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Does trawl fisheries affect the diet of fishes? A stable isotope analysis approach*

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ABSTRACT

Trawling is the main fishing practice worldwide and its ecosystem effects have been raising concern over the past decades. Long-term impacts can be monitored through changes in the trophic structure, and several studies evaluated trophic level (TL) shifts in fish populations between trawled and untrawled environments. However, published results are contrasting. We performed a metanalysis integrating all available studies that evaluated TL shifts in fishes between trawled and untrawled environments and conducted a local study comparing several features of the trophic ecology in two species of fishes. According to the metanalysis, TL does not change significantly with trawling. In contrast, the local study showed higher TLs and broader isotopic niches in the trawled environment. Diet reconstruction indicated a potential consumption of hake, the main discard component, at the trawled environment. All the studies used in the metanalysis were conducted in the Northern Hemisphere, whereas the local study represents the first data available from the Southern Hemisphere. As industrial commercial fisheries in Argentina are relatively recent, it is possible that our data are capturing the initial stage of ecological changes induced by trawling, compared with the historical fisheries located at the Northern Hemisphere.

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Patagonia; trophic position

1. Introduction

Bottom trawling is the dominant fishing gear worldwide [1] and comprises around 20% of global landings [2]. The practice implies ropes, boards, and chains dragged against the benthos, while every organism on its path is captured [3]. Bottom trawling extracts targeted and non-targeted species, generates discards, scraps the sea bottom, and alters the physico-chemical properties of the ground [4]. Ecosystem effects of trawling have been raising concern over the past decades [5]; even though the magnitude of the impact depends on a compromise between the intensity and the ecosystem robustness [6], there are many cases of a fishery collapse in the history of fisheries [7–9].

Bottom scrapping and discard production can increase the availability of food in the short term [10], reducing competition for food in systems that are prey-limited [11]. In

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addition, heavily trawled environments tend to be dominated by scavengers, smaller-bodied soft-bottom species, and species with short generational times [12,13]. As a result, trawling can change the relative abundance of prey for benthic and demersal top predators [14,15]. Over the years, changes in the relative composition of prey assemblages can affect the health and productivity of predator populations [16], leading to declines in the biomass, density, diversity, and size of individuals, and to reductions in food-web connectivity [11,17–20]. As a consequence, trawling can change the trophic structure of a community [21–23], where predator populations are expected to exhibit lower mean trophic level (TL) because of the decline in the TL of their preys or by the regional loss of the maximum sizes.

Accordingly, the Convention on Biological Diversity proposed the Marine Trophic Index as a possible indicator to monitor the sustainability of fisheries. Marine Trophic Index is calculated as the mean TL of fisheries landings [24] but does not account for changes in the size of the species (that might affect the TL), and it is restricted to landed species, which is biased by the target species [25]. Other works applied stable isotope analysis (SIA) to estimate the TL and evaluate possible impacts of trawling on demersal assemblages. SIA emerged as an important tool in trophic studies because it integrates information of large time scales and has proved accuracy on identifying general diet sources [26]. In particular, several studies evaluated TL shifts of demersal fishes between trawled and untrawled environments [27–29]. Despite the prediction by theory, TL between trawled and untrawled environments was reported to increase [19], decrease [30] and remain constant [22]. Such a variety of results was interpreted on the basis of the design of the study [31], the lack of complexity of the altered food webs [29], or ecological constraints [32–34]. More recently, the outreach of ecosystem modifications as a consequence of trawling is being questioned, as many studies demonstrated that at least the extent of trawled areas is significantly smaller than previously suggested [35,36].

To extract a global result, we performed a metaanalysis integrating all available studies that evaluated TL shifts as a possible outcome of trawling. Second, we carried out a local study comparing the trophic ecology of two reef fishes inhabiting trawled and untrawled environments of Northern Patagonia. The trophic ecology of these species was studied using SIA by: (i) comparing TL via the classical equation by Post [37], (ii) assessing the trends of $\delta^{15}\text{N}$ values with body size throughout growth, (iii) analysing the isotopic niche size and overlap, and (iv) estimating the probable contribution of the hake (*Merluccius hubbsi*), the main discard item of the local shrimp fishery, to the diet of both reef fishes.

2. Methods

2.1. Metaanalysis

We conducted a systematic review of empirical publication studies on trawling impact on the TL of fish populations. A systematic review is a structured approach involving four steps: identify the research question, develop a research protocol to explore databases, screen/select/classify results under pre-determined criteria and perform an analysis [38,39]. The search was conducted in April 2018 using Scopus and Google Scholar as

search engines, and the combination of terms ‘trawl*’ OR ‘trawl impacts’ AND ‘stable isotopes’ AND ‘trophic level’ OR ‘trophodynamic’ OR ‘diet’. Twenty works were first obtained. Then a set of criteria rules were applied to select only the studies which: (1) were conducted in marine fishes, (2) were evaluated using $\delta^{15}\text{N}$ values measured during the study, (3) compared between trawled/untrawled environments. The last requirement admitted studies conducted along with trawling intensity (i.e. low trawling intensity vs. high trawling intensity), or in before/after trawling studies. The analysis excluded the results obtained by modelling, using landing records or other TL approximations. The final list, split by species and areas, comprised 31 cases of study (Figure 1).

The metaanalysis was performed applying the random effect model that accounts for the variability between studies and its relative weight (i.e. the number of observations per study) [40]. When different size classes were available in the study, we consistently selected the largest size classes to match the rest of the studies conducted in adults. In before/after studies or of degrees of impact, the extremes (before, minimum impact, vs. later after, maximum impact) were selected as comparative counterparts. The analysis was conducted in R software V3.4.3 with the package ‘metafor’ [41].

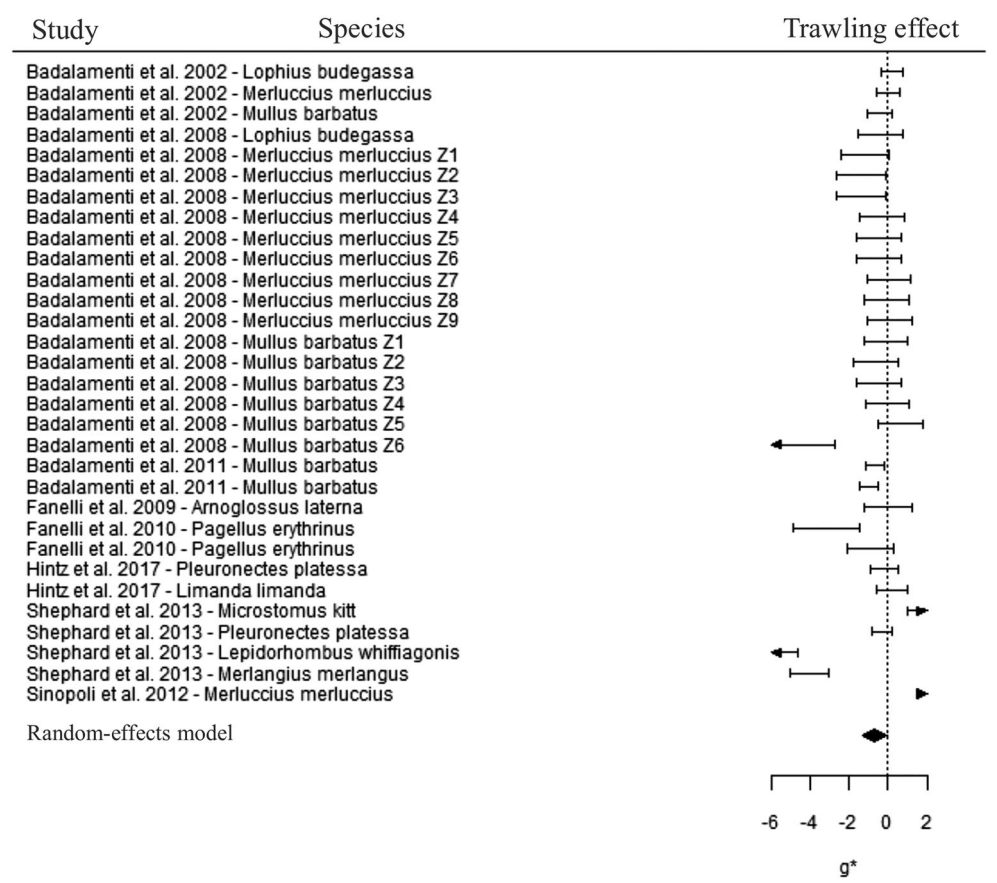


Figure 1. List of cases of study integrated at the metaanalysis with their relative contribution. Global trawling effect (g^*) is represented as a black diamond.

2.2. Local study

2.2.1. Study site

The coastline of North Patagonia, Argentina, is well known by the richness of its natural resources, which represents an attraction for both recreational and extractive human activities [42–45]. It has highly productive waters with a particular abundance of commercially exploited species; like the Argentine red shrimp *Pleoticus muelleri* and the Argentine hake *M. hubbsi*. Also, marine megafauna is abundant: several sea lions' colonies, at least six dolphin species (including the top apex predator *Orcinus orca*), and large reproductive colonies of cormorants, gulls and Magellanic penguins (*Spheniscus magellanicus*) [42,44]. The Argentine red shrimp fishery is the most important crustacean fishery of the southern Atlantic [46]. In North Patagonia operates a coastal fishery of at least 40 bottom trawlers that round up to two fishing trips per day. This coastal fishery contributes to around 25% of the national landings [47]. The shrimp season extends from October through March, and the dominant bycatch species is the juvenile of the hake [48].

2.2.2. Species selection

The Argentine sea bass, *Acanthistius patachonicus*, and the Argentine sandperch, *Pseudoperca semifasciata*, are temperate rocky reef fishes ranging from southern Brazil to northern Patagonia [49]. Both are long-living species that largely exceed 25 years. They present high site fidelity, very specific habitat requirements [50], complex reproduction strategies and long generational times [51]. These features of their life histories make them particularly vulnerable to local impacts, which sets good model species to monitor long-term changes in the environment. Both species are generalist predators with different diet preferences: the sea bass feeds mostly on benthic resources from the adjacent soft bottoms and from the reef. Crabs and Polychaeta were described as the most important prey items, and the hake was reported as a rare [52–54]. The sandperch presents a euriphagous feeding strategy; it consumes mostly pelagic and demersal resources [52,54]. Fishes consumption was described to increase with length, being the hake an important prey item of the larger individuals (68 cm according to [55] and 80 cm according to [56]).

2.2.3. Sample collection

Sampling took place during February and March of 2016 and 2018. The untrawled environment was selected using density maps of the regional marine traffic (www.marinetraffic.com) which was later verified with local fishermen (Figure 2) [47]. Samples were obtained through a longline sport fishing tournament that takes place at the selected untrawled environment. Simultaneously, samples from trawled environments were collected via the on-board observer programme (Figure 2). Sample collection at both sites followed identical protocols. To construct the baseline, zooplankton was collected in research cruises in November of 2016 and 2017 using a double planktonic net (MiniBongo standard net built by the Fishing Gear Program of the National Institute of Fishery Research and Development (INIDEP), 0.3 m diameter, 1.5 m total length, 200 µm mesh size). To reconstruct the diet, we used samples of hake, pelagic and benthic ecotype of *Munida gregaria*, *Agonopsis chiloensis*, *Triathalassothia argentina*, *Riberoclinus eigennmanni* and *Raneya brasiliensis*, *Patagonothoten sp.*, and *Afrodita longicornis*, which were obtained using a small bottom net (a standard 'chicored' or Pilot net built by the Fishing Gear Program of the

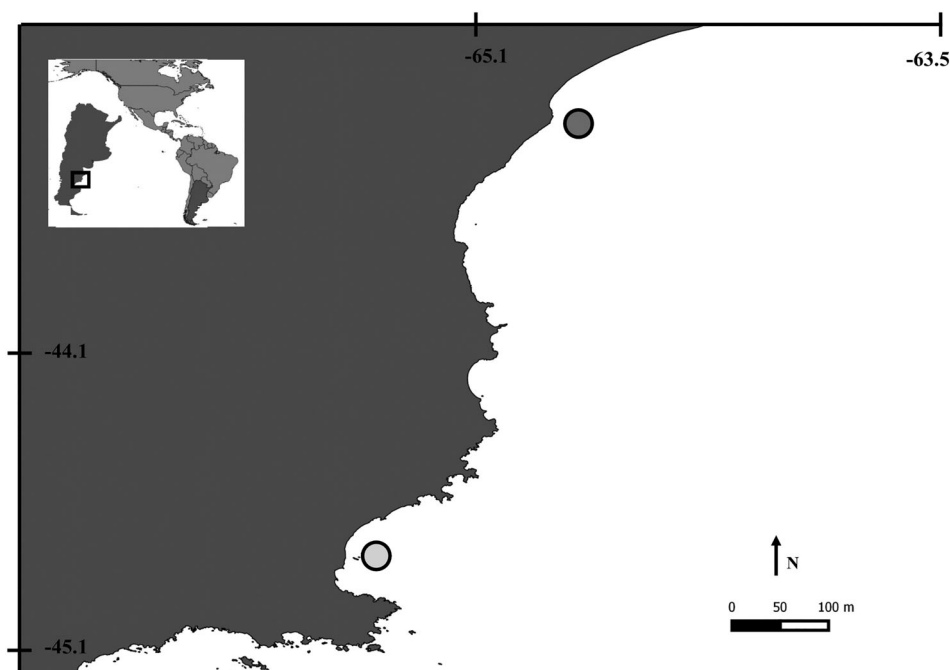


Figure 2. Study site. The dark grey circle indicates the trawled environment location and light grey circle the untrawled environment location.

National Institute of Fishery Research and Development (INIDEP), 5 m long, 0.5 m high, 0.02 m mesh size) in the research cruises mentioned before. Fishes and their potential prey were sampled in the same year in 2016. However, this could not be achieved during the second sampling event because the National Fishing Tournament was suspended in 2017, and the research cruise was cancelled due to funding issues in 2018.

2.2.4. Sample preparation

Fishes were identified, measured, and a fraction of dorsal muscle was extracted. Samples were labelled and immediately frozen. To estimate the TL, we used zooplankton as a baseline organism following [17]. Zooplankton samples were split fresh by size into two subsamples (<300 and >300 μm). The smaller subsample (<300 μm) was assumed to be herbivorous [57,58]. At the laboratory, these subsamples were dried for 72 h at 60°C, converted into a fine powder, and ≈ 1.25 mg per sample were used for stable isotope determination without applying any treatment. Given that C/N ratios of all samples were below 4, values were not corrected for lipid content [59].

Samples were analysed at the Stable Isotopes Center of the University of New Mexico, by elemental analyser continuous flow isotope ratio mass spectrometry that uses a Costech ECS 4010 Elemental Analyser coupled to a ThermoFisher Scientific Delta V Advantage mass spectrometer via a CONFLO IV interface. Isotope ratios were reported using the standard delta (δ) notation relative to V-AIR ($^{15}\text{N}/^{14}\text{N}$) and to Vienna Pee Dee Belemnite (V-PDB; $^{13}\text{C}/^{12}\text{C}$), respectively. Internal standards were run at the beginning, at intervals between samples and at the end of the analysis. Analyses were normalized to the

standards and those were calibrated against soy, tuna and whey protein, casein, IAEA N1, IAEA N2, USGS 42 and USGS 43. Mean SDs of reference materials were 0.03 ‰ and 0.08 ‰ for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values, respectively.

2.2.5. Analysis

Bulk carbon and nitrogen SIA were used to describe and compare the diet between sites in terms of their TL, the size and potential overlap of the isotopic niche, trends in $\delta^{15}\text{N}$ values (as a proxy of TL) along with the size and re-scaled Z-scores' location and distances.

(i) Trophic level comparison

To estimate the TL, we applied the equation by Post [37]:

$$\text{TL}_{\text{consumer}} = \lambda + ((\delta^{15}\text{N}_{\text{consumer}} - \delta^{15}\text{N}_{\text{baseline}})/\Delta^{15}\text{N})$$

being λ the TL of the baseline organism and $\Delta^{15}\text{N}$ the trophic discrimination factor, applying the general value for marine organisms of 3.4. TLs between environments were compared applying the non-parametrical test of Wilcoxon Mann Whitney.

(ii) Trophodynamic trends with body size

Increases in $\delta^{15}\text{N}$ values with body size were previously described for both species from other untrawled environments: predator capacity is supposed to be enhanced with ontogenetical growth [60], reflected here as a more piscivorous diet (higher $\delta^{15}\text{N}$ values). Then, linear regression analysis was applied to test the significance of the relationship between $\delta^{15}\text{N}$ and body size.

(iii) Isotopic niche comparison

Isotopic niche characteristics were studied using standard ellipse principles [61]. Standard ellipses describe the bivariate variability in the isotopic space, and overlap between ellipses was interpreted as the overlap between isotopic niches.

(iv) Diet reconstruction

Mixing models were performed using the R package MixSIAR [62] to calculate the probable diet compositions of both fishes. MixSIAR has the advantage to include fixed and random effects as covariates, and then compare models with or without these effects via deviance information criteria or DIC [63]. The procedure estimates the relative support for multiple models and the importance of the covariates to explain the observed variability in the predators' isotopic composition. Following this approach, we evaluated the existence of dietary differences of both species between trawled and untrawled environments, by comparing models that include or exclude the environment as a fixed factor. In addition, the year of sampling was included as a random factor to take into account possible differences between years (Table 2). If the model that includes the site as a covariate presents a better performance, the importance of fisheries discards as a

Table 2. Comparison of the mixing models fitted using MixSIAR. Values show the deviance information criterion (DIC) and the differences between models (Δ DIC) with different covariables.

	DIC	Δ DIC	DIC	Δ DIC
Covariables	Sandperch		Sea bass	
–	64.3	15.2	127.7	52.4
Environment	49.7	0.3	100.1	24.8
Year	63.4	14.3	114.8	39.5
Environment + Year	49.1	0	75.3	0

Note: Bold values show the selected model for each species. Environment and Year have two factors each: trawled and untrawled and 2016 and 2018, respectively.

food source would be discussed observing the relative contribution of hake to the diet of both species. Prey items were selected and grouped by ecological similarities following diet descriptions based on stomach contents analysis [53–56] and combined with SIA [52]. The mixing model was constructed including four food sources: (a) benthic invertebrates with similar $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values of *M. gregaria* benthic ecotype, *P. muelleri* and *A. longicornis*; (b) benthic fishes with similar composition of *A. chiloensis*, *T. argentina*, *R. eigennmanni* and *R. brasiliensis*; (c) pelagic invertebrates, represented only by *M. gregaria* pelagic ecotype, because it is the principal pelagic prey item of these fishes [50], and (d) discards represented by hakes between 15 and 35 cm of total length, as mean discarded size is 23 cm [64]. Prey had similar $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values in both environments (trawled and untrawled). Thus, food sources were constructed pooling samples of both sites, which is a requisite for model comparison using DIC. The TEF used were $\Delta^{15}\text{N} = 3.4 \pm 0.3$ and $\Delta^{13}\text{C} = 1 \pm 0.3$.

3. Results

3.1. Metanalysis

The metanalysis contrasted 31 cases from eight different studies. Studies were conducted on five species of flatfish: the scald fish *Arnoglossus laterna*, the megrim *Lepidorhombus whiffiagonis*, the dab *Limanda limanda*, the lemon sole *Microstomus kitt*, and the European plaice *Pleuronectes platessa*; as well as five other demersal species: the anglerfish *Lophius budegassa*, the whiting *Merlangius merlangus*, the hake *Merluccius Merluccius*, the red mullet *Mullus barbatus*, and the common pandora *Pagellus erythrinus*. Most of the species were reported to have benthic habitats. Five of the eight studies were conducted in the Mediterranean Sea, while two occurred in the Atlantic and one in the Pacific, all in the Northern Hemisphere. Overall, the global change of TL estimated from $\delta^{15}\text{N}$ values between trawled and untrawled environments resulted in a non-significant difference ($p = .0489$). The globally modelled estimator represented a decrease of 0.64 levels of TL in trawled environments (estimator = -0.64 of TL change [Confidence interval -1.432 and -0.003], Figure 1).

3.2. Local study

A total of 123 fishes were sampled, resulting in around 16 individuals for each treatment (species, site, and year). Body size ranged from 18 to 54 cm of total length for the sea bass

and between 32 and 83 cm of total length for the sandperch (Table 1). These ranges were selected to match the minimum and maximum sizes between sites. Although larger individuals were consistently obtained at the untrawled environment, they were excluded from the analyses.

(i) Trophic level comparison

Mean TL resulted significantly higher in the trawled environment, for both species and for both years ($p < .05$, Table 1).

(ii) Trophodynamic trends with body size

The relationship between $\delta^{15}\text{N}$ values and body size (total length) was only significant for the sandperch at the untrawled environment for both years ($p < .01$, Figure 3, Table 1). These relationships were positive (i.e. there is an increase in TL) but gentle, as the estimated slopes represented a total variation of 0.15 in TL units ($\delta^{15}\text{N} = 0.5\text{‰}$) at almost 40% of total body development.

(iii) Isotopic niche comparison

The comparison of the standard ellipses showed that isotopic niches were slightly larger and less overlapped at the trawled environment for both years (Figure 4, Table 1).

(iv) Diet reconstruction

The diet of both fishes was different between the trawled and the untrawled environments because mixing models including the environment as a covariable explained better the mixing variability (Table 2). The importance of hake as prey increased for the trawled environment (Table 3 and Figure 5). The effect of the year was also important only for the sea bass. The main component of the diet of both fishes was the pelagic ecotype of *M. gregaria*; except for the sea bass in 2016, where the main component was the hake (Figure 5).

Table 1. Sampling information per treatment: Number of samples (N), body size range, trophic level (TL) estimation, area of the corrected standard ellipse, and the slope of the linear regression analysis between body size and $\delta^{15}\text{N}$ values (b : slope magnitude, and p -value). (T) refers to trawled and (UT) untrawled environment.

Species	Environment	Year	N	Size (min–max), (mm)	TL	Ellipse area	$\delta^{15}\text{N}$ vs. Size	
							B	p -value
Sandperch	T	2016	14	183–745	4.23	0.63	1.90E–03	.041
Sandperch	UT	2016	17	320–740	4.20	0.31	2.04E–03	.003
Sandperch	T	2018	14	330–850	4.27	0.2	4.00E–04	.461
Sandperch	UT	2018	15	320–830	4.07	0.19	1.14E–03	.008
Sea bass	T	2016	15	144–533	4.48	0.6	1.00E–04	.951
Sea bass	UT	2016	17	240–530	4.11	0.34	4.30E–05	.972
Sea bass	T	2018	14	240–645	4.17	0.49	0.7e–0.3	.68
Sea bass	UT	2018	14	260–540	3.94	0.47	4.7e–0.4	.81

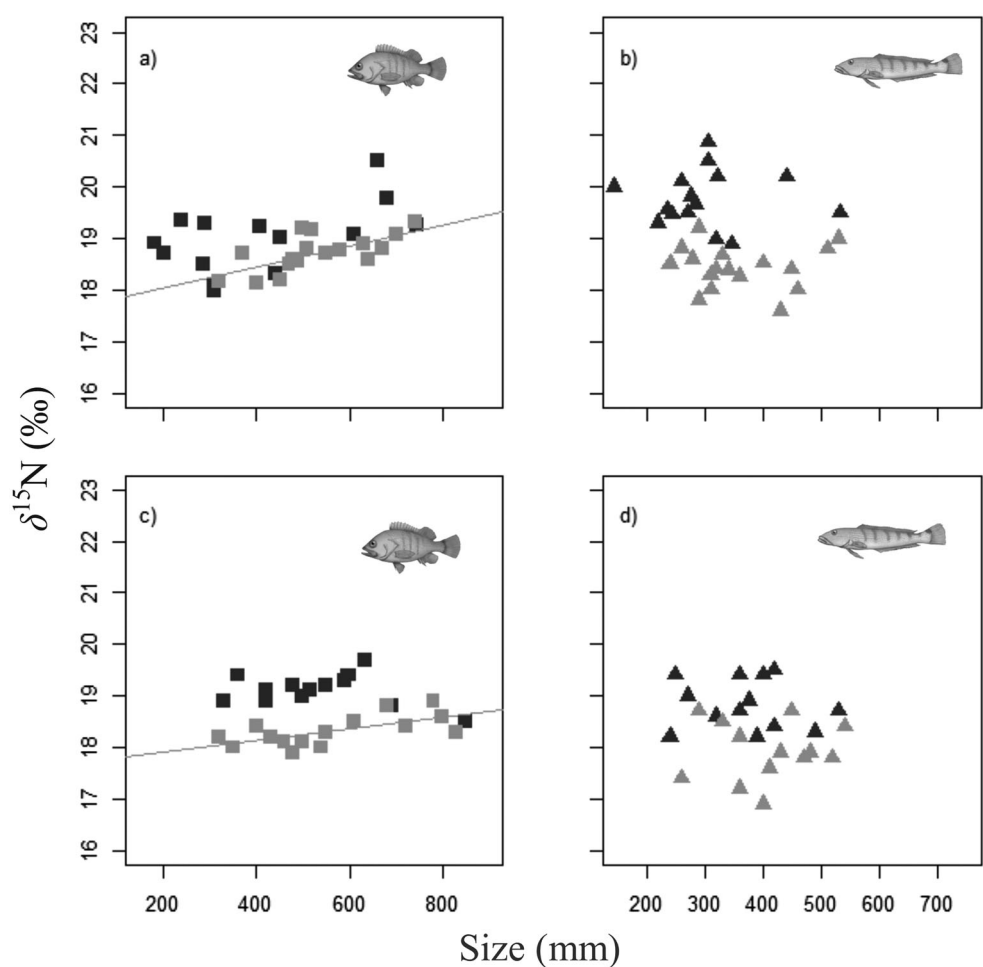


Figure 3. Relationship between $\delta^{15}\text{N}$ and body size (mm) organized by species and year: (a) sandperch 2016, (b) sea bass 2016, (c) sandperch 2018 and (d) sea bass 2018. Sandperch values are represented by squares and sea bass values are represented by diamonds. The individuals from the trawled environment are in dark grey while in light grey from untrawled environments. Significant trends in $\delta^{15}\text{N}$ with body size are shown by a linear function.

Table 3. Mean, standard deviation (SD) and 95% credible interval (CI) of proportional diet contributions of hake to both predators based on the best models.

Treatment	Year	Mean	SD	CI 2.5%	CI 97.5%
<i>Sandperch</i>					
UT	2016 and 2018	0.187	0.105	0.016	0.397
T	2016 and 2018	0.285	0.180	0.008	0.580
<i>Sea bass</i>					
UT	2018	0.098	0.071	0.002	0.267
	2016	0.199	0.129	0.005	0.452
T	2018	0.289	0.202	0.002	0.620
	2016	0.436	0.318	0.002	0.879

Note: T refers to trawled and UT refers to untrawled environment.

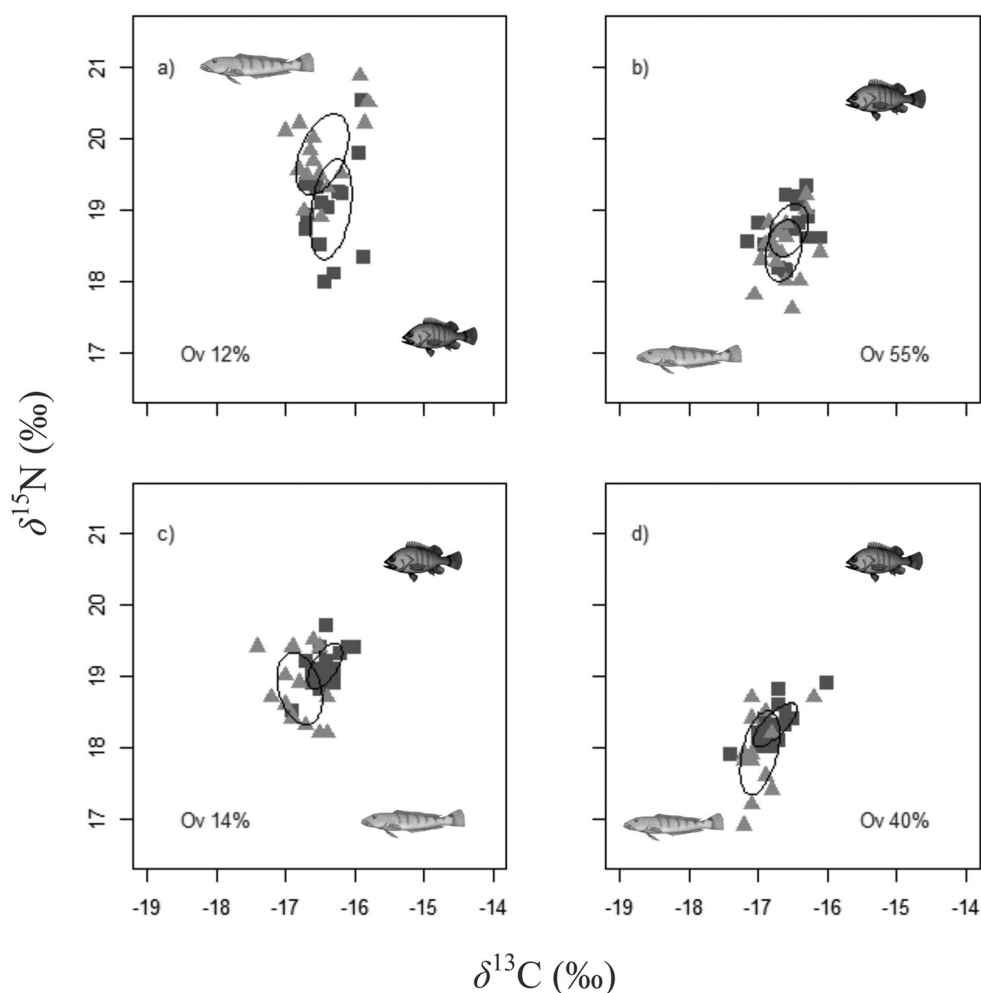


Figure 4. Biplot of $\delta^{13}\text{C}$ vs $\delta^{15}\text{N}$. Captions are organized by treatment: (a) trawled environment 2016, (b) untrawled environment 2016, (c) trawled environment 2018 and (d) untrawled environment 2018. Sea bass values are in light grey triangles and sandperch values in dark grey squares. Each isotopic niche is bordered by its corresponding standard ellipse. 'Ov' shows the percentage of overlap between ellipses.

4. Discussion

4.1. Metanalysis

No significant change was found when integrating all studies regarding TL shifts induced by bottom trawl activity. The direction of the global change in TL was negative but its magnitude was insufficient to consider trawling impacts as an important driving factor. Initial theory foreboded a decrease in TL as a result of trawling impacts. However, bibliography reported increases, decreases and no significant shifts. These results are unlikely to be an artefact of compensating negative and positive search results since the majority of the studies already suggested such outcome (e.g. 'Limited effects of trawling activity on the Mediterranean Sea', [Figure 1](#)).

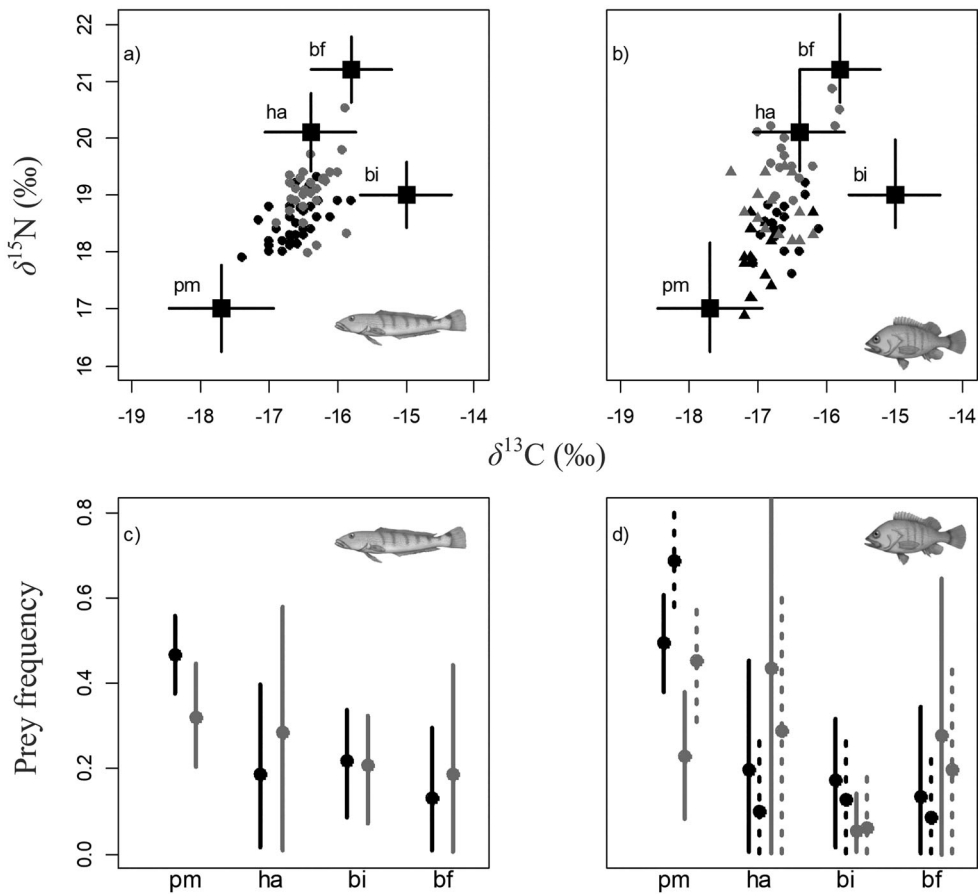


Figure 5. Mixing models data (panels a and b) and distributions of the feasible contributions of the food sources (mean \pm 95% CI percentage in panels c and d) for both species (sandperch in panels a and c and sea bass in panels b and d). In panels (a) and (b), food sources (squares) mean \pm SD $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ were corrected by TEFs ($\Delta^{15}\text{N} = 3.4 \pm 0.3$ and $\Delta^{13}\text{C} = 1 \pm 0.3$). Black symbols and lines correspond to the untrawled site whilst grey correspond to the trawled site. For the sea bass data and results are split by year, solid lines represent the year 2016 whilst dotted lines correspond to the year 2018. Results are based on three MCMC chains (length = 100,000 and burning = 50,000). Pm = *Munida gregaria* pelagic ecotype; ha = hake; bi = benthic invertebrates and bf = benthic fishes.

However, none of the authors denies the existence of trawling impacts in the TL. Arguments on the lack of significance included the limitations of study design, such as (a) insufficient length range of the fishes sampled, given that the higher TLs are reached at the maximum sizes, and those individuals are the most vulnerable to extraction [65], (b) incorrect species selection, applicable to the species whose principal prey are unaltered by trawling activity [33,34], or species with high plasticity on their feeding strategies, which could easily mask potential environment changes [11], or (c) incorrect technique, because they claimed trawling may affect diets but not isotopic pathways [22].

In the local study, we compared individuals at 79% of the maximum length in the sea bass and 63% of the maximum length in the sandperch. Our isotope data revealed a certain level of modifications in feeding strategies and the possible consumption of

preys that are affected by trawling activity (e.g. the hake). Then, our results not only support SIA as a good tracer of trawling disturbance in the ecosystem [33] but also overcame most of the limitations described above.

4.2. Local study

Between the selected trawled and the untrawled environments in Patagonia, trophic features of reef fishes were different, consistently through time and species. At the trawled environment, the TLs were significantly higher for both species, and isotopic niches were broader and less overlapped. Contrary to initial expectations, results suggest that the trawled environment could be offering a slightly different, and possibly broader, set of prey compared to the untrawled environment. Changes on the TL along with the size were only significant for the sandperch at untrawled environment, this concurs with [66] and reflects relative regular supply and availability of prey along with the body development of the fish. The consumption of discarded hakes (the main component of shrimp fisheries bycatch) by reef fishes in the trawled environment is a possible explanation. This is also supported by the mixing models results, where the hake gains importance as a prey item in the trawled environment for both species. We propose the consumed hake comes from discards because the sea bass and the sandperch do not include hake as a common prey item within the studied size ranges. Demersal fishes facing impacts are more likely to switch preys, reflecting the most abundant item available [67], and scavenger habits at trawled environments have been already reported before [68].

An increase in TL at the impacted environment is consistent with fisheries targeting low TL species (the shrimp) and discarding high TL species (hake). Moreover, it is possible that our results are underestimating the consumption of discards, since the natural prey *M. gregaria* is another important discard item of the shrimp fishery [69], and it is impossible to determine its origin. Another phenomenon that could be taken into account to interpret our results is the 'predator release effect' [70]. Considering a prey-limited system, the removal of larger predators (in this case by the fishery), reduces the competition for food, increasing the availability and access to prey for the remaining predators [71]. This effect could lead to an expansion of the trophic niche and/or the consumption-rate [11].

It could be argued that the differences in the trophic features shown in our local study are the result of inherent differences between ecosystems. However, as mentioned before, temperate reef fishes require strict habitat conditions [50]. Reproduction strategies and refugees can only occur in caves, and in order to have caves, fishes can only be found in rocky reef systems. If feeding habits or behaviours are modified at trawled environments (such as larger forage range), alterations are more likely to be a consequence of the human activity rather than of habitat modifications [31]. In addition, main prey items analysed, such as the pelagic and the benthic ecotypes of *M. gregaria* and the hake, are highly mobile species that exhibited the same isotope values in both environments, making the differences in percentages of consumption responsible for differences between trawled vs untrawled areas.

4.3. Metanalysis vs local study

Historical fishery development could be a component of current differences between cases.

The Northern hemisphere has centuries of history of fisheries development [2], in the Mediterranean, for example, there are records of fish consumption dated back to 5000 BC [72]. When stocks in Argentina started to be discovered [46] trawl fisheries in the Mediterranean were already showing signs of overexploitation [73]. Over centuries, ecosystems can adjust their strategies to face impacts [74], and even evolution could shape the interaction between ecosystems and fisheries [75].

Minimal impacts detected on the metanalysis could be a result of combining effects in different directions, such as the released predator effect and a decrease of quality and/or quantity of prey availability in the long term. Thus, the altered environment could present a decrease in predators biomass as well as in prey, as previously suggested by [66].

In the local study, although there was a specific aim to compare individuals of the same size range between environments (in order to avoid confounding factors: differences related to size rather than with the environment), it is still possible that trawled environments could have lost their maximum size classes. For both years and both species, the largest individuals were always captured at the untrawled environment. However, as the capture occurred with different fishing gears, we are incapable to ascertain whether the differences are due to the environment or are biased by the fishing methods. Thus, in case the untrawled environment presents larger individuals than the trawled environment, as in [65], changes on the TL for the local study could have met what was theoretically expected.

In the light of present results, we propose that at least in the early phase of fishery development, if we compare individuals of similar body size between impacted and non-impacted environments, there is a fair chance that prey availability at trawled environments is improved [31], either by the predator release effect, by discard availability or by damaged organisms [66]. Then, if fishes have the ability to vary the diet under impacted conditions, it is possible their trophic resources far from being impoverished are favoured by trawled activity, following a scheme of a mid-scale disturbance.

5. Conclusions

Bottom trawl activity has a small effect on the TL of fishes that do not imply significant and unidirectional changes. There is no evidence to assume a decrease in the TL of fishes as a result of trawling impacts and whether direction the change can take appears to be case-specific. Our study case, although significant, was in the line of the results of the metanalysis, showing subtle TL changes related to trawling. The difference in the significance could be explained by the distinct developing stages between the fisheries; the study case is located in a relatively recent fishery compared to the ones integrated by the metanalysis.

We interpret trawling activity alters the trophic structure of fish communities, but, in the long term, modifications of the environment obscure TL change. Based on this assumption, we propose that at least in the early phase of fishery development, prey availability at trawled environments is improved and opportunistic species could be favoured. But in the long term, the entire system adapts to the new conditions, while changes on TLs are absorbed or masked. A future approach to this question should integrate trophic information of other TLs, like the predator and prey of those fish species, as well as trends of abundance over the years.

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