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Who eats whom: Food webs in marine and brackish ecosystems

Quién se come a quién: Redes alimentarias en ecosistemas marinos y salobres

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ABSTRACT

The objective of the present review was to show a brief panorama of how food webs are built up in nature and realize the impact of heavy metals into the food web. Pointing out the most common stables isotopes used to study the trophodynamics in natural marine and brackish ecosystems. Evidencing primary producers, primary consumers, secondary consumers and tertiary consumers as steps of food web and it is respective carbon and nitrogen stable isotopic firm. We review some evidence of metal poisoning impacting in public and human health, particularly in methyl-mercury chemicals for cadmium and lead species on food webs. This review considered at least 60 scientific papers from around the world and some other papers written in Mexico to produce the present manuscript. Despite good advances on Trophic Ecology, even there is a gap in the knowledge of transfer of heavy metals in Food Webs. Both techniques: Stable Isotopes analysis and stomach content analysis play a key role for the well understanding of trophic dynamics in food webs.

Keywords: Food Web, Carbon, Nitrogen, Isotopes, Heavy Metals.

RESUMEN

El objetivo de esta revisión fue presentar un breve panorama de cómo se construyen las redes tróficas en la naturaleza y comprender el impacto de los metales pesados en ellas. Se destacaron los isótopos estables más comunes utilizados para estudiar la trofodinámica en ecosistemas marinos y salobres naturales. Se identificó al productor primario, al consumidor primario, al consumidor secundario y al consumidor terciario como etapas de la red trófica y sus respectivos isótopos estables de carbono y nitrógeno. Se revisaron algunas evidencias de envenenamiento por metales que impactan la salud pública y humana, particularmente en la presencia de metilmercurio en especies de cadmio y plomo en las redes tróficas. Esta revisión consideró al menos 60 artículos científicos de todo el mundo y algunos otros escritos en México para producir este manuscrito. A pesar del avance en ecología trófica, aún existe una brecha en el conocimiento sobre la transferencia de metales pesados en las redes tróficas. Ambas técnicas, el análisis de isótopos estables y el análisis del contenido estomacal, desempeñan un papel clave para comprender la dinámica trófica en las redes tróficas.

Palabras clave: Red alimentaria, carbono, nitrógeno, isótopos, metales pesados

INTRODUCTION

Remembering our science classes on elementary school, teachers taught us about how animals are involved into a food web, i.e. Primary producers (green plants: phytoplankton), primary consumers (snails, crabs, worms), Third consumers (birds) and fourth consumers (humans), and explained us the fact of who eats whom in the simplest way. In this elemental view, teachers explained how the energy is transferred to upper predators. However, this vision is not well integrated due to ecological complexity about and how species obtain its food according to predatory guild (Feeding habits).

Both, plants and animals must obtain their food for survival. Green plants and phytoplankton are well known for producing their own food using sun, water and carbon dioxide from atmosphere and nutrients in a biochemical process called Photosynthesis (Bassham et al., 1950)**.** For this reason, plants and phytoplankton are labeled as Primary producers. For the other hand, organisms which do not create their own food and must eat green plants or animals (preys), are called consumers (Polis et al., 1997). Animals which feed on plants exclusively are called herbivores (Kendall et al., 2009) and carnivores are those animals which feed on other animals (preys) (Polis et al., 1997). Finally, animals which feed on plants and animals belong to omnivorous feeding habits (González-Bergonzoni et al., 2012) Theres is a particular feeding guild: decomposer animals feed on dead organisms or organic wastes from the upper layers becoming its food for survival (Haimi, 2008).

I. Basics on Ecological Hierarchy:

On nature, phytoplankton is the primary producer and zooplankton feed on phytoplankton and decomposer (bacteria) feed on both: phytoplankton and zooplankton. In this way this ecological-trophic relationship is named Food chain (Pimm et al., 1991). Wherein the transferring of energy is in one ascending way; from the base of food web to upper trophic levels or top predator (Pimm et al., 1991, Jara-Marini et al., 2009, Soto-Jiménez et al., 2011).

The simplest vision of a food web in nature is composed by, primary produces such phytoplankton, green plants, seston, detritus which transfer the chemistry energy to primary consumers: zooplankton, bivalves, and snails. The transfer of nutrients (carbon and nitrogen) is a vector for pollutants to access to food web at same time as predator feed on preys. This trophodynamic is evidence in all the upper predators sit on the food web. Carbon, Nitrogen, Oxygen, and Hydrogen are essential elements to support live in the ocean and nutrition requirements by predator are satiated predating from small preys in the food web. This simple way to explain the food web is evidenced in Fig.1. Showing Who eats whom.

However, Ecology in food web has developed explanations on the way of how nutrients are transfer not only in a one ascending way. Zetina-Rejón et al., (2003) explains deeply in his paper the trophic relationships among species, involving benthic and pelagic species whose interact in the food web, and subsequently how is energy transfer to bottom chain to pelagic food web. Omnivore species are ubiquitous due are present in both benthic and pelagic food web apporting nutrients and dissolved particles to water column and settling down to bottoms wherein other species are supported by this waste natural budget.

For the other hand, marine and brackish environments food webs are made up at least 2 food chains (i.e. benthic and pelagic food chain) wherein trophodynamics interactions are even more complex (Mendoza-Carranza et al., 2016, Soto-Jiménez et al., 2011, Muro-Torres et al., 2019).

Therefore, food webs are composed of interconnecting different food chains (Zetina-Rejón et al., 2003). Most communities include various populations of producer organisms which are eaten by any number of consumer populations (Mendoza-Carranza et al., 2016). The crabs, for instance, are consumers as well as decomposers. Crabs will eat dead or living organisms. A secondary consumer may also eat any number of primary consumers or producers (Campbell et al., 2021).

II. How is energy transferred to a food web?

Nutrients are transferred in a food web by photosynthetic process, predation, or grazing on green plants or detritus. (Pimm et al., 1991). At the same time, pollutants are transferring ad or absorbed form into the diets for predator (Wang, 2002). It is well documented transfer of nutrient and pollutants in food webs, for instance, biomagnification of mercury (Hg) (Liu et al., 2019, Jara-Marini et al., 2011, Chen et al., 2016, Valladolid-Garnica et al., 2023, Li et al., 2024) or Biodilution of Lead (Pb) in artificial and natural Food chain. (Cui et al., 2011, Soto-Jiménez et al, 2011, Chen et al., 2016, Ga et al., 2021, Hu et al., 2021, Liu et al., 2022, Reyes-Márquez et al., 2022, Zheng et al., 2023, Li, et al., 2024).

Understanding the trophic dynamic in food web is required to define the trophic position of a living organism. The trophic position refers to how predators obtain their energy in the ecological hierarchy (Post, 2002). Trophic position #1 belongs to primary producers and according to stomach content analysis and stables isotopes it is possible to locate the predator species in the food web (Post, 2002).

In a food web, the energy is transferred from the base of the carbon and nitrogen sources to upper trophic levels, and not only in a unidirectional way, according to feeding habit this energy it may be imported to other food chain (pelagic chain) or to a bottom chain and vice versa, producing the benefit of importation and exportation of nutrients (Bottom-up and Top- Down effect) (Vidal & Murphy 2018).

In this ecological hierarchy, the energy is lost in each trophic level in two forms: first by producing heat and growth, and second, by digestion of the food.

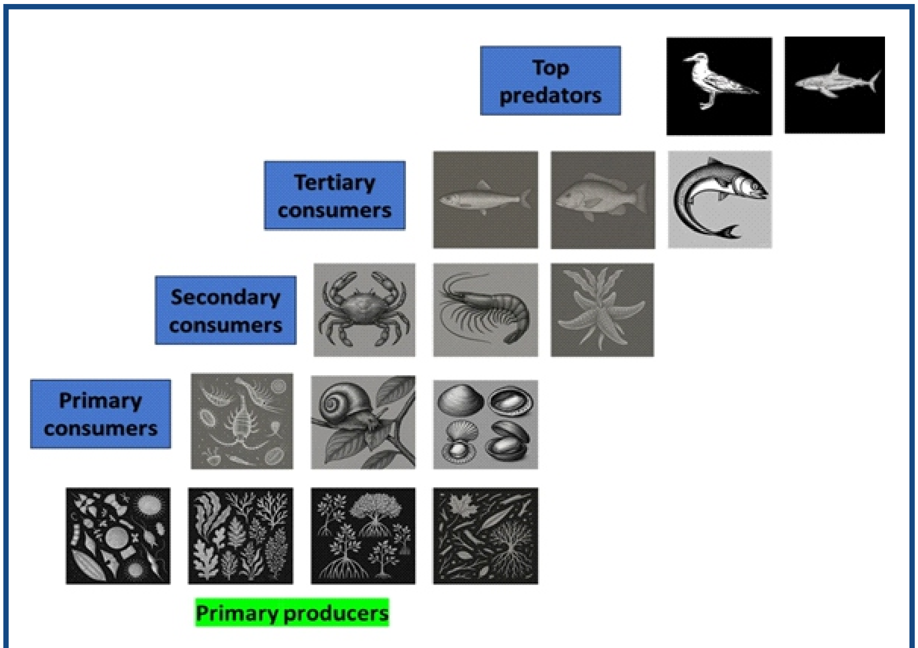

Fig. 1. The simplest vision of a food web that teachers taught us in our childhood.

Past decades research focus on digestion rates in some organisms; (it is time for complete degradation by stomach acids), assimilation of nutrients and evacuation rates to understand the trophic transfer in aquatic ecosystems (Wang, 2002). Despite good efforts, not all rates are the same for the rest of organisms and discrepancies are observed by size, feeding habitat, gonadal development, and age in species. It is worth noting that not only nutrients and energy flow through trophic level in food web.

Some pollutants act as opportunist agents taking the same route of nutrients transferring trough food webs occasioning deleterious effects in upper predators including in humans. It is well documented in Zebrafish effects as oxidative stress, tissues swelling and kidney disruption due to heavy metals included in diets (Bhagat et al., 2020).

Some terms such as Bioconcentration, bioaccumulation, biodilution and biomagnification are associated with trophic transfer in food webs (see Glossary), and refers to concentrate pollutant from abiotic fraction: sediment and water, or predating some preys. It has been reported some events of biomagnification affecting human health (biomagnification of Hg) (Harada, 1995, Chen et al., 2016, Jara-Marini et al., 2011, Yokoyama, 2018, Liu, et al., 2019, Wang 2002, Li et al., 2024) and in better scenarios biodilution or reduction in the concentration of contaminants trough food web (Soto-Jiménez et al., 2011, Ga et al., 2021, Hu et al., 2021, Liu et al., 2022, Reyes-Márquez et al., 2022, Zheng et al., 2023, Li et al., 2024).

III. Case of Studies by Biomagnification of methyl Mercury and Cadmium poisoning

There is bruising evidence of pollutants biomagnification in food webs (Harada 1995, Chen et al., 2002, Yokoyama, 2018, Liu, et al., 2019, Jara-Marini et al., 2011, Wang 2002, Li et al., 2024).

However just a few have documented the impact on human health. A sadness case was in Minamata Japan, wherein Chisso corporations produced acetaldehyde compounds and spilled waste effluents enriched of methylmercury to bay. Plants, crabs, snails, and fish were contaminated through the food web and reached humans (apex predators) by ingesting these kind of polluted protein sources (Harada, 1995, Yokoyama, 2018). Being Methyl mercury is the most commonly chemical form to be biomagnified in food web (Bloom 1992, Jara-Marini et al 2011).

Some toxic effects by Hg poisoning were: convulsions, salivating, difficulty walking, speech problems, fetal mortality, coma and serious affection in central nervous system (Yokoyama, 2018).

Early year, Iraq import seed polluted by mercury and as consequence 500 persons passed away at least and 6,500 went into hospital with similar symptoms by Hg poisoning (Jernelöv, 1976).

Another case of study by biomagnification of Cd in nature was the Itai-itai disease, was observed in patient were expose to Cd enrichment rice, and some toxic effects were osteomalacia and osteoporosis and cancer (Friber et al., 1971). The disruption in Ca metabolism caused painful fractures accompanied by severe bone pain and renal tubular disfunction. (Friber et al., 1971). Similarly, Cd poisoning was documented by Aoshima (2016) with similar symptoms in intoxicated patients.

Recently on December 1999, 410 patients were officially diagnosed or suspected of having Itai-itai disease (Friber et al., 1971, Nogawa, 1996, Aoshima, 2012) Since then, 380 patients have died of the condition; 85 of these patients underwent autopsies performed in Toyama University Hospital (Kitagawa, 2002). As recently as 2000, 20 new cases (1 man and 19 women) were officially recognized by the local government of Toyama. (Aoshima, 2012) These cases reflect a large Cd body burden originated from past environmental Cd exposure by the contaminated Jinzu River in Toyama, Japan (Nishijo et al., 2017).

For these experiences, it is very important to know how food webs are built up, and which species are involved in, and determinate the path of a pollutant takes out to reach upper trophic levels in order to understand process of biomagnification or biodilution in food webs. In order to evaluate this phenomenon is important to determine TP by stables isotopes and stomach content to build the food web up.

IV. Stables isotopes and Food webs.

Definition:

Are atoms of the same element, however, is different only in the number of neutrons in the nuclei of these atoms. This fact is illustrated in Fig. 2. Wherein N isotopes differ in the total content of neutron in each one isotope (i.e. δ^{14}N: 7 neutrons, δ^{15} N: 8 neutrons, δ^{16}N: 9 neutrons).

Almost all elements in nature are stable, but there are some exception U^{235}, U^{238}, To^{232} K^{40}, Cd^{113}, CD^{109} and others. The most commonly light stable isotopes used as tracers in trophic ecology research are:

Carbon: ^{12}C and ^{13}C (Nier, 1950)
Nitrogen: ^{14}N and ^{15}N
Oxygen: ^{16}O, ^{17}O, ^{18}O.
Sulphur: ^{32}S, ^{33}S, ^{34}S, ^{36}S.
Hydrogen: ^{1}H, ^{2}H.
Fry et al (2006) reviews in his book the basis of Carbon and Nitrogen stable isotopes for your knowledge.

Isotope Notation and Measurement

Stables isotopes have their own special notation. The δ values denote a difference measurement made relative to standards during analysis:

$$\delta^{H}X = [(R_{sample}/R_{standard} - 1)] * 1000$$ **Formula 1**

Wherein:
H: Heavy isotope signal
X: Carbon or Nitrogen isotopic signal
R_{Sample}: Ratio of light/heavy isotope
$R_{Standar}$: Quotient for Carbon or Nitrogen standards.
The standards used for the isotopic composition are: PeeDee Belemnite (PDB) for Carbon and Nitrogen Air for Nitrogen. The Quotient for light carbon/heavy carbon and light nitrogen/Heavy nitrogen are 0.011180 and 0.0036765 respectively (Fry, 2006). This data is used in the formula 1 above mentioned to solve delta value up in the calculi.
Both ratios of ^{12}C and ^{13}C and ^{14}N, and ^{15}N are used to identify carbon sources in the food web, being autochthonous or allochthonous, the origin of carbon source (Doi, 2009).
Stable isotopes are excellent option as environmental tracers and there are a range of exciting applications of stable isotopes in environmental research particularly on trophodynamics in food webs. There is considerable interest in using stables isotopes particularly those of nitrogen and carbon, to evaluate the structure and dynamics of ecological communities Peterson and Fry 1987, Kling et al. 1992, France 1995, Vander Zander et al. 1999, Postet al. 2000).

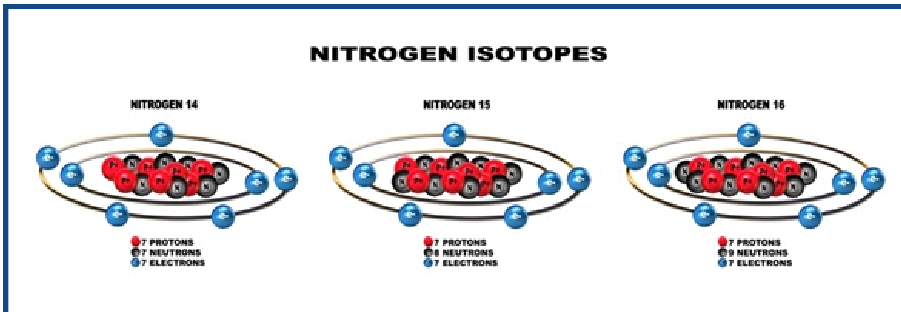

Fig.2. **Nitrogen isotopes 16N,15N,14N shown differ on the number of neutrons in nucleus of their atoms.**

One advantage of using stable isotope techniques is that they combine benefits of both the trophic-level and food web paradigms in food web ecology (Fry, 2006, Post, 2002). Many studies use trophic levels because they are simple to define, characterize the functional role of organisms, and facilitate estimates of energy or mass flow through ecological communities (Hairston and Hairston 1993, Jara-Marini et al., 2009, Soto-Jiménez et al., 2011).

In contrast, food webs capture the complexity of trophic interactions in ecological communities, but are time-consuming to construct, often subjective in their resolution and scope (Post, 2.002), and typically hold all trophic links to be of equal importance, which makes them ineffectual for tracking energy or mass flow through ecological communities (Hairston & Hairston 1993, Polis & Strong 1996, Persson et al., 1999, Vander Zanden and Rasmussen 2001, Post, 2002).

Stable isotope techniques can provide a continuous measure of trophic position that integrates the assimilation of energy or mass flow through all the different trophic pathways leading to an organism (Post, 2002). Stable isotopes have the potential to simultaneously capture complex interactions, including trophic omnivore guild and tracking energy or mass flow through ecological communities (Peterson and Fry 1987, Kling et al.1992, Cabana and Rasmussen 1996).

The ratio of stable isotopes of nitrogen ($\delta^{15}N$) can be used to estimate trophic position because the $\delta^{15}N$ of a consumer is typically enriched by 3–4‰ relative to its diet (DeNiro & Epstein 1981, Minagawa & Wada 1984, Peterson & Fry 1987). In contrast, the ratio of carbon isotopes ($\delta^{13}C$) changes just a few (1‰) as carbon moves through food webs

(Rounick & Winterbourn 1986, Peterson & Fry 1987, France & Peters 1997) and, therefore, typically can be used to evaluate the ultimate sources of carbon for an organism when the isotopic signature of the sources are different (DeNiro & Epstein 1981, Minigawa & Wada 1984, Peterson & Fry 1987).

V. Trophic position (TP) using Carbon and Nitrogen Isotopes

According to Hobson & Welch (1992). The simplest model for estimating the Trophic Position (TP) of a secondary consumer is:

$$TP: = \lambda + (\delta^{15}N_{secondary\ consumer} - \delta^{15}N_{base})/\Delta_n \qquad \textbf{Formula 2}$$

Wherein:

λ: is the trophic position of the organism used to estimate $\delta^{15}N_{base}$ (e.g., λ = 1 for primary producers)

$\delta^{15}N_{secondaryconsumer:}$ is the isotopic sign recorded in muscle predator

$\delta^{15}N_{base:}$ isotopic sign of potential prey

Δ_n: is the enrichment or fractionation in $\delta^{15}N$ per trophic level (3.49‰.)

In general, consumers are enriched in the heavier isotope (more positive in δ^{15} N signal) relative to their food resource (Post, 2002, Fry, 2006). Because these isotopes are assimilated into an organism's body over time, they provide a more quantitative measure of resource use over time than other techniques such as gut content analysis or direct observation, which produce only a snapshot of what the organism most recently consumed (Hobson & Welch 1992, Post, 2002, Fry, 2006).

VI Fractionation:

The simplest way to understander fractionation process is a modification in Carbon and Nitrogen stable signal recorded in tissues of predators (Hobson & Welch 1992, Post, 2002, Fry, 2006).

Once the organisms feed on another, -Carbon and Nitrogen are incorporated into the tissue predators-, displaying an increase in Carbon and Nitrogen signal in predator compared to it is diet. Being in the range of 1.5‰ for Carbon and 3.0 to 4.0‰ for Nitrogen isotopic signal (Vander Zander & Rasmussen, 2001).

This increase in the isotopic signs allows us to build the food web up. Increasing the nitrogen signal as increase the trophic level in the food web (Vander Zander & Rasmussen 2001Post, 2002, Fry, 2006). This makes the nitrogen isotopes particularly useful in interpreting where an organism sits in the trophic structure of an ecosystem. Given the Nitrogen enrichment between trophic levels, an organism highly enriched in relation to basal food sources is likely to be higher in the food chain than herbivores (which feed directly on the plants) or omnivores (which feed on both plant and animal matter). Carbon isotopes are used to identify autotrophic sources which support the whole ecosystem, nitrogen isotopes are used to identify the trophic levels of the ecosystem (Hobson & Welch 1992, Post, 2002, Fry, 2006).

Relative enrichment with increasing trophic level often allows a better interpretation of dietary relationships than gut-content analysis alone because isotope ratios record material that is actually assimilated (Adams & Sterner, 2000).

Stable isotopes are becoming a standard analytical tool in food web ecology. Differences in carbon and nitrogen isotope ratios between consumers and their diet provide information on energy flows, nutrient sources, and trophic relationships. Typically, carbon provides information on the primary energy source (e.g. benthic vs. pelagic photosynthesis), while nitrogen allows discrimination among trophic levels (Post 2002).

In figure 3. We used carbon and nitrogen stable isotopes to draw the food web in a lagoonal-sturine system in the Gulf of California. We analyzed primary producers (phytoplankton and macroalgae), primary consumers, Secondary consumers and tertiary consumers in order to realize how is structured the food web in our sampling location.

The carbon and nitrogen signals ranges for Primary producers (Phytoplankton, macroalgae: *Caulerpa* spp, *Gracilaria vermiculophyla*) from -20.85±1.93 to -19.78±1.93 and 6.5±1.76 to 7.77±0.99 respectively.

Followed by primary consumers (Zooplankton, Bivalves: *Crassostrea cortiziensis* and *Mytella strigata*, snail: *Litorinna pintado* and worm: *Streblospio benedecti*) with carbon signal of -23±0.8 to -20.12±1.25. In the case of nitrogen isotopes; is possible to observe a substantial increase in nitrogen signal compare to Primary producers (mean value from 7.01

to 10.58) indicating the process of fractionation by predator and elucidating the second trophic level. (Fig. 3)

Some secondary consumers were collected (shrimp: *Penaeus vannamei*, Blue Crab: *Callinectes sapidus* and hermit Crab: *Petrochirus californiensis*) carbon and nitrogen stables isotopes values range from -21.18±0.20 to -14.70 and 12.80±0.20 to 16.50±0.20 for nitrogen isotopic value. Similarly to low trophic levels, nitrogen isotopic signal increase from (10.58 to 15.04) elucidating an upper trophic level compared to secondary consumers. Same tendency was observed for tertiary consumers (*Acchirus mazatlanus, Cyclopseta querna, Isophistus remifer, Pomadasys branickii*) Carbon and Nitrogen values of -16.37±1.12 and -14.87±0.70 and 15.21±0.33 to 18.78±0.30 respectively (Fig. 3).

Using formula 2 by Hobson & Welch (1992), it was possible to determinate the trophic level wherein species sit on the food web. Trophic level 1 corresponding to primary producers followed by trophic position 2, for primary consumers. In the case of secondary consumer was possible to find TP of 3.58 to 3.90. Finally, the highest TP was found in tertiary consumers (TP of 3.5 to 4.57). Being *Pomadasys branickii the* top predator under this scenario analyzed by carbon and nitrogen isotopes.

It is worth to mention, this study did not count with stomach content to describe the potential prey in each predator, using both vegetable and animal tissues was possible to elucidate the food web. However, integrating the whole vision of stables isotopes and stomach content would be possible to construct a robust view of food web and notice who eats whom in nature.

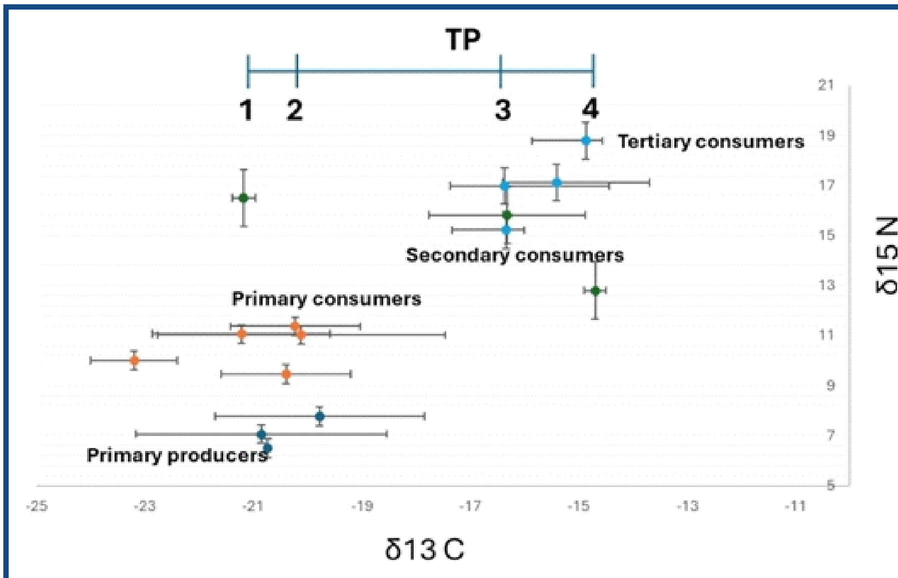

Fig. 3. Range of ^{13}C and ^{15}N for marine organisms of an estuarine system according to an isotopic trophic position equation (Hobson & Welch 1992), 3.4‰ of ^{15}N enrichment was used.

Both C and N stables isotopes and stomach full content analysis will provide real insight of how biota are interconnected by ecological nodes developed by feeding habits. However, this is not enough, so far, we have recognized the structure of food web, another issue is determining which dietary nitrogen source is the predominant in a predator considering abiotic (Dry and rainy season, salinity, temperature) ad biotic (age, size, gender) factor in food transfer. In order to solve this dilemma, some lineal equations are used for this purpose **(**Moore & Semmens, 2008, Phillips et al., 2014).

VII. Mixing models method for determination of source proportion.

Almost all predators are opportunistic predators and sometimes they might change their source of protein (preys) according to their seasonal availability, abundance and shortage (Fry, 2006). Some crustaceans, fish, and birds may have at least 2 sources of protein when they feed on them (Moore & Semmens, 2008, Phillips et al., 2014). And as a consequence, both ^{13}C and ^{15}N isotopic signals are incorporated into edible tissue of predator (Pry, 2006, Phillips et al., 2014). In the past, we could infer the diet by stomach content analysis, actually it is possible to determine which source in predator is more significant according to isotopic signals of Nitrogen sources using some lineal equations (Phillips et al., 2014, Moore & Semmens, 2014).

The Mixing models are mathematical lineal aquations used to determine the proportional contribution of sources to a predator. And allow to calculate the proportion of sources as food to a predator which feed on them (Phillips et al., 2014, Moore & Semmens, 2014).

Assuming a ^{15}N fractionation of 3.4‰ and using a mixing model program MixSir (Moore & Semmens, 2014) is possible to determinate the relative proportion (per cent) for each dietary source of any predator assuming the fact that predator is feeding of these sources.

VIII. Case of study: Predator feeding of 3 sources of protein

The Sardine (*Anchoa mundeola*), is well known by its filtering feeding guilds of these three sources: Phytoplankton, Zooplankton and Seston. Unfortunately, it was not possible to take a look to stomach content in sardine, so in order to identify which source is reflected in tissues of predator, using carbon and nitrogen signal and the MIXSIR program was possible to identify the major relative contribution on sardine feeding on these three sources of food.

We used Carbon and Nitrogen isotopes signals to feed the MixSir program and this software will solve the lineal equation resulting in a relative proportion and allow us to realize about the real contributions of sources to predators.

The result of relative contribution of sources to sardine was Phytoplankton (10%), Zooplankton (80%) and seston (10%). Despite being feeding on 3 sources, zooplankton is the principal source reflected in edible tissue of sardine. Indicating a preferential diet based on zooplankton make up principally of copepods (80%) in this lagoonal-estuarine system (Fig. 4)

This trophic feeding scenario might change according to environmental factors (temperature, salinity, rainy and dry seasons). By the paragraphs mentioned above, sampling is required over the year or years for determinate any kind of fluctuation.

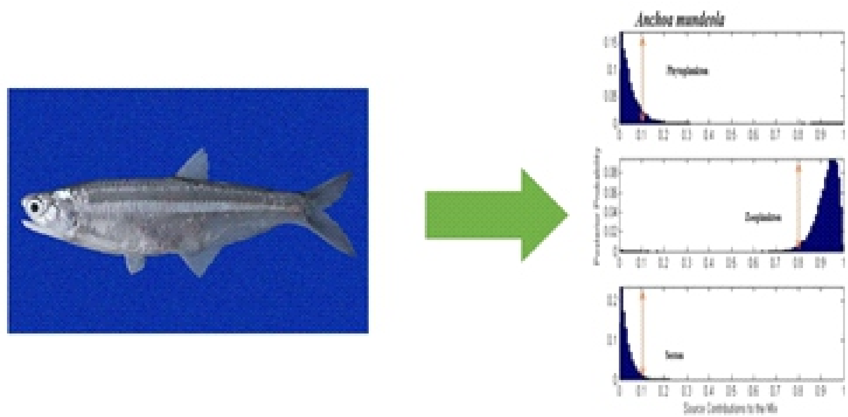

Fig. 4. **Relative contributions of three sources: phytoplankton, zooplankton and seston as food source for sardine.**

VIIII. Pollutants and Food webs in nature

As increasing human population on coasts, the impact of anthropogenic activities on the food web is high too. Some principal anthropogenic activities developed near to coast are industrial and domestic wastewater effluents, animal cattle, electricity power plant, aquaculture and agriculture (Paez-Osuna et al., 2007) releasing pollutants particularly heavy metals, microplastics, pesticides and others to lagoons, estuaries and oceans (Jara-Marini et al., 2009, Jara-Marini et al., 2011, Soto-Jiménez et al., 2011).

Heavy metal definition:

Heavy metals are defined as a substance that conduce electricity, has a metal cluster, is malleable and ductile, form cations and has basic oxides (Jadaa & Mohammed, 2023) Since the point of view of density, heavy metals are those, whose density exceeds 5g per cubic centimeters (Jadaa & Mohammed 2023).

Since biological point of view, metals are considered as essential and not essential. The essential metals have a definitive biological function in the organisms such as: Iron (Fe: hemoglobin), Copper (Cu: respiratory enzymes), Cobalamin (Co: Vitamin B12) Manganese and Zinc (Enzymes) (Foster & Charlesworth, 1996, Soto-Jiménez 2011).

In spite of being essential metals, they are becoming toxic to organisms when they exceed the optimal range of concentrations in biota. (Mertz, 1998). For the other hand, elements such as Cd, Pb, Ag, As, Cr, Hg, and

Sn are not essential for organisms, and they are toxic even in very low concentrations (Rainbow, 1993).

Heavy metals are incorporated mainly into food webs by dietary routes (Wang 2002). They might be bioconcentrated by single cells as phytoplankton, adsorbed on cell membrane (Levy et al., 2008), or suspended organic matter (Yusuf et al., 2021). Bioaccumulated by ingesting this polluted phytoplankton by herbivorous predators and subsequently transferred to secondary and tertiary consumers and upper trophic levels.

IX. Current knowledge of contaminants on the food webs.

Once stablished the trophic web (by using stables isotopes and/or stomach content analysis) in an ecosystem is very important realize how pollutants are transferred in this ecological arrangement. There are hundreds of scientist papers regarding to bioconcentration, bioaccumulation, biomagnification or biodilution on food web (for definitions, see Glossary). However, these ecological studies have been carried out in terrestrial, polar artic and freshwater environments wherein food chains are short compared with those of marine environments and commonly supported by two or three carbon and nitrogen sources as a base of food web (Pimm et al., 1991). And it is so difficult trying any comparison between field studies due contrasting chemical and physical factors, species discrepancies and others (Soto-Jiménez, 2011).

Nowadays, there are some publications on trophic transfer of heavy metals on the food web using or not stables isotopes (Table 1, Table 2). Some worldwide findings reported in these papers were number or trophic levels in food webs (4 – 5 trophic levels) (Hobson and Welch 1992), bioconcentration of heavy metals in primary producers (Levy at al., 2008), bioaccumulation of metals in primary, secondary and tertiary consumers. Biomagnification of essential elements and no essential (Cd, As, Hg) and biodilution of Cd, Pb and As. (table #1).

Actually, Mexico has done good efforts to understand the trophic-dynamics of nutrients and metals in food webs (Table #2). These studies have been developed in coastal lagoon, estuaries, and wetland. It is worth noting that fluctuant physical and chemical factor affects the isotopic signal in biota and may change lit bite trophic position or carbon and nitrogen sources preferences by predators (for this reason is required to take samples in contrast season: dry and rainy season). In spite of this scenario, it is possible to track the pollutants along the food web, and focus on key species to transfer the major load metal to upper predators.

Some findings found in Mexican scientist papers include biomagnification of trace metal in an impacted mangrove System (Jara-Marini et al., 2011), biodilution of essential and no essential metals (Reyes-Marquez et al., 2022). Mendoza-Carranza et al., (2016) elucidate two food chains: pelagic and benthic food chain. By using stables isotopes, was possible de built up the food web in different locations and recognizing 3-5.3 trophic levels (Jara-Marini et al., 2020, Soto-Jimenez et al., 2023).

Table 1. **Transfer of heavy metals using or not Stables isotopes around the world.**

Authors:	**Location:**	**$\delta^{13}C$ / $\delta^{15}N$ Stables isotopes:**	**Findings:**
Hobson & Welch (1992)	Artic Food Web, Canada	Done	4-5 trophic levels Artic code fish is linkage between primary producers and higher vertebrate fish.
Chen et al., (2016)	Lakes from nor'easter USA	None	Biomagnification of Hg and Zn. Biodilution of As and Pb.
Altindag & Yigit (2005)	Beysehir lake, Turkey	None	Found the next tendencies: Cd>Pb>Cr>Hg in water Pb>Cd>Cr>Hg in sediments Pb>Cd>Cr>Hg in Plankton Cd>Pb>Cr>Hg in muscle fish No biomagnification of

			heavy metals.
Tulonen et al., (2006)	Lakes from Finland	None	Positive correlation between Cd load and waste discharges. Correlation between pH and Cd concentration in isopods. High metal concentration in perchs (*perca fluviatilis*).
Cui et al., (2011)	Yellow river, China	Done	4 trophic levels. Cd, Zn and Hg increasing with trophic level. As, Cr, Cu, Mn, Ni and Pb decreasing with trophic level. No biomagnification was observed.
Liu et al., (2019)	Laizhou Bay, China	Done	4 Trophic levels. Biomagnification of Hg and Cr. Biodilution of Cu.
Ga et al., (2021)	Liaodong Bay, China	Done	4 trophic levels. Biodilution of Cu, Cd, Pb, Zn, Cr.
Zheng et al., (2023)	Zhanjiang Mangrove National Reserve, China	Done	3 trophic levels. Biodilution of Cd, Cu, Zn and Pb.
Hu, et al., (2021)	Swan Lagoon, China	Done	4 Trophic levels. Biodilution of Cd, Cr, Cu, Pb. Neither biomagnification nor biodilution was observed in Zn concentrations.

Liu et al., (2022)	Laizhou Bay, China	Done	4 trophic levels. Biodilution of Pb, As, and Ni. Sea food in this study is a potential concern for its consumption.
Li et al., (2024)	Honghe wetland, China	Done	5.5 Trophic levels. Biodilution of Cu, Zn and Pb. Biomagnification of Hg along food web.

Table 2. Currently knowledge of trophic transfers of heavy metals in food webs in lagoonal, estuarine and marine environment in several locations of Mexico.

Authors:	Location:	δ^{13}C / δ^{15}N Stables isotopes:	Findings:
Jara-Marini et al., (2009)	Urias Lagoon, Sinaloa	Done	No biomagnification trough food web. Theres partial biomagnification between Phytoplankton and crabs particularly in Cu and Zn.
Mendoza-Carranza et al. (2016)	Centla, Tabasco	None	Botton food chain is the principal source of metal to biota.
Soto-Jiménez et al., (2011)	Trophic transfer of Pb through artificial food chain, laboratory conditions.	None	Biodilution of Pb along food chain Deleterious effects on brine shrimps and fish by ingesting Pb enrichment in meals.

Jara-Marini et al., (2011)	Urias Lagoon, Sinaloa	Done	Biomagnification of Hg
Jara-Marini et al., (2020)	Tobari Bay, Sonora	Done	5.3 trophic levels Biomagnification of Cd, Cu, and Zn. Data on Pb transfer is not conclusive
Reyes-Marquez et al., (2022)	Tampamachoco, Veracruz	None	Biodilution of Pb, Cu, Cr as trophic level increased. Cd and Pb showed temporal biomagnification tendency.
Soto-Jiménez et al., (2023)	Mazatlán, Teacapán, Sinaloa	Done	3 Trophic levels Biomagnification of Cu and Zn.
Valladolid-Garnica et al., (2023)	Mazatlán, Teacapán, Sinaloa	Done	Trophic Magnification factor (TMF) for As, Hg, Se, was 4.07, 1.90 and 1.77 respectively. TMF for pelagic food chain was As, Hg and Se: 3.63, 3.16, 1,94 respectively.

X. Conclusion:

As scientists, it is required to unify all criteria and efforts to understand how natural aquatic ecosystems are integrated. Since the beginning the curiosity to find a logical order in nature has been an imperious necessity to explain how nature works. Good efforts have been made to satisfy this proposal. Visual analyses in species: animal behaviors and feeding guilds have been used for study the food webs. Recently, stomach content and stables isotopes are employed to hierarchy food webs. These tools provide by themselves an excellent panorama of the ecological hierarchy in the environment. Besides, allow us to analyze some pollutants inside of food webs such as microplastics, organic compounds and particularly heavy metal in food web. Every day, species requires to satisfy their nutritional requirements (Carbon, hydrogen, Oxygen, Nitrogen) and at the same time facing anthropogenic pollutants which are incorporated in predator by dietary ingesta, and a as a consequence producing a trophic transfer of nutrients and pollutant at the same time.

A keystone for the analysis of transference of heavy metals is to intent to predict the chemical behavior of pollutant along the food web, for instance Hg and its preference of bioaccumulate in adipose tissues, or Pb metal, mimic to Ca in hard structures, such as skill and bones. Besides, recognize some sublethal effect of metal in prey and predator as a biomarker in the monitor species and as a signal of perturbance of ecological equilibrium in nature. So far, there is a gap in knowledge on trophic dynamic in food webs. Ecologist and Biologist and Scientist must join efforts to clarify the real panorama of trophic dynamics it will be possible to take a plan for restauration or prevention of other contaminants such as PCBs, metals, microplastics and another compounds.

Glossary terms:

Bioconcentration: is a ratio between heavy metal content in an organism and the available metal content in the environment (sediment or water).

Bioaccumulation: is the process wherein heavy metal is incorporated in to animal tissues by predation or dietary via.

Biotransfering: is the process wherein predator increase its metal content by predating on polluted preys. There are different forms of transferring in nature.

Biomagnification is defined as a chemical and physiological process wherein heavy metals concentration increase as trophic level rise in at least 3 trophic levels.

Biodilution is the reduction of heavy metal concentration in plants and animals as trophic levels increase.

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LITERATURE CITED

Adams, T. S., & Sterner, R. W. (2000). The effect of dietary nitrogen content on trophic level 15N enrichment. *Limnology and oceanography*, *45*(3), 601-607. https://doi.org/10.4319/lo.2000.45.3.0601

Altındağ, A., & Yiğit, S. (2005). Assessment of heavy metal concentrations in the food web of lake Beyşehir, Turkey. *Chemosphere*, *60*(4), 552-556. https://doi.org/10.1016/j.chemosphere.2005.01.009

Aoshima, K. (2016). Itai-itai disease: Renal tubular osteomalacia induced by environmental exposure to cadmium—historical review and perspectives. *Soil Science and Plant Nutrition*, *62*(4), 319-326. https://doi.org/10.1080/00380768.2016.1159116

Aoshima, K. (2012). [Itai-itai disease: cadmium-induced renal tubular osteomalacia]. *Nihon Eiseigaku Zasshi, 67*, 455–63.

Bassham, J.A., Benson, A.A., & Calvin, M (1950). The path of carbon in photosynthesis. VIII. The role of malic acid. — Journal of Biological Chemistry **185**: 781–787.

Bhagat, J., Zang, L., Nishimura, N. & Shimada, Y. (2020). Zebrafish: An emerging model to study microplastic and nanoplastic toxicity. *Science of the Total Environment*, *728*, 138707. https://doi.org/10.1016/j.scitotenv.2020.138707

Bloom, N. S. (1992). On the chemical form of mercury in edible fish and marine invertebrate tissue. *Canadian journal of fisheries and aquatic sciences*, *49*(5), 1010-1017.https://doi.org/10.1139/f92-113

Cabana, G., & Rasmussen, J. B. (1996). Comparison of aquatic food chains using nitrogen isotopes. *Proceedings of the National Academy of sciences*, *93*(20), 10844-10847. https://doi.org/10.1073/pnas.93.20.10844

Campbell, T. I., Tweedley, J. R., Johnston, D. J., & Loneragan, N. R. (2021). Crab diets differ between adjacent estuaries and habitats within a sheltered marine embayment. *Frontiers in Marine Science*, *8*, 564695. https://doi.org/10.3389/fmars.2021.564695

Chen, J., Hintelmann, H., Zheng, W., Feng X., Cai, H., Wang, Z., Yuan, S., Wang, Z. (2016). Isotopic evidence for distinct sources of mercury in lake waters and sediments. *Chemical Geology, 426,* 33-44, https://doi.org/10.1016/j.chemgeo.2016.01.030

Cui, B., Zhang, Q., Zhang, K., Liu, X., & Zhang, H. (2011). Analyzing trophic transfer of heavy metals for food webs in the newly-formed wetlands of the Yellow River Delta, China. *Environmental Pollution*, *159*(5), 1297-1306. https://doi.org/10.1016/j.jhydrol.2014.09.038

DeNiro, M. J., & Epstein, S. (1981). Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et cosmochimica acta*, *45*(3), 341-351. https://doi.org/10.1016/0016-7037(81)90244-1

Doi, H. (2009). Spatial patterns of autochthonous and allochthonous resources in aquatic food webs. *Population Ecology*, *51*, 57-64. https://doi.org/10.1007/s10144-008-0127-z

France, R. L. (1995). Differentiation between littoral and pelagic food webs in lakes using stable carbon isotopes. *Limnology and Oceanography*, *40*(7), 1310-1313. https://doi.org/10.4319/lo.1995.40.7.1310

France, R. L., & Peters, R. H. (1997). Ecosystem differences in the trophic enrichment of ^{13}C in aquatic food webs. *Canadian Journal of Fisheries and Aquatic Sciences*, *54*(6), 1255-1258. https://doi.org/10.1139/f97-044

Foster, I. D. L., & Charlesworth, S. M. (1996). Heavy metals in the hydrological cycle: trends and explanation. *Hydrological processes*, *10*(2), 227-261.https://doi.org/10.1002/(SICI)1099-1085(199602)10:2<227::AID-HYP357>3.0.CO;2-X

Fry, B. (2006). *Stable isotope ecology* (Vol. 521, p. 318). New York: Springer.

González-Bergonzoni, I., Meerhoff, M., & Davidson, T.A. (2012). Meta-analysis shows a consistent and strong latitudinal pattern in fish omnivory across ecosystems. Ecosystem, volume 15, pages 492–503. https://doi.org/10.1007/s10021-012-9524-4

Haimi, J. (2008). Decomposer animals and bioremediation of soils. Environmental Pollution. Volume 107, Issue 2. Pages 233-238. ISSN 0269-7491. https://doi.org/10.1016/S0269-7491(99)00142-6

Harada, M. (1995). Minamata disease: methylmercury poisoning in Japan caused by environmental pollution. *Critical reviews in toxicology*, *25*(1), 1-24. https://doi.org/10.3109/10408449509089885

Hairston Jr, N. G., & Hairston Sr, N. G. (1993). Cause-effect relationships in energy flow, trophic structure, and interspecific interactions. *The American Naturalist*, *142*(3), 379-411.

Hobson, K. A., & Welch, H. E. (1992). Determination of trophic relationships within a high Arctic marine food web using $\delta^{13}C$ and $\delta^{15}N$ analysis. *Marine Ecology Progress Series*, *84*(1), 9–18. http://www.jstor.org/stable/24829721

Hu, C., Shui, B., Yang, X., Wang, L., Dong, J., & Zhang, X. (2021). Trophic transfer of heavy metals through aquatic food web in a seagrass ecosystem of Swan Lagoon, China. *Science of the total environment*, *762*, 143139. https://doi.org/10.1016/j.chemosphere.2023.138211

Jadaa, W., & Mohammed, H. (2023). Heavy metals–definition, natural and anthropogenic sources of releasing into ecosystems, toxicity, and removal methods–an overview study. *Journal of Ecological Engineering*, *24*(6), 249-271. https://doi.org/10.12911/22998993/162955. ISSN 2299–8993, License CC-BY 4.0

Jara-Marini, M.E., Soto-Jiménez M. F. &. Páez-Osuna, F. (2009). Trophic relationships and transference of cadmium, copper, lead and zinc in a subtropical coastal lagoon food web from SE Golf of California. Chemosphere, Volume 77, Issue 10, Pages 1366-1373, ISSN 0045-6535, https://doi.org/10.1016/j.chemosphere.2009.09.025

Jara-Marini, M. E., Soto-Jiménez, M. F., & Páez-Osuna, F. (2011). Mercury transfer in a subtropical coastal lagoon food web (SE Gulf of California) under two contrasting climatic conditions. *Environmental Toxicology*, *27*(9), 526-536. https://doi.org/10.1002/tox.20670

Jara-Marini, M. E., Molina-García, A., Martínez-Durazo, Á., & Páez-Osuna, F. (2020). Trace metal trophic transference and biomagnification in a semiarid coastal lagoon impacted by agriculture and shrimp aquaculture. *Environmental Science and Pollution Research*, *27*, 5323-5336. https://doi.org/10.1007/s11356-019-06788-2

Jernelöv, A. (1976). Environmental contamination by mercury in Iraq. *Bulletin of the World Health Organization*, *53*(Suppl), 113.

Kendall, D.C., Raubenheimer D., & Choat J.H. (2009). Nutritional ecology of marine herviborous fishes: ten years on. British Ecological Society: Functional Ecology. Volume 23, Issue 1, pages 79-92. https://doi.org/10.1111/j.1365-2435.2008.01524.x

Kitagawa M. A review and database construction of autopsy findings of patients with Itai-itai disease for future medical studies. Kankyo Hoken Report 2002;68:21–37.

Kling, G. W., Fry, B., & O'Brien, W. J. (1992). Stable isotopes and planktonic trophic structure in arctic lakes. *Ecology*, *73*(2), 561-566. https://doi.org/10.2307/1940762

Levy, J. L., Angel, B. M., Stauber, J. L., Poon, W. L., Simpson, S. L., Cheng, S. H., & Jolley, D. F. (2008). Uptake and internalisation of copper by three marine microalgae: comparison of copper-sensitive and copper-tolerant species. *Aquatic toxicology*, *89*(2), 82-93. https://doi.org/10.1016/j.aquatox.2008.06.003

Liu, J., Cao, L., & Dou, S. (2019). Trophic transfer, biomagnification and risk assessments of four common heavy metals in the food web of Laizhou Bay, the Bohai Sea. *Science of the total environment*, *670*, 508-522. https://doi.org/10.1016/j.scitotenv.2019.03.140

Li, X., Wang, Q., Liu, F., Lu, Y., & Zhou, X. (2024). Quantifying the bioaccumulation and trophic transfer processes of heavy metals based on the food web: A case study from freshwater wetland in northeast China. *Science of The Total Environment*, *928*, 172290. https://doi.org/10.1016/j.scitotenv.2024.172290

Liu, Y., Hua, Z., Lu, Y., Gu, L., Luan, C., Li, X., ... & Chu, K. (2022). Quinolone distribution, trophodynamics, and human exposure risk in a transit-station lake for water diversion in east China. *Environmental Pollution*, *311*, 119985. https://doi.org/10.1016/j.scitotenv.2022.156818

Mendoza-Carranza, M., Sepúlveda-Lozada, A., Dias-Ferreira, C., Geissen, V., (2016). Distribution and bioconcentration of heavy metals in a tropical aquatic food web: A case study of a tropical estuarine lagoon in SE Mexico. Environmental Pollution, Volume 210, 2016, Pages 155-165, ISSN 0269-7491, https://doi.org/10.1016/j.envpol.2015.12.014.

Minagawa, M., & Wada, E. (1984). Stepwise enrichment of ^{15}N along food chains: further evidence and the relation between δ15N and animal age. *Geochimica et cosmochimica acta*, *48*(5), 1135-1140. https://doi.org/10.1016/0016-7037(84)90204-7

Muro-Torres, V. M., Soto-Jiménez, M. F., Green, L., Quintero, J., & Amezcua, F. (2019). Food web structure of a subtropical coastal lagoon. *Aquatic Ecology*, *53*, 407-430. https://doi.org/10.1007/s10452-019-09698-0

Nishijo, M., Nakagawa, H., Suwazono, Y., Nogawa, K., & Kido, T. (2017). Causes of death in patients with Itai-itai disease suffering from severe chronic cadmium poisoning: a nested case–control analysis of a follow-up study in Japan. *BMJ open*, *7*(7), e015694.

Nogawa K, Kido T. Itai-itai disease and health effects of cadmium. Chang LW, ed. Toxicology of metals. New York: CRCpress, 1996:353–69.

Persson, A., Barkman, A., Hansson, L. A. (1999). Simulating the effects of biomanipulation on the food web of Lake Ringsjön. In: Hansson, LA., Bergman, E. (eds) Nutrient Reduction and Biomanipulation as Tools to Improve Water Quality: The Lake Ringsjön Story. Developments in Hydrobiology, vol 140. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-2462-3_14

Phillips, D. L., Inger, R., Bearhop, S., Jackson, A. L., Moore, J. W., Parnell, A. C., & Ward, E. J. (2014). Best practices for use of stable isotope mixing models in food-web studies. *Canadian Journal of Zoology*, *92*(10), 823-835. https://doi.org/10.1139/cjz-2014-0127

Pimm, S., Lawton, J. & Cohen, J. (1991). Food web patterns and their consequences. *Nature* 350, 669–674 https://doi.org/10.1038/350669a0

Polis, G. A., & Strong, D. R. (1996). Food web complexity and community dynamics. *The American Naturalist*, *147*(5), 813-846.

Polis, G.A., Anderson., W.B., & Holt, R.D. (1997). Toward an integration of landscape and food web ecology. The dynamics of spatially subsidized food webs. Annual Review of Ecology, Evolution and Systematic. Volume 28 289-316. https://doi.org/10.1146/annurev.ecosys.28.1.289

Post, D. M., Pace, M. L., & Hairston, Jr. (2000). Ecosystem size determines food-chain length in lakes. *Nature*, *405*(6790), 1047-1049. https://doi.org/10.1038/35016565

Post, D. M. (2002). Using stable isotopes to estimate trophic position: models, methods, and assumptions. *Ecology*, *83* (3), pages: 703-718. https://doi.org/10.1890/0012-9658(2002)083[0703:USITET]2.0.CO;2

Reyes-Márquez, A., Aguíñiga-García, S., Morales-García, S. S., Sedeño-Díaz, J. E., & López-López, E. (2022). Temporal distribution patterns of metals in water, sediment, and components of the trophic structure in a tropical coastal lagoon of the Gulf of Mexico. *Environmental Science and Pollution Research*, *29*(41), 61643-61661. https://doi.org/10.1007/s11356-021-17815-6

Rounick, J. S., & Winterbourn, M. J. (1986). Stable carbon isotopes and carbon flow in ecosystems.*BioScience*,*36*(3), 171-177. https://doi.org/10.2307/1310304

Soto-Jiménez, M.F., Arellano-Fiore, C., Rocha-Velarde, R., Jara-Marini, M.E., Ruelas-Inzunza, J. & Paez-Osuna, F. (2011). Trophic Transfer of Lead Through a Model Marine Four-Level Food Chain: *Tetraselmis suecica*, *Artemia franciscana, Litopenaeus vannamei*, and *Haemulon scudderi*. Archive of Environmental Contamination and Toxicology. Volume 61, pages 280–291 https://doi.org/10.1007/s00244-010-9620-4

Soto-Jiménez, M. F., Valladolid Garnica, D. E., Torres-Rojas, Y. E., Jara Marini, M. E., & Muro-Torres, V. M. (2023). Trophodynamics of Arsenic, Mercury, and Selenium in the Food Webs of the Southeastern Gulf of California. *Mercury, and Selenium in the Food Webs of the Southeastern Gulf of California*. http://dx.doi.org/10.2139/ssrn.4608087

Tulonen, T., Pihlström, M., Arvola, L., & Rask, M. (2006). Concentrations of heavy metals in food web components of small, boreal lakes. *Boreal Environment Research*, *11*(3), 185. ISSN 1239-6095.

Vander Zanden, M. J., Casselman, J. M., & Rasmussen, J. B. (1999). Stable isotope evidence for the food web consequences of species invasions in lakes. *Nature*, *401*(6752), 464-467. https://doi.org/10.1038/46762

Vander Zanden, M. J. V., & Rasmussen, J. B. (2001). Variation in $\delta^{15}N$ and $\delta^{13}C$ trophic fractionation: implications for aquatic food web studies. *Limnology and oceanography*, *46*(8), 2061-2066. https://doi.org/10.4319/lo.2001.46.8.2061

Valladolid-Garnica, D. E., Jara-Marini, M. E., Torres-Rojas, Y. E., & Soto-Jiménez, M. F. (2023). Distribution, bioaccumulation, and trace element transfer among trophic levels in the southeastern Gulf of California. *Marine Pollution Bulletin*, *194*, 115290. https://doi.org/10.1016/j.marpolbul.2023.115290

Vidal, M. C., & Murphy, S. M. (2018). Bottom-up vs. top-down effects on terrestrial insect herbivores: A meta-analysis. *Ecology letters*, *21*(1), 138-150. https://doi.org/10.1111/ele.12874

Wang, W. X. (2002). Interactions of trace metals and different marine food chains. *Marine Ecology Progress Series*, *243*, 295-309.

Yokoyama, H. (2018). *Mercury pollution in Minamata*. Springer Nature. ISSN 2191-5555. https://doi.org/10.1007/978-981-10-7392-2

Yusuf, M., Pamungkas, A., & Hudatwi, M. A. (2021). Distribution of Turbidity Values, Total Suspended Solids and Heavy Metals Pb, Cu in Tanah Merah Beach Waters and Semujur Island Waters, Bangka Tengah Regency. In *IOP Conference Series: Earth and Environmental Science* (Vol. 750, No. 1, p. 012038). IOP Publishing.https://doi.org/10.1088/1755-1315/750/1/012038

Zheng, R., Liu, Y., & Zhang, Z. (2023). Trophic transfer of heavy metals through aquatic food web in the largest mangrove reserve of China. *Science of the Total Environment*, *899*, 165655. https://doi.org/10.1016/j.scitotenv.2023.165655

Zetina-Rejon, M. J., Arreguın-Sanchez, F., & Chavez, E. A. (2003). Trophic structure and flows of energy in the Huizache–Caimanero lagoon complex on the Pacific coast of Mexico. *Estuarine, Coastal and Shelf Science*, *57*(5-6), 803-815. https://doi.org/10.1016/S0272-7714(02)00410-9