the myctophid *Diaphus termophilus* in warm core eddies in the Tasman Sea, Brandt (1981) showed that with increasing water temperature size distributions shifted towards smaller specimens. These in situ findings are in line with theoretical considerations suggesting changes in size as an effect of increasing oxygen demand with increasing water temperatures (e.g. Cheung *et al.*, 2012). The results of this study may be interpreted in line with these results, indicating that observed changes in community LFDs between OMZ and tropical region were similar to changes between historical and 2015 samples after a period of warming (see Fig. 7), indicating a relative increase in smaller specimens in both cases. This interpretation is supported by the latitudinal change of community LFDs as measured by Aitchison distance d_A , which increased from the tropics to the temperate region. The d_A gradient is in accordance with stronger warming at higher latitudes, and the corresponding log difference pattern indicates (Fig. 8/9), that temperate systems respond with a relative increase of larger specimens in 2015, opposite to tropical/subtropical systems. The increase in d_A for the subtropics was correlated with a significant change in cohort structure by means of an increase in dominance of younger cohorts (Table 5, H10).

The difference between the equivocal findings at species level where no association with changes of size parameters of size patterns (only for cohort structure, H10), and the clear patterns at community level may be seen in the way abundance weighting was applied to the community LFDs. For instance, the bathylagid *Bathlagichthys greyae* was much more abundant than the directmid *Diretmus pauciradiatus*, so by abundance weighting the increase of small specimens for *B. greyae* outweighs the increase of large specimens for *D. pauciradiatus*, whereas in the tabulated counting in Table 3

these two species score equally. The differential response by means of cohort structure rather than changes in maximum sizes in the subtropics and tropics can be interpreted in way that mesopelagic fishes by means of their daily vertical migration may be better adapted to strong temperature gradients and thus may be able to find their optimum along this gradient. In case of warming plus decline in oxygen availability, a suite of responses are possible that would lead to a decrease in maximum sizes (Eka *et al.*, 2010): changes in growth due to higher metabolic demands of respiration, avoidance of OMZ regions by larger specimens, and changes in spatial patterns including DVM so they are not captured. Differences in DVM characteristics are evident for the tropical Atlantic and the OMZ region, indicating increased fluxes in the latter as indicated by hydroacoustics (Klevjer *et al.*, 2016). Regarding a possible long-term trend, these increased fluxes could be linked to increased productivity, given that trade winds have increased (Polyakov *et al.*, 2010) likely influencing coastal upwelling.

YFT tagging studies

Tagging approach

Results from the tagging experiments are only shown as far as they concern habitat preferences, which in turn are important to assess the habitat correlations in the preceding chapters. Other results such as indicating predatory events and behavioural differences of YFT hunting in association with dolphins will be presented in due time.

The hypothesis for the tagging studies was that habitat quality changes would affect water temperature and oxygen contents, and that this change in habitat quality could trigger a shift in spatial distributions of the tuna species, i.e. yellowfin (YFT) and bigeye tuna (BET), in Cabo Verde with subsequent effects for the fisheries. The aim of WP 12-2 is to investigate habitat use these species.

Stramma *et al* (2012) show expanding Oxygen Minimum Zones (OMZs) in the eastern tropical seas. Possible consequences of OMZ expansion to the marine ecosystem include loss of vertical habitat for high oxygen demand tropical big pelagic fishes like tunas and the associated increased risk of overfishing of these species by surface fishing gear.

All fish were captured by means of hand line fishing and of rod fishing, applying circle hooks or J-hooks, depending on the fishermen's experience in using circle hooks. Until August 2017, 5 YFT with sizes >100 cm were successfully tagged. However, only under-sized BET were caught. Reference data for length-age in ICCAT reports (Anonymous, 2011) indicate sizes for 0 group YFT from 42 to 53 and for age group 1 from 60 to 89 cm. Age group 2 has sizes from 100 to 128 cm, so that all tagged YFT were age 2.

Results and discussion

Consistent for five tagged YFT, swimming depth rarely was deeper than 80 m (Fig. 11). No deep dives were undertaken. SF1 was deployed south of the island Maio, Cabo Verde. The specimen swam north along the east coast of Maio and then turned west between Maio and Boa Vista.

The epipelagic swimming characteristics of YFT augment the interpretation of surface features associated with wind stirring and surface cooling which were indicated as significant factors in the analysis of CPUE and spatial distribution of catches.

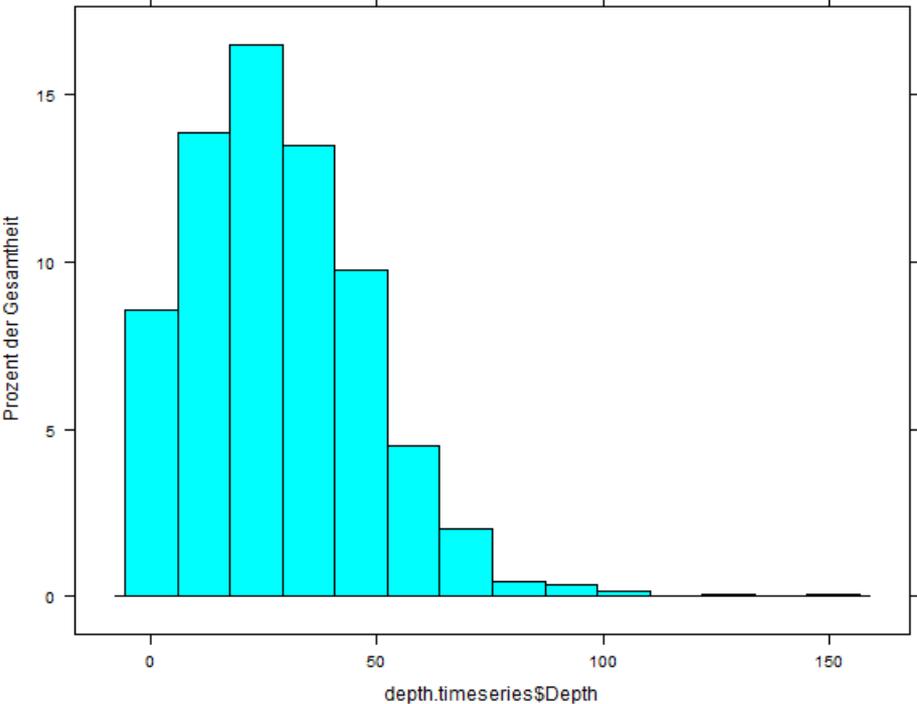


Figure 11: Depth profile of YFT SF1 swimming.

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Appendix

Table 4: Comparison of length frequency distributions by species in selected ocean regions from 1966-71 to 2015, corresponding size ranges and changes in population structure with Engel MT 1600 and "Aal"-net and literature data.

Comparisons undertaken for two historical reference periods, Feb-Apr and Jan-May. Additionally size ranges from 2015 indicated obtained with the "Mesopelagos" net (Olivar *et al.*, 2017), modal lengths in parentheses. These samples were captured with a so-called "Mesopelagos" net (opening 5 * 7 m, 5 separately closed codends). "Mesopelagos" size parameters were presented from pooled samples along a transect from 15°S to 30 °N in the tropical and subtropical Atlantic, including all samples down to 1000 m catching depth. The "Mesopelagos"-net had 30 mm meshes in the forenet and 4 mm meshes in the codend. Cvm – Cramér-von Mises test. Reported maximum size based on Gibbs (1964), Baird (1971), Nafpaktitis et al. (1977), Hulley (1981) and Whitehead et al. (1984).

FAMILY	SPECIES	COMPARISON 1966/71 – 2015 FOR REGION	REFERENCE PERIOD FEB- APR CVM SIGNIFICANCE	REFERENCE PERIOD FEB- APR SIZE RANGE [MM]	REFERENCE PERIOD JAN- MAY CVM SIGNIFICANCE	REFERENCE PERIOD JAN- MAY SIZE RANGE [MM]	SIZE RANGE [MM]	CHANGES IN LFD CHARACTERISTICS IN 2015	RANGE "MESO- PELAGOS" [MM]	REPORTED MAXIMUM SIZE [MM]
				1966-71		1966-71	2015		2015	
Bathylagidae	<i>Bathylagichthys greyae</i>	SUBTROPICS			p>0.95	47 - 147	32 - 135	Increased dominance of younger cohort		160
Diretmidae	<i>Diretmoides pauciradiatus</i>	TROPICS	p>0.95	16 - 72	p>0.95	16 - 72	24.7 - 118.2	Additional older cohort		370
Diretmidae	<i>Diretmus argenteus</i>	TROPICS	p>0.95	12 - 80	p>0.95	12 - 190	24.6 - 98.9	Increased dominance of younger cohort & decline in max. size		125
Gonostomatidae	<i>Bonapartia pedaliota</i>	TROPICS	p>0.95	36 - 77	p>0.95	32 - 77	28 - 78.2	Increased dominance of older cohort	30-70(43)	69
Gonostomatidae	<i>Diplaphos taenia</i>	TROPICS	p>0.95	65 - 130	n.s	46 - 136	55.5 - 147		23-58	276
Gonostomatidae	<i>Gonostoma denudatum</i>	TROPICS	p>0.95	43 - 140	p>0.95	43 - 140	73.2 - 146.3	Increased dominance of older cohort		140
Myctophidae	<i>Ceratoscopelus maderensis</i>	SUBTROPICS			n.s	32 - 81	26 - 69.9			81
Myctophidae	<i>Ceratoscopelus warmingii</i>	SUBTROPICS	p>0.95	37 - 68	n.s	17 - 77	21 - 73			81
Myctophidae	<i>Ceratoscopelus warmingii</i>	TROPICS	p>0.95	20 - 80	p>0.95	20 - 80	16.6 - 75.9	Additional younger cohort	18-82(19,40)	81
Myctophidae	<i>Diaphus rafinesquii</i>	SUBTROPICS	p>0.95	40 - 74	p>0.95	30 - 92	23 - 84	Increased dominance of younger cohort	26-72(35,55)	90
Myctophidae	<i>Electrona risso</i>	TROPICS	p>0.95	21 - 82	p>0.95	21 - 82	36.2 - 84.1	Increased dominance of older cohort		82
Myctophidae	<i>Hygophum macrochir</i>	TROPICS			p>0.95	23 - 54	22.9 - 65	Shift in modal size	12-50	60

Myctophidae	<i>Hygophum taaningi</i>	TROPICS	n.s	25 - 52	n.s	25 - 52	11.7 - 59		14-30	61.2
Myctophidae	<i>Lepidophanes gausi</i>	SUBTROPICS	p>0.95	36 - 45	p>0.95	29 - 47	18 - 51	Additional younger cohort	18-62(19,52)	50
Myctophidae	<i>Lepidophanes guentheri</i>	TROPICS	n.s	34 - 71	n.s	30 - 76	24.9 - 78			78
Myctophidae	<i>Myctophum affine</i>	TROPICS			p>0.95	13 - 47	22.5 - 51	Increased dominance of older cohort	15-72	60
Myctophidae	<i>Nannobranchium isaacsi</i>	TROPICS	p>0.95	36 - 126	p>0.95	36 - 126	53.1 - 158	Additional older cohort		133.4
Myctophidae	<i>Notoscopelus caudispinosus</i>	SUBTROPICS			p>0.95	38 - 130	35 - 140	Shift in modal size		140
Myctophidae	<i>Notoscopelus resplendens</i>	SUBTROPICS	p>0.95	60 - 73	p>0.95	21 - 85	18 - 84	Increased dominance of younger cohort		95
Myctophidae	<i>Notoscopelus resplendens</i>	TROPICS	p>0.95	29 - 86	p>0.95	29 - 91	16.1 - 95.5	Increased dominance of older cohort	18-70(23,35)	95
Phosichthyidae	<i>Vinciguerria nimbaria</i>	SUBTROPICS			p>0.95	25.2 - 50	17 - 42	Additional younger cohort		48
Phosichthyidae	<i>Vinciguerria nimbaria</i>	TROPICS	p>0.95	23 - 48	n.s	21 - 56	18 - 54.5		14-50	48
Sternoptychidae	<i>Argyropelecus affinis</i>	TROPICS	p>0.95	35 - 72	p>0.95	31 - 75	25.6 - 78	Increased dominance of younger cohort	14-61	72
Sternoptychidae	<i>Argyropelecus hemigymnus</i>	SUBTROPICS	p>0.95	17 - 33	p>0.95	12 - 44	18.8 - 39.2	Change in cohort structure : 2 modal lengths instead of 1 with younger cohort increased	12-28	39
Sternoptychidae	<i>Argyropelecus sladeni</i>	TROPICS	p>0.95	15 - 72	p>0.95	15 - 72	19.9 - 83.5	Increased dominance of older cohort	12-40	70
Stomiidae	<i>Astronesthes richardsoni</i>	TROPICS	n.s	26 - 185	n.s	26 - 185	22.9 - 172			145
Stomiidae	<i>Chauliodus sloani</i>	TROPICS	p>0.95	60 - 235	p>0.95	60 - 235	98 - 248.1	Decrease in dominance of older cohort	31-191	>300
Stomiidae	<i>Malacosteus niger</i>	TROPICS	n.s	62 - 175	n.s	38 - 175	100.7 - 155.8		28-108	240

Table 5 Association tests

Both tests are applied against H_0 with a uniform distribution, equivalent to an odds ratio of 1 in Fisher's exact test. For odds ratio values = Inf, the 95% confidence limits was $\gg 1$

Alternative Hypothesis	Test statistics
1966/71 – 2015, tropics and subtropics, reference periods in 1966-71 indicated	
H1a : Differences in LFDs, Feb-Apr	$X^2 = 8.9$, df = 1, p-value = 0.002
H1b : Differences in LFDs, Jan-May	$X^2 = 5.1$, df = 1, p-value = 0.02
H2 : Association between seasons Feb-Apr and Jan-May for significant LFD changes	Odds ratio = Inf, p-value = 0.004
H3 : Association between regions for significant LFD changes, months Feb-Apr	Odds ratio= 0, p-value = 0.53
H4 : Association between regions for significant LFD changes, months Jan-May	Odds ratio=0.62, df = 1, p-value = 1
H5 : Association between significant LFD changes and increases in maximum size, months Feb-Apr	Odds ratio= 13.53, p-value = 0.07
H6 : Association between significant LFD changes and increases in maximum size, months Jan-May	Odds ratio=3.68, p-value = 0.19
H7 : Association between significant LFD changes and decreases in minimum size, months Feb-Apr	Odds ratio=0.43, p-value = 0.61
H8 : Association between significant LFD changes and increases in minimum size, months Jan-May	Odds ratio=0.82, p-value = 1
H9 : Differences in cohort structure, months Jan-May	$X^2 = 0$, df = 1, p-value = 1
H10 : Association between changes in cohort structure and region, months Jan-May	Odds ratio=Inf, p-value =0.009
2015, tropics vs. OMZ	
H11: Differences in LFDs	$X^2 = 4.5$, df = 1, p-value = 0.03
H12: Differences in maximum sizes	$X^2 = 14$, df = 1, p-value = 0.0001
H13: Differences in maximum sizes	$X^2 = 2.5$, df = 1, p-value = 0.11
H14: Differences in cohort structure	$X^2 = 0.09$, df = 1, p-value = 0.76

Table 6 : Comparison of length frequency distributions by species in the tropics and the OMZ region in 2015, corresponding size ranges and changes in populations structure with "Aal"-net..

5%- and 95%-quantile from permutation test and true difference 1966/71-2015 indicated.

FAMILY	SPECIES	REGIONS COMPARED	CVM SIGN. LEVEL	RANGE TROPICS	RANGE OMZ	CHANGES IN LFD CHARACTERISTICS IN OMZ
Diretmidae	<i>Diretmus argenteus</i>	TROPICS-OMZ	p>0.95	24.65 - 98.86	22.3 - 61.8	Decreased dominance in younger cohort
Gonostomatidae	<i>Bonapartia pedaliota</i>	TROPICS-OMZ	p>0.95	28.01 - 78.21	18.1 - 72.5	Increased dominance in older cohort
Gonostomatidae	<i>Diplophos taenia</i>	TROPICS-OMZ	p>0.95	55.52 - 147	48.5 - 116.3	Increased dominance in younger cohort
Gonostomatidae	<i>Gonastoma denudatum</i>	TROPICS-OMZ	n.s	73.24 - 146.34	30 - 145	
Myctophidae	<i>Ceratoscopelus warmingii</i>	TROPICS-OMZ	n.s	16.55 - 75.9	20.9 - 69.2	
Myctophidae	<i>Electrona risso</i>	TROPICS-OMZ	p>0.95	36.2 - 84.12	30 - 80.3	Shifts in modal sizes
Myctophidae	<i>Hygophum macrochir</i>	TROPICS-OMZ	p>0.95	22.92 - 65.03	13.1 - 55.8	Increased dominance in older cohort
Myctophidae	<i>Lepidophanes guentheri</i>	TROPICS-OMZ	p>0.95	24.91 - 78	23.9 - 77.2	Increased dominance in younger cohort
Myctophidae	<i>Nannobranchium isaacsi</i>	TROPICS-OMZ	p>0.95	53.07 - 158	22.7 - 135	Increased dominance in older cohort
Myctophidae	<i>Notoscopelus resplendens</i>	TROPICS-OMZ	p>0.95	16.09 - 95.54	18 - 93.2	Increased dominance in older cohort
Phosichthyidae	<i>Vinciguerria nimbaria</i>	TROPICS-OMZ	p>0.95	18.02 - 54.51	18.6 - 49.6	Increased dominance in older cohort
Sternoptychidae	<i>Argyropelecus affinis</i>	TROPICS-OMZ	n.s	25.6 - 77.96	14.8 - 72.9	
Sternoptychidae	<i>Argyropelecus sladeni</i>	TROPICS-OMZ	p>0.95	19.91 - 83.45	23.2 - 73.2	Increased dominance of younger cohort
Stomiidae	<i>Malacosteus niger</i>	TROPICS-OMZ	p>0.95	100.7 - 155.85	84.3 - 148.6	Increased dominance in younger cohort