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*Chapter 15*

**STUDYING JELLYFISH FISHERIES:  
TOWARD ACCURATE NATIONAL CATCH  
REPORTS AND APPROPRIATE METHODS  
FOR STOCK ASSESSMENTS**

*Lucas Brotz\* and Daniel Pauly*

*Sea Around Us*, Institute for the Oceans and Fisheries,  
University of British Columbia, Vancouver, Canada

**ABSTRACT**

People have been catching and eating jellyfish for centuries, predominantly in Asia. More recently, jellyfish fisheries have expanded around the globe, primarily for export to China and Japan. However, catch data for jellyfish remain scant. Many countries fishing for jellyfish do not explicitly report their catches to the Food and Agriculture Organization of the United Nations (FAO), and reported data are often problematic. Here, we estimate historic and current catches of jellyfish from 1950 to the present. We review past trends in global catch data for jellyfish and speculate on future catch potential. Research and management of jellyfish fisheries is inadequate, especially given the current rates of expansion and the unique challenges presented by jellyfish populations. Historically, jellyfish have been understudied, resulting in the current dearth of knowledge on jellyfish population dynamics and jellyfish fishery management. We discuss how jellyfish can be studied using straightforward adaptations of standard methods for size-based analysis of fish populations, and encourage researchers to rapidly scale up the study of these increasingly important animals.

**Keywords:** jellies, jellyfish fishery, scyphomedusae, Scyphozoa, zooplankton fisheries, growth, mortality, length-frequency data

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\* *Sea Around Us*, Institute for the Oceans and Fisheries, 2202 Main Mall, University of British Columbia, Vancouver, BC, V6T 1Z4, Canada. Email: lucasbrotz@gmail.com.

## INTRODUCTION

Jellyfish populations are increasing in numerous coastal regions of the globe [1], often causing severe economic losses for industries such as tourism, fisheries, power generation, and aquaculture [2]. As these problems are likely to increase [3], it has been suggested that finding new uses for jellyfish as food and medicine could help to control jellyfish populations, especially with regard to nuisance species [2, 4, 5]. While such a strategy as a means to an end is flawed [6], the proliferation of jellyfish in some areas is already leading to new fisheries and increased investigations of the use of jellyfish for nutrition, medicines, and other applications (Table 1). Jellyfish have also been central to a number of breakthroughs in fields such as biotechnology and biomedicine [e.g., 7, 8], as well as design engineering [9-11]; however, these applications do not require large amounts of jellyfish, unlike some of the possible uses listed in Table 1.

The idea of consuming jellyfish as food is relatively new in the Western Hemisphere, and is often met with reactions ranging from surprise to disgust. However, eating jellyfish is anything but novel, as people have been doing it for centuries. Consumption of jellyfish dates back to at least 1,700 years ago [12]. Today, China continues to be the dominant producer and consumer of jellyfish, representing approximately 60% of contemporary global capture production [13], as well as the importation of jellyfish from many other countries. Indeed, jellyfish are such a popular food item in China that many imitation products are now being sold there that contain no actual jellyfish, but are artificially made using brown algae [14]. China is also the only country in the world to produce jellyfish through aquaculture using large saltwater ponds, as well as employing hatchery programs whereby hundreds of millions of juvenile jellyfish are cultured and released annually with the hopes of supplementing wild stocks [14], a strategy that has only had partial success (see below).

**Table 1. Examples of uses for jellyfish other than as food for humans**

Category	Uses	Sample reference(s)
Agriculture	Livestock feeds	[15, 16]
	Fertilizers	[17-24]
	Insecticides	[25, 26]
Aquaculture	Finfish and shellfish feeds	[27-31]
Cosmetics	Gelatin/emulsifier	[32, 33]
Environmental monitoring	Pollution detection	[34, 35]
Fishing	Bait	[36-40]
Materials science	Absorbent polymers	[41, 42]
	Cement additive	[16]
	Nanoparticle filters	[43]
Pharmaceuticals	Antihypertensive peptides	[44, 45]
	Anticoagulants	[46]
	Antimicrobials	[47, 48]
	Antioxidants	[49-53]
	Bioactive compounds	[53-62]
	Collagen	[63-70]
	Mucins	[71, 72]

Jellyfish populations are often subject to large interannual fluctuations in abundance. In fact, changes in biomass of edible jellyfish are probably larger than for any other fishery [73]. Jellyfish are most often caught from small boats using dip-nets. However, a wide variety of active and passive fishing gears are used in different areas of the world. At least 30 different species of jellyfish have been identified as “edible” [13]; however, species that are primarily targeted for food belong to the paraphyletic Order Rhizostomeae. Jellyfish belonging to this group are typically less fragile than other jellies and will produce the desired crunchy texture that is characteristic of edible jellyfish after processing. With the exception of Mexico, the Food and Agriculture Organization of the United Nations (FAO) reports all jellyfish catches as “*Rhopilema* spp.,” which is incorrect in many cases. Combined with the fact that the taxonomy of edible jellyfish is considerably confused [38], this makes it difficult to determine exactly which jellyfish are being caught and eaten.

Although some may be eaten fresh in coastal areas [14], jellyfish are most often processed in a stepwise salting procedure that takes weeks. The process may vary somewhat, but typically involves soaking jellyfish in a variety of different mixtures of salt and alum (usually potassium aluminum sulfate) in order to partially dehydrate the jellyfish, decontaminate them, and produce the desired crunchy and crispy texture. Semi-dried (i.e., processed) jellyfish are then either sold at markets or packaged and shipped. Prior to consumption, jellyfish are usually soaked in water to remove the salt and alum, and then sliced, often blanched, and served as appetizer salads or as ingredients in other dishes. Ready-to-eat jellyfish products are also available as snacks that can be consumed straight from the package.

Desalted, processed edible jellyfish are typically 92-96% water and 3-7% protein, primarily collagen. With only 36 kcal per 100 g serving [74], edible jellyfish have been declared as a natural diet food. There is a long list of purported health benefits from eating jellyfish according to Traditional Chinese Medicine [14, 75]; however, very few of these have been tested using scientific criteria. In addition, there are health concerns about the consumption of jellyfish related to the use of alum during processing, which contains aluminum, detectable in the final product [76-78]. As such, whether the effects of eating jellyfish are positive or negative for human health remains unresolved.

## ESTIMATING THE GLOBAL CATCH OF JELLYFISH

At least 23 countries have been involved in jellyfish fisheries (Table 2). Some countries (e.g., Turkey) appear to have abandoned their jellyfish fisheries, while others (e.g., Canada) had test fisheries that were unsuccessful. There are 19 nations currently fishing for jellyfish, with estimated current average landings of at least 900,000 tonnes annually [13]. Despite the proliferation of jellyfish fisheries, catch data remain scant. Many countries do not explicitly report their jellyfish catches to FAO, and even reported data are often problematic. As such, a catch reconstruction of jellyfish landings from 1950 to the present was developed. Methods were based on those that have been employed for a myriad of fisheries catch reconstructions [79-81], whereby the following steps are followed:

1. Identification and validation of existing reported catch time series (e.g., FAO statistics);
2. Identification of countries and time periods not covered by (1), i.e., missing catch data, via literature searches and consultations;
3. Search for available alternative information sources to supply the missing catch data in (2), through extensive literature searches and consultations with local experts;
4. Development of data anchor points in time for missing data items;
5. Interpolation for time periods between data anchor points for total catch;
6. Estimation of final total catch time series estimates for total catch, combining reported catches (1) and interpolated missing data series (5).

Using this methodology, a global catch reconstruction for jellyfish was developed by combining the catches of each country (Figure 1). Major findings are discussed below, and details for all countries in the analysis can be found in [82].

As mentioned, China has the longest history of fishing for edible jellyfish, and is the world's largest producer. Estimating China's catch is a challenge due to inconsistencies in reporting. For example, FAO reports no catch prior to 1970; however, Dong et al. [83] report annual landings dating back to 1957 from a variety of sources, including China Fishery Statistical Yearbooks. The targeted species is *Rhopilema esculentum*, a conspicuous rhizostome that fetches the highest price for edible jellyfish. Catch statistics for jellyfish in China were also reported by Li et al. [84] from 1980 to 2012. For the period 1980-1990, it appears that landings reported to FAO were for *processed* jellyfish, rather than wet weight. As processed *R. esculentum* weighs only 15% of the original wet weight [84], we can assume that landings from this period are only 15% of the true value, i.e., underreported more than sixfold. When we examine Chinese landings from the 1950s, '60s, and '70s, they are of a similar magnitude to those from the 1980s, and as such, it suggests that reported landings prior to 1990 are similarly for processed jellyfish. While this is clearly a major assumption with significant consequences for a catch reconstruction estimate, the current scale of reported jellyfish landings in China is on the order of several hundred thousand tonnes. That scale, combined with China's long history of fishing jellyfish, would seem to justify the assumption.

Catches of *R. esculentum* in China began declining in the 1970s, likely due to overexploitation [83]. This led to extensive research on the life cycle and culturing of the species [14], and in 1984, ephyrae were released into Chinese coastal waters with the hopes of supplementing the wild stock and increasing the catch. For almost 2 decades, the hatchery program continued to expand and was declared an economic success [14, 85]. However, recent landings of this species have declined despite increased restocking programs, which now release hundreds of millions of ephyrae annually. Around the turn of the century, another rhizostome, the giant jellyfish *Nemopilema nomurai*, began increasing in abundance in East Asian waters [86-88]. With declining catches of *R. esculentum*, jellyfish fishers in China quickly turned their attention to *N. nomurai*, with landings on the order of hundreds of thousands of tonnes in recent years [84]. Curiously, despite these massive catches, catches of *N. nomurai* appear to be absent from FAO statistics.

**Table 2. Countries that are known to fish for jellyfish**

Country	Dates
Australia	1995 - present
Bahrain	2004 - present
Canada	1984; 2002
China	<1950 - present
Ecuador	2013 - present
Honduras	2013 - present
India	1984 - present
Indonesia	<1950 - present
Iran	2010? - present
Japan	<1950 - present
Korea (South)	1980s? - present
Malaysia	<1950? - present
Mexico	2000 - present
Myanmar	1995? - present
Nicaragua	2008; 2013 - present
Pakistan	2007? - present
Philippines	1976 - present
Russia	2000 - present
Sri Lanka	1986 - present
Thailand	1970 - present
Turkey	1984 - 2006
U.S.A.	1993 - present
Vietnam	1990s - present

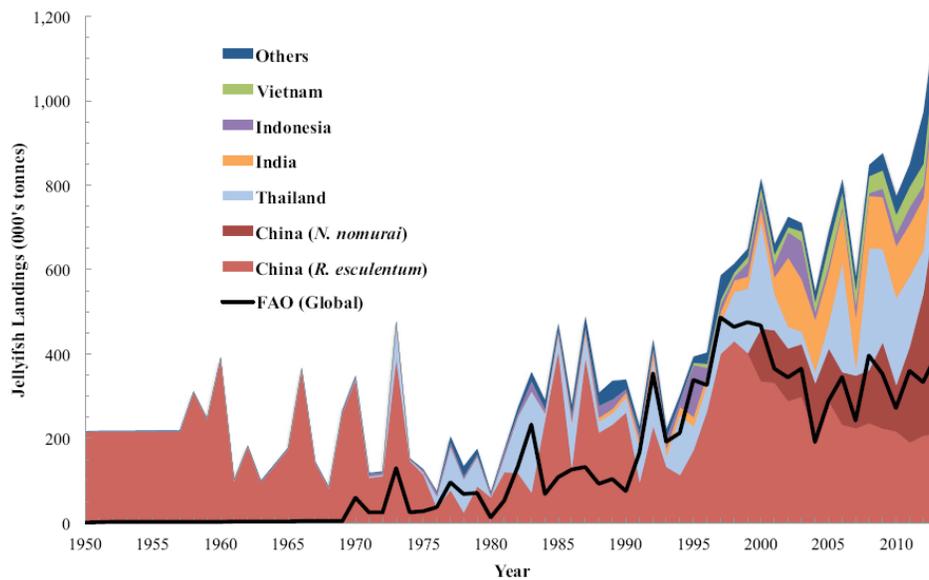


Figure 1. Estimated global jellyfish landings for two primary species in China and all species for other countries.

Other countries such as Indonesia, Japan, and Malaysia also had fisheries for jellyfish by the middle of the 20<sup>th</sup> century; however, the scale of these operations was small compared to China's. Thailand's jellyfish fisheries began in the 1960s or 1970s, and have expanded to the point where Thailand is now the world's second largest producer. More recently, significant fisheries for jellyfish have developed in India, Vietnam, and Mexico, resulting in a global catch that has exceeded 500,000 tonnes since 1997 (Figure 1), ironically the same year when world jellyfish catches "peaked" according to FAO statistics. FAO also reports (relatively small) catches from several countries that are not known to have jellyfish fisheries, including Namibia, the United Kingdom, and the Falkland Islands. We suspect that these reports are for discarded jellyfish that are caught as bycatch in other fisheries. While such catches should indeed be reported, they should also be differentiated from targeted landings. Clearly reporting to and by FAO needs to improve, especially in the case of jellyfish.

### STOCK ASSESSMENT FOR JELLYFISH FISHERIES

To understand and manage jellyfish fisheries, stock assessments are required which, if only for expediency, ought to draw as much as possible from the existing toolkit of fishery managers. These conceptual toolkits, and the mathematical models used to implement them, were mostly derived, however, from the study of bony fishes. This has misled many jellyfish specialists to assume, *a priori*, that standard models to describe the growth and mortality of teleosts would not apply to jellyfish (as is also often, and equally falsely, assumed for squids [89]). Instead, these specialists have studied jellyfish using a disparate array of concepts and models, with the result that few generalities have emerged which could help in optimizing the management of jellyfish fisheries or predicting growth and mortality patterns in unstudied jellyfish taxa.

The von Bertalanffy growth function (VBGF) is one of the standard models of fishery science; for length, the VBGF has the form

$$L_t = L_\infty \cdot \{1 - \exp[-K(t - t_0)]\} \quad (1)$$

where  $L_t$  is the length at age  $t$ ,  $L_\infty$  is the asymptotic length (roughly corresponding to the maximum length in the population in question),  $K$  is a parameter of dimension  $\text{time}^{-1}$ , expressing how fast  $L_\infty$  is approached, and  $t_0$  is the (usually negative) age at size = 0 (and not discussed further here).

The seasonal oscillations in the growth of fish and invertebrates can be very marked (Figure 2). A variant of the VBGF which accounts well for seasonal oscillation of growth in length [90] has the form

$$L_t = L_\infty \cdot \{1 - \exp[-K(t - t_0) + S(t) - S(t_0)]\} \quad (2)$$

where  $L_\infty$ ,  $K$  and  $t_0$  are defined as in the standard VBGF (see above), and where  $S(t) = (CK/2\pi) \cdot \sin \pi(t - t_s)$  and  $S(t_0) = (CK/2\pi) \cdot \sin \pi(t_0 - t_s)$ . This equation involves two parameters more than the standard VBGF:  $C$  and  $t_s$ . Of these, the former is easier to visualize, as it expresses the amplitude of the growth oscillations. When  $C = 0$ , the seasonally oscillating

VBGF reverts to the standard VBGF. When  $C = 0.5$ , the seasonal growth oscillations are such that growth rate increases by 50% at the peak of the ‘growth season,’ i.e., in ‘summer,’ and, briefly, declines by 50% in ‘winter.’ When  $C = 1$ , growth increases by 100%, i.e., doubles during ‘summer,’ and becomes zero in the depth of ‘winter.’ In fishes, moreover,  $C = 1$  when the difference in mean monthly SST in the hottest summer month is about 10°C higher than in the coldest month. For lower summer-winter differences,  $C$  is correspondingly lower.

The second new parameter,  $t_s$ , expresses the time between  $t = 0$  and the start of a sinusoid growth oscillation. For visualization, it helps to define  $t_s + 0.5 = WP$  (‘Winter Point’), which expresses, as a fraction of the year, the period when growth is slowest. WP is often near 0.1 (i.e., early February) in the northern and 0.6 (early August) in the southern hemisphere, hence the name. Note that it is not necessarily the alternation of high summer and low winter temperatures which causes the seasonal oscillations of growth. Also note that the seasonally oscillating VBGF cannot describe long periods of zero growth (and values of  $C > 1$ ; but see [91, 92]).

For weight, the VBGF takes the form

$$W_t = W_\infty \{1 - \exp[-K(t - t_0)]\}^b \quad (3)$$

with  $W_\infty$  being the weight corresponding to  $L_\infty$  as obtained through a length-weight relationship of the form  $W = a \cdot L^b$ . (Seasonally oscillating forms of the VBGF for weight exist [92], but are not discussed here).

Similarly, in fisheries research, the model most commonly used to represent the mortality of fish is

$$N_{t_2} = N_{t_1} \cdot \exp[Z(t_2 - t_1)] \quad (4)$$

where  $N_{t_1}$  and  $N_{t_2}$  are numbers at time  $t_1$  and  $t_2$  and  $Z$  is the instantaneous rate of total mortality, with  $Z = M+F$ , and  $M$  natural and  $F$  fishing mortality. The usefulness of this representation of mortality lies not only in that  $Z$  can be readily separated into its components, but also that the ratio  $M/K$ , which is an explicit parameter of various stock assessment models, tends to be constant within taxa.

The parameters of the VBGF (asymptotic sizes and  $K$ ) can be estimated by applying length-frequency analysis (LFA; [96]) to jellyfish bell diameter (i.e., ‘length’) frequency data [95]. To illustrate this, a selection of LFA methods, i.e., the ELEFAN method (Figure 2) and Wetherall plots for growth estimation, and length-converted catch curves for mortality estimation were applied to 34 sets of bell diameter frequency data of jellyfish. This led to the estimates of parameters of the VBGF and estimates of mortality (notably natural mortality;  $M$ ) useful for modeling the life history of jellyfish.

Note that the crucial step in estimating the parameters of the VBGF does not consist of the estimation of asymptotic bell diameter, for which the maximum size in a field sample usually provides a good approximation, nor with the parameters describing the seasonality of growth, which can be approximated from first principles. Rather, the crucial parameter of the VBGF is  $K$ . How well this parameter is estimated can be assessed by plots such as those shown in Figure 3, which are a standard feature of the ELEFAN procedure.

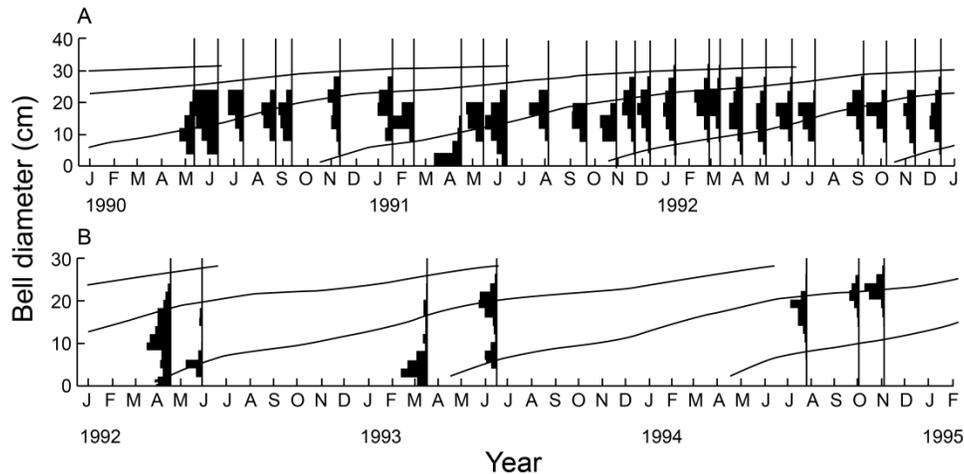


Figure 2. Jellyfish growth curve fitting with ELEFAN. Panel A: *Aurelia aurita* from Tokyo Bay, Japan in 1990-1992 (L/F data from [93]), with  $L_{\infty} = 35.5$  cm and  $K = 0.86$  year<sup>-1</sup> for fixed values of  $C = 0.5$  and  $WP = 0.1$ . Panel B: First 3 of the 6-years' L/F data of *Catostylus mosaicus* from Botany Bay, Australia sampled between March 1990 and February 1998 [94] with  $L_{\infty} = 37.0$  cm and  $K = 0.60$  year<sup>-1</sup> for fixed values of  $C = 0.5$  and  $WP = 0.7$ . These two growth curves were selected from thousands of alternatives using a search algorithm in ELEFAN (see Figure 5 and text). (Modified from [95]).

The applications of Wetherall plots (Figure 4A) and catch curves (Figure 4B) yielded the mean value of  $M/K$  for jellyfish that was estimated is about 3 year<sup>-1</sup>, about two times higher than the values reported for fishes, which usually range between 1 and 2 year<sup>-1</sup> [96]. This high value of  $M/K$  may be due to, at least in some cases, shrinkages of the bells of jellyfish [97], which could have biased the (fixed) interrelationships of number, size, and age, and which are assumed in LFA. Note that when  $K$  is underestimated by ELEFAN or other LFA,  $M$  is also underestimated (and conversely for overestimation), for which reason the above estimate of  $M/K$  should be robust.

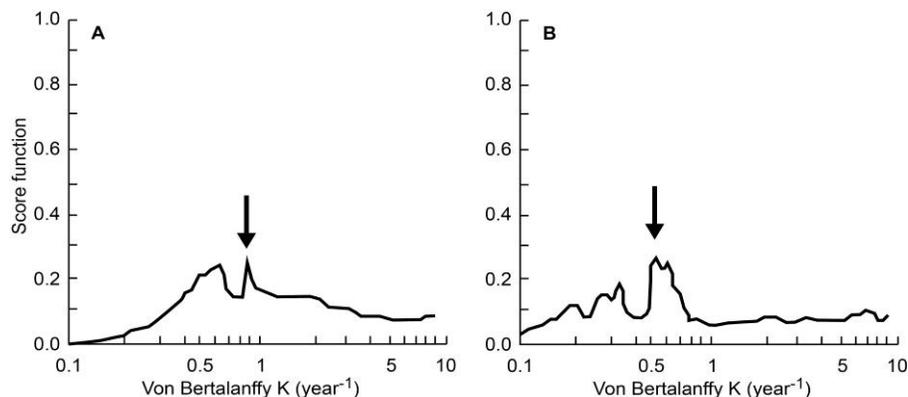


Figure 3. Examples of the goodness-of-fit estimator of ELEFAN in relation to  $K$ , as used to estimate this parameter (and to assess the uncertainty associated with the point estimate) when the other parameters of the seasonally oscillating VBGF ( $L_{\infty}$ ,  $C$ , and  $WP$ ) are known or assumed (see arrows). Panel A: for *Aurelia aurita* (see Figure 2A); the best fitting  $K$  value is not very distinct from adjacent values; hence, the best estimate of  $K$  ( $= 0.86$  year<sup>-1</sup>) is uncertain. Panel B: *Catostylus mosaicus* (see Figure 2B), for which  $K$  ( $= 0.60$  year<sup>-1</sup>) is more reliably estimated. (Modified from [95]).

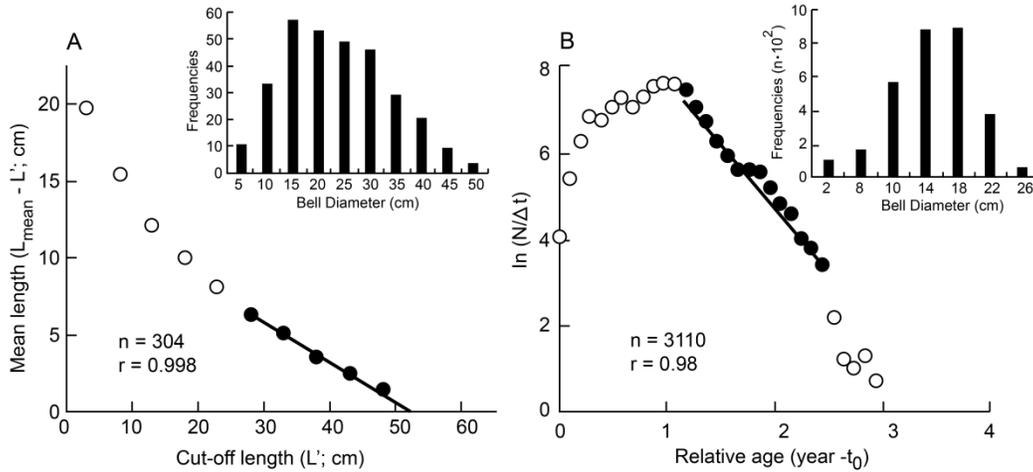


Figure 4. Methods to estimate M/K or Z from L/F data. Panel A: Wetherall Plot applied to a cumulative bell diameters of *Chrysaora melanaster* from the Bering Sea, USA (inset; from [98]) sampled in September 1996, 1997, and 1999. Only the lengths fully retained by the gear (straight section of graph; bell diameters >25 cm) are used for the regression, which yielded  $L_{\infty} = 56.3$  cm and  $Z/K = 2.86$ . Panel B: A catch curve applied to bell diameter data for *Aurelia aurita* in Tokyo Bay, Japan (inset; from [93]), sampled from May 1990 to December 1992. Using the von Bertalanffy growth parameters in Figure 2A, yields an estimate of  $Z = 2.95$  year<sup>-1</sup>. (Modified from [95]).

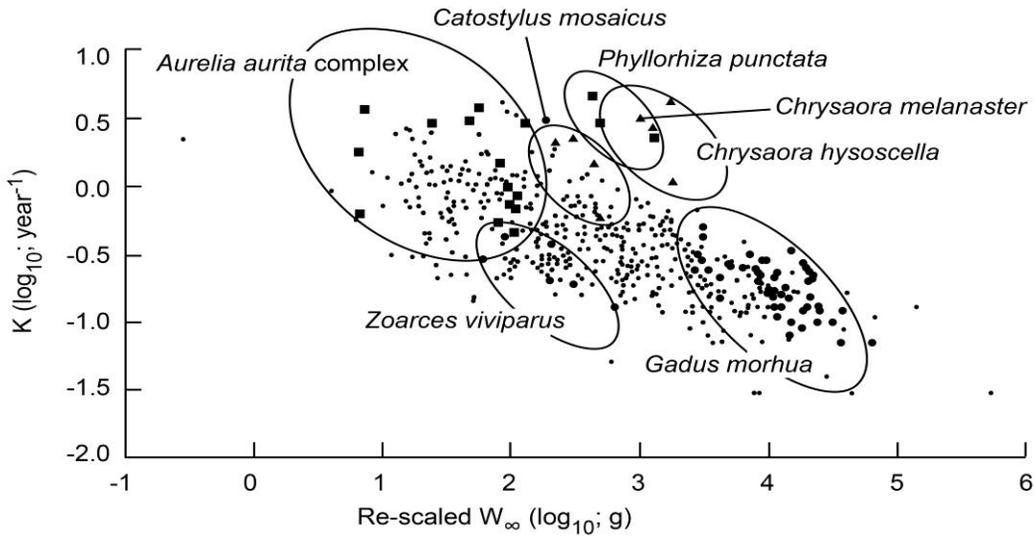


Figure 5. Auximetric plot of  $(\log_{10})K$  against re-scaled values of  $(\log_{10})W_{\infty}$  for the major groups of jellyfishes, on a background of grey dots representing fishes (including two highlighted species, *Zoarces viviparus* and *Gadus morhua*). As might be seen, the *Aurelia aurita* complex and *Catostylus mosaicus* resemble small fishes in their growth pattern, but *Chrysaora* spp. and *Phyllorhiza punctata* (and other species in [95]) may grow faster (higher K for a given  $W_{\infty}$ ) than fishes. (Modified from [95]).

Moreover, it was found that by scaling their asymptotic weight ( $W_{\infty}$ , a parameter of the VBGF) to the weight they would have if they had the same water content as fish, most jellyfish could be shown to grow at the same rate as small fishes. Thus, as in fish, the VBGF

parameters  $K$  and  $W_{\infty}$ , when plotted in a double logarithmic ('auximetric') plot, tend to cluster into ellipsoid shapes, which increase in area when shifting from species to genera, families, etc. (Figure 5). This potentially provides a powerful tool for testing comparative hypotheses on jellyfish life history. These results are compatible with the suggestion that the VBGF is not only a convenient mathematical function for describing the growth of jellyfish, but that it does so because their respiratory physiology makes this growth function, derived from physiological considerations, the model of choice [89, 92].

The auximetric plot in Figure 5, finally, suggests that some jellyfish (*Aurelia aurita* complex, *Catostylus mosaicus*), once their high water content is accounted for, have growth patterns similar to small and very small fishes, such as guppies and anchovies. Others (*Phyllorhiza punctata*, *Chrysaora* spp.) may grow faster than fishes (i.e., have higher values of  $K$  for their value of  $W_{\infty}$ ). However, the accuracy of the position of an organism on an auximetric plot depends on the accuracy of the growth parameters, and in the case of jellyfish, on a correct conversion to standard water content. Because of this, these results are still preliminary. However, it is encouraging that, as in fish (here exemplified by *Gadus morhua* and *Zoarcetes viviparus*, the different populations in a given species appear to form ellipsoid clusters on an auximetric plot (see [www.fishbase.org](http://www.fishbase.org) for more). Genera and higher taxa can be expected, as well, to form such clusters, albeit larger ones. This suggests that the large cluster for the *Aurelia aurita* complex would, indeed, include more than one species, as long suggested by taxonomists [99].

## CONCLUSION

An increasing number of countries have started fishing for jellyfish in recent years with the hopes of profitably exporting catches to East Asia (see Table 2). Often, this follows closely on the heels of collapses of more traditional fishery resources. While such 'fishing down' [100] may seem like an obvious progression, new jellyfish fisheries face a number of barriers to 'success.' With only a tiny fraction of the more than 1,200 species of jellyfish preferred for consumption, new processing techniques will need to be developed if other species are to meet some of the demand. Processing of jellyfish should also be improved to eliminate the associated concerns with human and environmental health. In addition, fluctuations due to changes in market demand should be considered for those hoping to develop jellyfish fisheries to supply Asian markets (e.g., higher demand for Chinese New Year celebrations).

Knowledge of the biology and ecology of most jellyfish species is limited, and as such, implementing management strategies is a challenge, especially given the tendency for jellyfish populations to fluctuate strongly [73]. Also, the reluctance of jellyfish researchers to even attempt at using standard models of fish stock assessment derived from studies of teleost fishes (as illustrated here) will have to be overcome, as there is no time to re-invent the wheel.

While fishing for jellyfish is likely to expand given the decline of fisheries around the world [81] and the local increases in jellyfish blooms [1], it is unlikely to solve our jellyfish problems [6] or feed the world.

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## REFERENCES

- [1] Brotz, L; Cheung, WWL; Kleisner, K; Pakhomov, E; Pauly, D. Increasing jellyfish populations: trends in Large Marine Ecosystems. *Hydrobiologia*, 2012, 690, 3-20.
- [2] Purcell, JE; Uye, S; Lo, WT. Anthropogenic causes of jellyfish blooms and their direct consequences for humans: a review. *Marine Ecology Progress Series*, 2007, 350, 153-174.
- [3] Graham, WM; Gelcich, S; Robinson, KL; Duarte, CM; Brotz, L; Purcell, JE; Madin, LP; Mianzan, H; Sutherland, KR; Uye, S-i, Pitt, KA; Lucas, CH; Bøgeberg, M; Brodeur, RD; Condon, RH. Linking human well-being and jellyfish: ecosystem services, impacts, and societal responses. *Frontiers in Ecology and the Environment*, 2014, 12, 515-523.
- [4] Richardson, AJ; Bakun, A; Hays, GC; Gibbons, MJ. The jellyfish joyride: causes, consequences and management responses to a more gelatinous future. *Trends in Ecology and Evolution*, 2009, 24, 312-322.
- [5] Purcell, J. Jellyfish and ctenophore blooms coincide with human proliferations and environmental perturbations. *Annual Review of Marine Science*, 2012, 4, 209-235.
- [6] Gibbons, MJ; Boero, F; Brotz, L. We should not assume that fishing jellyfish will solve our jellyfish problem. *ICES Journal of Marine Science*, 2016, 73, 1012-1018.
- [7] Miyawaki, A. Green Fluorescent Protein Glows Gold. *Cell*, 2008, 135, 987-990.
- [8] Nilsson, DE; Gislén, L; Coates, MM; Skogh, C; Garm, A. Advanced optics in a jellyfish eye. *Nature*, 2005, 435, 201-205.
- [9] Dabiri, JO. Jellyfish-inspired propulsion. *Integrative and Comparative Biology*, 2011, 51, E29.
- [10] Gemmell, BJ; Colin, SP; Costello, JH; Dabiri, JO. Suction-based propulsion as a basis for efficient animal swimming. *Nature Communications*, 2015, 6, 8790.
- [11] Costello, JH; Colin, SP; Gemmell, BJ; Dabiri, JO; Sutherland, KR. Multi-jet propulsion organized by clonal development in a colonial siphonophore. *Nature Communications*, 2015, 6, 8158.
- [12] Omori, M; Nakano, E. Jellyfish fisheries in southeast Asia. *Hydrobiologia*, 2001, 451, 19-26.
- [13] Brotz, L. Jellyfish fisheries - a global assessment. In Pauly, D, Zeller, D, editors. *Global Atlas of Marine Fisheries: A Critical Appraisal of Catches and Ecosystem Impacts*. Washington, D.C., U.S.A.: Island Press, 2016, 110-124.
- [14] You, K; Ma, CH; Gao, HW; Li, FQ; Zhang, MZ; Qiu, YT; Wang, B. Research on the jellyfish (*Rhopilema esculentum*) and associated aquaculture techniques in China: current status. *Aquaculture International*, 2007, 15, 479-488.
- [15] Hsieh, YHP; Rudloe, J. Potential of utilizing jellyfish as food in Western countries. *Trends in Food Science and Technology*, 1994, 5, 225-229.

- [16] CIESM. New partnerships for blue biotechnology development - innovative solutions from the sea. In: Briand, F, editor., *Report on CIESM International Workshop*, Monaco, 11-12 November 2010, The Mediterranean Science Commission.
- [17] Fukushi, K; Ishio, N; Tsujimoto, J; Yokota, K; Hamatake, T; Sogabe, H; Toriya, K; Ninomiya, T. Preliminary study on the potential usefulness of jellyfish as fertilizer. *Bulletin of the Society of Sea Water Science, Japan*, 2004, 58, 209-217.
- [18] Fukushi, K; Tsujimoto, J; Yokota, K. Determination of inorganic constituents in jellyfish. *Bunseki Kagaku*, 2005, 54, 175-178 (in Japanese with English abstract).
- [19] Chun, KW; Damdinsuren, E; Yeom, K; Ezaki, T. Effect of jellyfish fertilizer application on seedling growth. *Journal of the Japanese Society of Revegetation Technology*, 2011, 37, 155-158.
- [20] Kim, Y-R; Kim, S-W; Damdinsuren, E; Ezaki, T; Chun, KW. The effect of jellyfish (*Nemopilema nomurai*) fertilizer on tree growth in hillside erosion control works. *Journal of Forest and Environmental Science*, 2012, 28, 227-231.
- [21] Hossain, ST; Sugimoto, H; Asagi, N; Araki, T; Ueno, H; Morokuma, M; Kato, H. The use of desalinated-dried jellyfish and rice bran for controlling weeds and rice yield. *Journal of Organic Systems*, 2013, 8, 28-37.
- [22] Hussein, OS; Saleh, OI. Effect of soaking in jellyfish on some parameters of wheat and lentil seedlings. *Journal of Environmental Science, Toxicology and Food Technology*, 2014, 8, 32-39.
- [23] Hussein, OS; Sayed, RM; Saleh, OI. Uses of jellyfish in pre sowing seeds treatment and pest control. *American Journal of Experimental Agriculture*, 2015, 5, 60-69.
- [24] Seo, J-I; Kim, Y-R; Otsuki, K; Kim, S-W; Yeom, K-J; Yi, J-S; Ahn, Y-S; Ezaki, T; Chun, K-W. Contributions of jellyfish fertilizer to survival and growth of seedlings planted in a recently burned forest, Republic of Korea. *Journal of the Faculty of Agriculture, Kyushu University*, 2014, 59, 181-189.
- [25] Yu, HH; Liu, XG; Dong, XL; Li, CP; Xing, RE; Liu, S; Li, PC. Insecticidal activity of proteinous venom from tentacle of jellyfish *Rhopilema esculentum*. *Bioorganic and Medicinal Chemistry Letters*, 2005, 15, 4949-4952.
- [26] Yu, HH; Li, RF; Dong, XL; Xing, RG; Liu, S; Li, PC. Efficacy of venom from tentacle of jellyfish *Nemopilema nomurai* against the cotton bollworm *Helicoverpa armigera*. *Biomed Research International*, 2014.
- [27] Gopakumar, G; Madhu, K; Jayasankar, R; Madhu, R; Kizhakudan, JK; Josileen, J; Ignatius, B; Vijayagopal, P; Joseph, S; Mohamed, G, Varghese, M. Live feed research for larviculture of marine finfish and shellfish. editor. 2008, Marine Fisheries Information Service (197), Technical and Extension Series. Central Marine Fisheries Research Institute, Indian Council of Agricultural Research, Cochin, India, 2008.
- [28] Miyajima, Y; Masuda, R; Kurihara, A; Kamata, R; Yamashita, Y; Takeuchi, T. Juveniles of threadsail filefish, *Stephanolepis cirrhifer*, can survive and grow by feeding on moon jellyfish *Aurelia aurita*. *Fisheries Science*, 2011, 77, 41-48.
- [29] Miyajima, Y; Masuda, R; Yamashita, Y. Feeding preference of threadsail filefish *Stephanolepis cirrhifer* on moon jellyfish and lobworm in the laboratory. *Plankton and Benthos Research*, 2011, 6, 12-17.
- [30] Wakabayashi, K; Sato, R; Ishii, H; Akiba, T; Nogata, Y; Tanaka, Y. Culture of phyllosomas of *Ibacus novemdentatus* in a closed recirculating system using jellyfish as food. *Aquaculture*, 2012, 330, 162-166.

- [31] Liu, C-s; Chen, S-q; Zhuang, Z-m; Yan, J-p; Liu, C-l; Cui, H-t. Potential of utilizing jellyfish as food in culturing *Pampus argenteus* juveniles. *Hydrobiologia*, 2015, 754, 189-200.
- [32] Cho, S; Ahn, J-R; Koo, J-S; Kim, S-B. Physicochemical properties of gelatin from jellyfish *Rhopilema hispidum*. *Fisheries and Aquatic Sciences*, 2014, 17, 299-304.
- [33] Chanchareern, P; Laohakunjit, N; Kerdchoechuen, O; Thumthanaruk, B. Extraction of type A and type B gelatin from jellyfish (*Lobonema smithii*). *International Food Research Journal*, 2016, 23, 419-424.
- [34] Morabito, R; Dossena, S; La Spada, G; Marino, A. Heavy metals affect nematocysts discharge response and biological activity of crude venom in the jellyfish *Pelagia noctiluca*. *Cellular Physiology and Biochemistry*, 2014, 34, 244-254.
- [35] Templeman, MA; Kingsford, MJ. Trace element accumulation in *Cassiopea* sp. from urban marine environments in Australia. *Marine Environmental Research*, 2010, 69, 63-72.
- [36] Prabhu, MS. The perch fishery by special traps in the area around Mandapam in the Gulf of Mannar and Palk Bay. *Indian Journal of Fisheries*, 1954, 1, 94-129.
- [37] Thomas, PA. Goat fishes (Family Mullidae) of the Indian Seas. *Marine Biological Association of India Memoirs III*, 1969.
- [38] Omori, M; Kitamura, M. Taxonomic review of three Japanese species of edible jellyfish. *Plankton Biology and Ecology*, 2004, 51, 36-51.
- [39] Varghese, M; Kasinathan, C; Gandhi, A. Trap fishing in the Gulf of Mannar and Palk Bay, Marine Fisheries Information Service (197), Technical and Extension Series. Central Marine Fisheries Research Institute, Indian Council of Agricultural Research, Cochin, India, 2008.
- [40] Mianzan, H; Quiñones, J; Palma, S; Schiariti, A; Marcelo Acha, E; Robinson, KL; Graham, WM. *Chrysaora plocamia*: a poorly understood jellyfish from South America. In: Pitt KA, Lucas CH, editors. *Jellyfish Blooms*. Dordrecht: Springer; 2014; 219-236.
- [41] Belgorodsky, B; Fadeev, L; Hendler, N; Mentovich, E; Gozin, M; Richter, S; Reshef-Steinberger, L; Nudelman, R; Gulakhmedova, T. Jellyfish-derived polymer. United States Patent Application, Pub. No. US 2015/0335014 A1, Provisional Application No. 61/749,396 filed on January 7, 2013. Ramot at Tel-Aviv University Ltd., November 26, 2015.
- [42] Shamah, D. Israeli tech turns jellyfish into paper towels. Times of Israel, edition of April 8, 2014.
- [43] Patwa, A; Thiery, A; Lombard, F; Lilley, MKS; Boisset, C; Bramard, JF; Bottero, JY; Barthelemy, P. Accumulation of nanoparticles in "jellyfish" mucus: a bio-inspired route to decontamination of nano-waste. *Scientific Reports*, 2015, 5, 11387.
- [44] Zhuang, Y; Sun, L; Zhang, Y; Liu, G. Antihypertensive effect of long-term oral administration of jellyfish (*Rhopilema esculentum*) collagen peptides on renovascular hypertension. *Marine Drugs*, 2012, 10, 417-426.
- [45] Zhuang, Y; Sun, L; Li, B. Production of the angiotensin-I-converting enzyme (ACE)-inhibitory peptide from hydrolysates of jellyfish (*Rhopilema esculentum*) collagen. *Food and Bioprocess Technology*, 2012, 5, 1622-1629.
- [46] Rastogi, A; Biswas, S; Sarkar, A; Chakrabarty, D. Anticoagulant activity of moon jellyfish (*Aurelia aurita*) tentacle extract. *Toxicon*, 2012, 60, 719-723.

- [47] Ovchinnikova, TV; Balandin, SV; Aleshina, GM; Tagaev, AA; Leonova, YF; Krasnodembsky, ED; Men'shenin, AV; Kokryakov, VN. Aurelin, a novel antimicrobial peptide from jellyfish *Aurelia aurita* with structural features of defensins and channel-blocking toxins. *Biochemical and Biophysical Research Communications*, 2006, 348, 514-523.
- [48] Yin, MM; Liu, D; Xu, F; Xiao, L; Wang, QQ; Wang, BL; Chang, YL; Zheng, JM; Tao, X; Liu, GY; Zhang, L. A specific antimicrobial protein CAP-1 from *Pseudomonas* sp. isolated from the jellyfish *Cyanea capillata*. *International Journal of Biological Macromolecules*, 2016, 82, 488-496.
- [49] Yu, HH; Liu, XG; Xing, RE; Liu, S; Guo, ZY; Wang, PB; Li, CP; Li, PC. In vitro determination of antioxidant activity of proteins from jellyfish *Rhopilema esculentum*. *Food Chemistry*, 2006, 95, 123-130.
- [50] Zhuang, YL; Sun, LP; Zhao, X; Wang, JF; Hou, H; Li, BF. Antioxidant and melanogenesis-inhibitory activities of collagen peptide from jellyfish (*Rhopilema esculentum*). *Journal of the Science of Food and Agriculture*, 2009, 89, 1722-1727.
- [51] Balamurugan, E; Reddy, BV; Menon, VP. Antitumor and antioxidant role of *Chrysaora quinquecirrha* (sea nettle) nematocyst venom peptide against Ehrlich ascites carcinoma in Swiss Albino mice. *Molecular and Cellular Biochemistry*, 2010, 338, 69-76.
- [52] Zhuang, YL; Sun, LP; Zhao, X; Hou, H; Li, BF. Investigation of gelatin polypeptides of jellyfish (*Rhopilema esculentum*) for their antioxidant activity *in vitro*. *Food Technology and Biotechnology*, 2010, 48, 222-228.
- [53] Leone, A; Lecci, RM; Durante, M; Meli, F; Piraino, S. The bright side of gelatinous blooms: nutraceutical value and antioxidant properties of three Mediterranean jellyfish (Scyphozoa). *Marine Drugs*, 2015, 13, 4654-4681.
- [54] Rottini, G; Gusmani, L; Parovel, E; Avian, M; Patriarca, P. Purification and properties of a cytolytic toxin in venom of the jellyfish *Carybdea marsupialis*. *Toxicon*, 1995, 33, 315-326.
- [55] Gusmani, L; Avian, M; Galil, B; Patriarca, P; Rottini, G. Biologically active polypeptides in the venom of the jellyfish *Rhopilema nomadica*. *Toxicon*, 1997, 35, 637-648.
- [56] Li, CP; Yu, HH; Liu, S; Xing, RE; Guo, ZY; Li, PC. Factors affecting the protease activity of venom from jellyfish *Rhopilema esculentum*. *Bioorganic and Medicinal Chemistry Letters*, 2005, 15, 5370-5374.
- [57] Nishimoto, S; Goto, Y; Morishige, H; Shiraishi, R; Doi, M; Akiyama, K; Yamauchi, S; Sugahara, T. Mode of action of the immunostimulatory effect of collagen from jellyfish. *Bioscience Biotechnology and Biochemistry*, 2008, 72, 2806-2814.
- [58] Morishige, H; Sugahara, T; Nishimoto, S; Muranaka, A; Ohno, F; Shiraishi, R; Doi, M. Immunostimulatory effects of collagen from jellyfish *in vivo*. *Cytotechnology*, 2011, 63, 481-492.
- [59] Kawabata, T; Lindsay, DJ; Kitamura, M; Konishi, S; Nishikawa, J; Nishida, S; Kamio, M; Nagai, H. Evaluation of the bioactivities of water-soluble extracts from twelve deep-sea jellyfish species. *Fisheries Science*, 2013, 79, 487-494.
- [60] Leone, A; Lecci, RM; Durante, M; Piraino, S. Extract from the zooxanthellate jellyfish *Cotylorhiza tuberculata* modulates gap junction intercellular communication in human cell cultures. *Marine Drugs*, 2013, 11, 1728-1762.
- [61] Badre, S. Bioactive toxins from stinging jellyfish. *Toxicon*, 2014, 91, 114-125.

- [62] Mariottini, GL; Pane, L. Cytotoxic and cytolytic cnidarian venoms. A review on health implications and possible therapeutic applications. *Toxins*, 2014, 6, 108-151.
- [63] Nagai, T; Worawattanamateekul, W; Suzuki, N; Nakamura, T; Ito, T; Fujiki, K; Nakao, M; Yano, T. Isolation and characterization of collagen from rhizostomous jellyfish (*Rhopilema asamushi*). *Food Chemistry*, 2000, 70, 205-208.
- [64] Huang, HY; Tso, TK; Li, CH; Cheng, JW; Shen, WH. Isolation and partial characterization of collagen from edible *Rhopilema esculenta* jellyfish. *Faseb Journal*, 2005, 19, A1032-A1033.
- [65] Addad, S; Exposito, J-Y; Faye, C; Ricard-Blum, S; Lethias, C. Isolation, characterization and biological evaluation of jellyfish collagen for use in biomedical applications. *Marine Drugs*, 2011, 9, 967-983.
- [66] Krishnan, S; Perumal, P. Preparation and biomedical characterization of jellyfish (*Chrysaora quinquecirrha*) collagen from southeast coast of India. *International Journal of Pharmacy and Pharmaceutical Sciences*, 2013, 5, 698-701.
- [67] Barzideh, Z; Latiff, AA; Gan, C-Y; Abedin, MZ; Alias, AK. ACE inhibitory and antioxidant activities of collagen hydrolysates from the ribbon jellyfish (*Chrysaora* sp.). *Food Technology and Biotechnology*, 2014, 52, 495-504.
- [68] Barzideh, Z; Abd Latiff, A; Gan, C-Y; Benjakul, S; Abd Karim, A. Isolation and characterisation of collagen from the ribbon jellyfish (*Chrysaora* sp.). *International Journal of Food Science and Technology*, 2014, 49, 1490-1499.
- [69] Zhang, J; Duan, R; Huang, L; Song, Y; Regenstein, JM. Characterisation of acid-soluble and pepsin-solubilised collagen from jellyfish (*Cyanea nozakii* Kishinouye). *Food Chemistry*, 2014, 150, 22-26.
- [70] Derkus, B; Arslan, YE; Bayrac, AT; Kantarcioglu, I; Emregul, KC; Emregul, E. Development of a novel aptasensor using jellyfish collagen as matrix and thrombin detection in blood samples obtained from patients with various neurodisease. *Sensors and Actuators B: Chemical*, 2016, 228, 725-736.
- [71] Masuda, A; Baba, T; Dohmae, N; Yamamura, M; Wada, H; Ushida, K. Mucin (Qniumucin), a glycoprotein from jellyfish, and determination of its main chain structure. *Journal of Natural Products*, 2007, 70, 1089-1092.
- [72] Ohta, N; Sato, M; Ushida, K; Kokubo, M; Baba, T; Taniguchi, K; Urai, M; Kihira, K; Mochida, J. Jellyfish mucin may have potential disease-modifying effects on osteoarthritis. *BMC Biotechnology*, 2009, 9, 98.
- [73] Kingsford, MJ; Pitt, KA; Gillanders, BM. Management of jellyfish fisheries, with special reference to the Order Rhizostomeae. *Oceanography and Marine Biology*, 2000, 38, 85-156.
- [74] USDA, National Nutrient Database for Standard Reference, Release 28, 2015: United States Department of Agriculture, Agricultural Research Service, Nutrient Data Laboratory, Washington, D.C., U.S.A.
- [75] Hsieh, YHP; Leong, FM; Rudloe, J. Jellyfish as food. *Hydrobiologia*, 2001, 451, 11-17.
- [76] Armani, A; Tinacci, L; Giusti, A; Castiglioglio, L; Gianfaldoni, D; Guidi, A. What is inside the jar? Forensically informative nucleotide sequencing (FINS) of a short mitochondrial *COI* gene fragment reveals a high percentage of mislabeling in jellyfish food products. *Food Research International*, 2013, 54, 1383-1393.

- [77] Ogimoto, M; Suzuki, K; Kabashima, J; Nakazato, M; Uematsu, Y. Aluminium content in foods with aluminium-containing food additives. *Food Hygiene and Safety Science*, 2012, 53, 57-62 (in Japanese with English abstract).
- [78] Wong, WWK; Chung, SWC; Kwong, KP; Ho, YY; Xiao, Y. Dietary exposure to aluminium of the Hong Kong population. *Food Additives and Contaminants Part A - Chemistry Analysis Control Exposure and Risk Assessment*, 2010, 27, 457-463.
- [79] Zeller, D; Booth, S; Davis, G; Pauly, D. Re-estimation of small-scale fishery catches for US flag-associated island areas in the western Pacific: the last 50 years. *Fishery Bulletin*, 2007, 105, 266-277.
- [80] Zeller, D; Harper, S; Zylich, K; Pauly, D. Synthesis of underreported small-scale fisheries catch in Pacific island waters. *Coral Reefs*, 2015, 34, 25-39.
- [81] Pauly, D; Zeller, D. Catch reconstructions reveal that global marine fisheries catches are higher than reported and declining. *Nature Communications*, 2016.
- [82] Brotz, L, Jellyfish fisheries of the world: what's the catch? PhD Dissertation, University of British Columbia, Vancouver, Canada, 2016.
- [83] Dong, Z; Liu, D; Keesing, JK. Contrasting trends in populations of *Rhopilema esculentum* and *Aurelia aurita* in Chinese waters. In: Pitt KA, Lucas CH, editors. *Jellyfish Blooms*. Dordrecht, Netherlands: Springer, 2014; 207-218.
- [84] Li, J; Ling, J; Cheng, J. On utilization of two edible macro-jellyfish and evaluation of the biomass of *Nemopilema nomurai* in China Sea. *Marine Fisheries*, 2014, 36, 202-207 (in Chinese with English abstract).
- [85] Dong, J; Jiang, LX; Tan, KF; Liu, HY; Purcell, JE; Li, PJ; Ye, CC. Stock enhancement of the edible jellyfish (*Rhopilema esculentum*) in Liaodong Bay, China: a review. *Hydrobiologia*, 2009, 616, 113-118.
- [86] Dong, ZJ; Liu, DY; Keesing, JK. Jellyfish blooms in China: Dominant species, causes and consequences. *Marine Pollution Bulletin*, 2010, 60, 954-963.
- [87] Yan, L; Li, S; Ding, F. The preliminary studies on the dynamics of macro-jellyfish resources and their relationship with fisheries in the East China Sea and Yellow Sea. *Marine Fisheries*, 2004, 26, 9-12 (in Chinese with English abstract).
- [88] Uye, S. Blooms of the giant jellyfish *Nemopilema nomurai*: a threat to the fisheries sustainability of the East Asian Marginal Seas. *Plankton and Benthos Research*, 2008, 3, 125-131.
- [89] Pauly, D. Why squid, though not fish, may be better understood by pretending they are. *South African Journal of Marine Science*, 1998, 20, 47-58.
- [90] Somers, IF. On a seasonally oscillating growth function. *Fishbyte, Newsletter of the Network of Tropical Fisheries Scientists*, 1998, 6, 8-11.
- [91] Pauly, D; Soriano-Bartz, M; Moreau, J; Jarre-Teichmann, A. A new model accounting for seasonal cessation of growth in fishes. *Australian Journal of Marine and Freshwater Research*, 1992, 43, 1151-1156.
- [92] Pauly, D. Gasping Fish and Panting Squids: Oxygen, Temperature and the Growth of Water-Breathing Animals. Excellence in Ecology. Vol. 22. Oldendorf/Luhe, Germany: International Ecology Institute; 2010.
- [93] Omori, M; Ishii, H; Fujinaga, A. Life history strategy of *Aurelia aurita* and its impact on the zooplankton community of Tokyo Bay. *ICES Journal of Marine Science*, 1995, 52, 597-603.

- 
- [94] Pitt, KA; Kingsford, MJ. Temporal and spatial variation in recruitment and growth of medusae of the jellyfish, *Catostylus mosaicus*. *Marine and Freshwater Research*, 2003, 54, 117-125.
- [95] Palomares, MLD; Pauly, D. The growth of jellyfishes. *Hydrobiologia*, 2009, 616, 11-21.
- [96] Pauly, D. Beyond our original horizons: the tropicalization of Beverton and Holt. *Reviews in Fish Biology and Fisheries*, 1998, 8, 307-334.
- [97] Hamner, WM; Jenssen, RM. Growth, degrowth, and irreversible cell differentiation in *Aurelia aurita*. *American Zoologist*, 1974, 14, 833-849.
- [98] Brodeur, RD; Sugisaki, H; Hunt, GL. Increases in jellyfish biomass in the Bering Sea: implications for the ecosystem. *Marine Ecology Progress Series*, 2002, 233, 89-103.
- [99] Dawson, MN; Jacobs, DK. Molecular evidence for cryptic species of *Aurelia aurita*. *Biological Bulletin*, 2001, 200, 92-96.
- [100] Pauly, D; Christensen, V; Dalsgaard, J; Froese, R; Torres, F. Fishing down marine food webs. *Science*, 1998, 279, 860-863.