AGE, GROWTH, AND ABUNDANCE FLUCTUATION OF JORDAN'S DAMSEL, *TEIXEIRICHTHYS JORDANI* (ACTINOPTERYGII: PERCIFORMES: POMACENTRIDAE), IN THE SOUTHERN TAIWAN STRAIT

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Background. Information on the age, growth, and abundance fluctuation is important for fisheries conservation and management because stock assessment models rely on these biological parameters. However, the limited biological information makes it difficult to develop the proper and effective management for Jordan's damsel, *Teixeirichthys jordani* (Rutter, 1897), which is a part of commercial fisheries, exploited by trawl fishery in the southern Taiwan Strait. Therefore, this study would intend to provide the necessary information about the age, growth, and abundance fluctuation for this species to fill the gap in the current knowledge.

Materials and methods. Age and growth of Jordan's damsel were assessed based on 407 individuals collected in March–November 2006 from the southern Taiwan Strait. Sagittal otoliths were used for the age determination and growth parameters were estimated by three growth functions. According to the Akaike's Information Criterion corrected for small sample sizes (AICc), the best fitting model was selected. To explore drivers of the Jordan's damsel abundance in the southern Taiwan Strait, the Spearman rank correlation was used to discuss linkages between a time series (1994~2010) of catch per unit effort (CPUE) of Jordan's damsel and several forcing factors: fishing, sea surface temperature anomaly (SSTA), the Pacific Decadal Oscillation (PDO), and chlorophyll-a (CHL).

Results. The fish age ranged from 0 to 3 years; and the estimated growth parameters of the von Bertalanffy model (the best fitting model) were $L_\infty = 122.19$ mm (standard length), $k = 0.316$ year^{-1}, and $t_0 = -2.5477$. Spearman rank correlation indicated fishing effort ($P < 0.000$, $\rho = -0.826$), CHL ($P < 0.001$, $\rho = -0.780$), and PDO ($P < 0.000$, $\rho = 0.876$) were significant predictors of CPUE between 1994 and 2010, however SSTA was not a significant predictor of CPUE ($P = 0.294 > 0.05$).

Conclusion. *Teixeirichthys jordani* displayed positively allometric growth and this study providing population structure (size and age distribution) and growth parameters would be beneficial for population assessment and fishery management for Jordan's damsel. For Jordan's damsel in the southern Taiwan Strait, fishing may cause abundance fluctuations by affecting population dynamics, and biophysical conditions associated with PDO and El Niño-Southern Oscillation (ENSO) may be not adequate to affect the stock fluctuation though CHL and PDO were significant predictors of CPUE.

Keywords: age, growth, abundance fluctuation, *Teixeirichthys jordani*, Taiwan Strait

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INTRODUCTION

The Jordan's damsel, *Teixeirichthys jordani* (Rutter, 1897), a demersal fish belonging to the family Pomacentridae, distributed in the Indo-West Pacific including the Red Sea, Mozambique Channel, and also Australia, China, and Japan (Froese and Pauly 2019). The Jordan's damsel is a non-migratory species inhabiting corals and boulders (Khalaf 2004). In China, this species mainly occurs in the Taiwan Strait and the South China Sea, inhabiting sandy bottom with a depth range of 30~50 m (Zhu 1985). Jordan's damsel, which is important in the aquarium fish trade, is not exploited by commercial fisheries within the majority of its range (Khalaf et al. 2006). On the other hand, it is a part of commercial trawl fishery in the southern Taiwan Strait, the Minnan-Taiwan Bank fishing ground (MTBFG). The annual harvest of Jordan's damsel in the MTBFG accounted for 5.38% of the pair-trawl catches during 1977~1978 (Zhang and Zhang 1982) and for 1.6% of the single-trawl catches from 2000 to 2001 (Xiao 2007). While annual harvest of this species in the coastal waters of Nanpeng Islands accounted for 6.42% of the trawl catches in 1991 (Lin et al. 2000). During 1994~2010, the yield of this species has been exceeded 2×10^4 t in the MTBFG.

Growth assessment and understanding of growth patterns in fish are essential for stock assessment (Liu et al. 2009, Wells et al. 2013) and population dynamics (Van Beveren et al. 2014), and thus are important for species management and conservation (Pardo et al. 2013). However, only a little information on the age and growth of Jordan's damsel is available. Among the few studies, the first contribution on Jordan's damsel growth was made with samples from a New Caledonian lagoon, the length–weight relation ($W = 0.0197 \times L^{3.072}$) was provided by Kulbicki et al. (2005). And then, the length–weight relation for male ($W = 0.170 \times L^{2.002}$) and female ($W = 0.123 \times L^{2.121}$) of this species in Gulf of Aqaba, Jordan were studied (Al-Zibdah and Kan'an 2009). In China, Wang et al. (2011) analysed 69 species from the northern South China Sea and concluded that the length–weight relation of this species was $W = 0.048 \times L^{2.93}$. The exponent *b* from Kulbicki et al. (2005) study and Wang et al. (2011) study were similar and higher than those in Al-Zibdah and Kan'an (2009) study, while the parameter *a* in these studies was different. However, the von Bertalanffy growth model for *T. jordani* has not been provided.

Fluctuation of the fish population abundance may be an effect of fishing (Anderson et al. 2008), environmental fluctuations (Gong and Suh 2012), and/or life-history strategies (Yatsu et al. 2008). In fact, the abundance fluctuation of a dominant, economically important fish species can impact the health and food supply of human society that relies on these species, by influencing species distribution, reproduction, and extinction (Davis et al. 2005, Hsieh et al. 2006). Also, studying the abundance fluctuation can provide important implications for fishery monitoring and management (Clark 2010). However, there is little information about the population dynamics for *T. jordani*. A relative framework is urgently needed to study to the observed abundance fluctuation of the Jordan's damsel.

Therefore, the objectives of this paper were (1) to assess the best fitting growth function with the length-at-age data for Jordan's damsel off the southern Taiwan Strait; (2) to examine linkages between time series of catch per unit effort (CPUE) and several forcing factors: fishing, Sea Surface Temperature Anomalies (SSTA), Pacific Decadal Oscillation (PDO), and Chlorophyll-a (CHL); and (3) to preliminarily analyse growth characteristics and the factors that may cause the abundance fluctuation.

MATERIALS AND METHODS

The MTBFG as an upwelling fishing ground (Hong et al. 1991, Hu et al. 2003), located in the southern Taiwan Strait and acting as the interface between the East China Sea and the South China Sea, is impacted by the Zhe-Min Coastal Current (ZMCC), the Kuroshio Branch Water (KBW), and the South China Sea Warm Current (SCSWC) (Jan et al. 2002) (Fig 1), therefore it offers an ideal habitat to Jordan's damsel because it provides adequate nutrients and high production to abundant marine organisms (Hong et al. 1999).

Fish collection. Jordan's damsel individuals were collected in March–November 2006 off the southern Taiwan Strait. A total of 407 fish specimens were caught from 11 stations during the sampling period by using a single trawler (Fig. 1). The trawl net was 42 m in length and 70 m in entrance perimeter, and the mesh size was 16 mm. The duration of each haul varied from 1 to 3 h with an average ship speed of 2.9 knots (5.4 km · h⁻¹). All individuals were measured for standard length and weighed with an accuracy of 1 mm and 1 g, respectively.

Catches and fishing efforts. Catches and fishing vessels of this species were collected from 1994 to 2010 in the MTBFG. In this study, the CPUE has been used to represent abundance (Maunder and Punt 2004) and is estimated as catches·number of fishing vessels⁻¹.

Environmental data. The Sea Surface Temperature (SST) from 1994 to 2010 for the MTBFG were obtained from Advanced Very High-Resolution Radiometer (AVHRR*) and Moderate Resolution Imaging Spectroradiometer (MODIS**) at a spatial resolution of 4 km. Among them, the SST values from 1993 to 2002 were all obtained from the AVHRR. The SST values from 2003 to 2009 were obtained from the mean value of the AVHRR and MODIS, and the SST in 2000 was obtained from the MODIS. As a proxy indicator of the productivity, monthly mean values of the CHL were obtained from the sea-viewing Wide Field-of-View satellite sensor (Sea WiFS***) at a spatial resolution of 9 km. These records were only available for the period 1997~2010. The PDO values were obtained from the website****. Values of SST, CHL, and PDO were converted to annual means.

Age determination. Sagittal otoliths were cleaned, dried, and their radius was measured to the nearest 0.01 mm. Otoliths were

embedded in epoxy resin and cut into 500-μm thick transverse sections with a diamond blade. Two readers independently estimated the fish age, and the results were used only if the age readings matched each other. If they were not consistent, a third reader was asked to resolve the disagreement. If all third reads were not the same, the individual was excluded from growth analysis and statistical tests.

Length–weight relation (LWR). LWR was based on the allometric equation (Sparre and Venema 1992)

$$W = a \times L_s^{\ b}$$

where W is the weight of the fish [g], L_s is the standard length [mm], a is a coefficient related to body form, and b is an exponent indicating isometric or allometric growth (Froese 2006). The t-test was used for testing isometric growth when $b = 3$.

Growth modelling. Three models were used to fit length-at-age data:

The von Bertalanffy growth function (VBGF, von Bertalanffy 1938)

$$L_s = L_\infty \left(1 - e^{-k(t - t_0)}\right)$$

The Gompertz growth function (GGF, Gompertz 1825)
$$L_s = L_\infty e^{-e^{-k(t - t_0)}}$$

The Robertson growth function (RGF, Ricker 1975)

$$L_s = L_\infty \left(1 + e^{-k(t - t_0)}\right)^{-1}$$

where L_s is the standard length, L_∞ is the asymptotic standard length, k is the growth coefficient, t is the age and t_0 is the theoretical age when length equals zero. The Akaike's Information Criterion corrected for small sample sizes (AICc) (Katsanevakis 2006) was used to selection of the best fitting model with the smallest AICc.
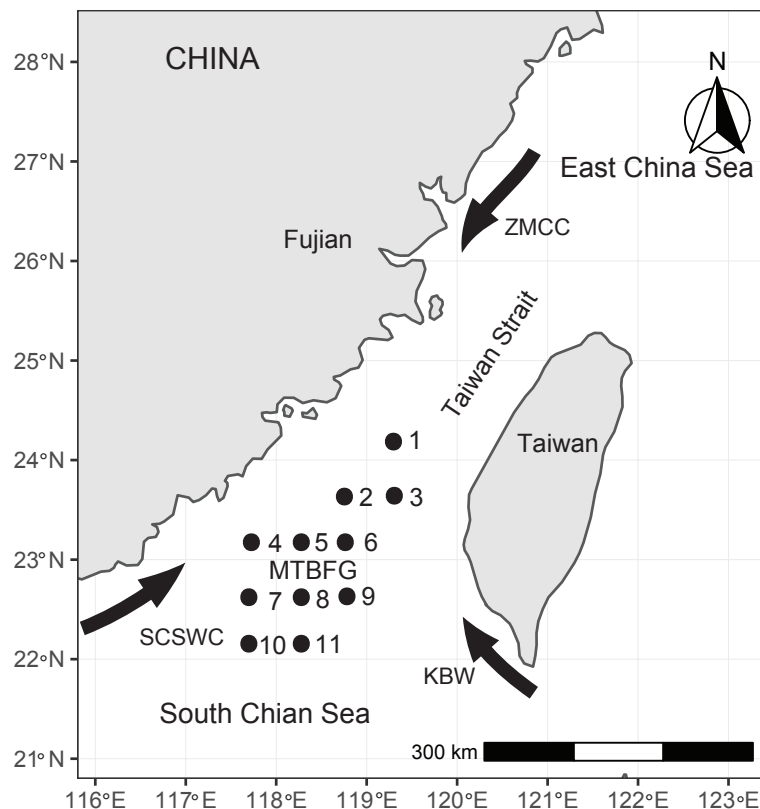
$$AIC_c = nlog\frac{RSS}{n} + 2K + \frac{2K(K+1)}{n - K - 1}$$

where n was the sample size, RSS was the residual sum of squares, K was the number of estimated parameters.

Spearman rank correlation. To explore the effects of SSTA (mean value of SST), PDO, and CHL on Jordan's damsel CPUE, Spearman rank correlation, which evaluates monotonic connections between two factors (Spearman 1906), were implemented. Spearman's coefficient (ρ) was estimated as

$$\rho = 1 - \frac{6 \times \sum d_i^2}{n(n^2 - 1)}$$

where d^2 is the squared rank differences between variables and n is the number of samples.
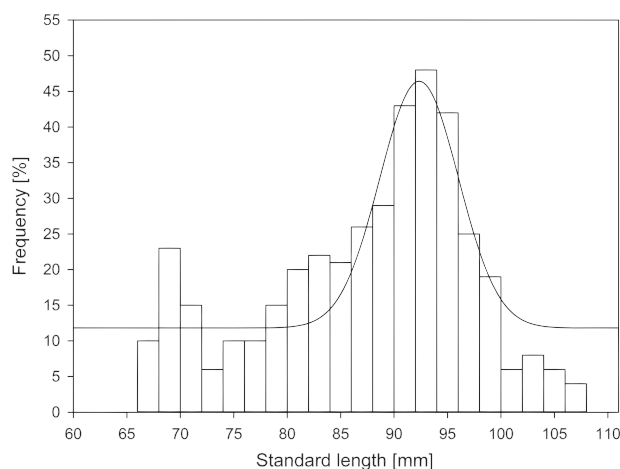

Fig. 1. Sampling area and survey stations (denoted by numbers) of the Jordan's damsel, *Teixeirichthys jordani*, in the southern Taiwan Strait in 2006; the ZMCC, KBW, and SCSWC are the Zhe-Min Coastal Current, the Kuroshio Branch Water, and the South China Sea Warm Current, respectively

RESULTS

Size and age estimations. The standard length of Jordan's damsel ranged from 67 mm to 107 mm (Fig. 2). The overall mean standard length (± standard deviation SD) of this species was 87.49 ± 9.65 mm. The dominant group for standard length was 71~100 mm and it accounted for 83.78% (n = 341). The age values for Jordan's damsel ranged from 0 to 3 years. The majority of individuals were aged 1± (28.26%) and 2± (48.89%). The mean value and 95% confidence interval of per year class were estimated (Fig. 3).

Growth estimation. The LWR was significant (P < 0.001) and had high value of R^2 (R^2 = 0.986). The species in the MTBFG displayed allometric growth (b > 3, t-test, t = 4.71, df = 405, P < 0.001). The LWR was W = 0.036 $L_s^{3.09\,9}$ (Fig. 4), and the 95% confidence interval of coefficient a and exponent b were 0.033–0.040 and 3.058–3.139, respectively. The lowest AICc indicated that the VBGF was the best fitting model for this species (Table 1). VBGF (L_s) of Jordan's damsel was the non-inflexion point curve, which increased with age and tended to the asymptotic value. The growth model parameters were 122.19 mm L_s for L_∞, 0.316 year^{-1} for k, and 2.548 for t_0 (Fig. 3).
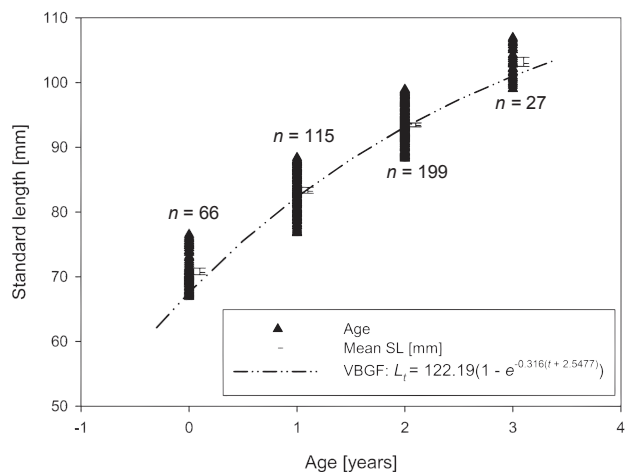
Abundance fluctuation. The CPUE time series showed two decreasing periods and one short increasing period (Fig. 5). During the first decreasing period (1994~2001), CPUE decreased dramatically from the highest value (9.759 t · vessel^{-1} in 1994) to the lowest value (6.131 t · vessel^{-1} in 2001). Then CPUE reached a small peak in 2003; meanwhile, the fishing effort decreased dramatically and reached the lowest value in 2003. Thereafter, CPUE steadily decreased from 2003 to 2010, although the catches were increasing (Fig. 5). Spearman rank correlation indicated sea surface temperature anomaly (SSTA) was not a significant predictor of the CPUE (P = 0.294 > 0.05). The fishing effort (P < 0.000, ρ = −0.826), CHL (P < 0.001, ρ = −0.780), and PDO (P < 0.000, ρ = 0.876) were significant predictors of the CPUE between 1994 and 2010.

DISCUSSION

Growth characteristics. This is the first study to select the best fitting model among the three growth functions. VBGF is considered the common growth model applied in fisheries science (Katsanevakis 2006, Katsanevakis and Maravelias 2008), although this model is not always the best fitting model for some species such as *Thunnus albacares* (Bonnaterre, 1788) (see Katsanevakis 2006), *Carcharhinus acronotus* (Poey, 1860) (see Barreto et al. 2011), *Galeus sauteri* (Jordan et Richardson, 1909) (see Liu et al. 2011), *Bathyraja interrupta* (Gill et Townsend, 1897) (see Ainsley et al. 2014), and others. For Jordan's damsel the VBGF was the best fitting model. Results of this study provide population structure (size and age distribution) and growth parameters that could provide the essential information and input parameters for population dynamics and conservation.

Fig. 3. Data on age–length distribution for Jordan's damsel, *Teixeirichthys jordani*, sampled from the southern Taiwan Strait in 2006, distributed for 1-year intervals; mean and 95% confidence interval per year class are shown; von Bertalanffy growth model is also included; n is the number of individuals in different age groups
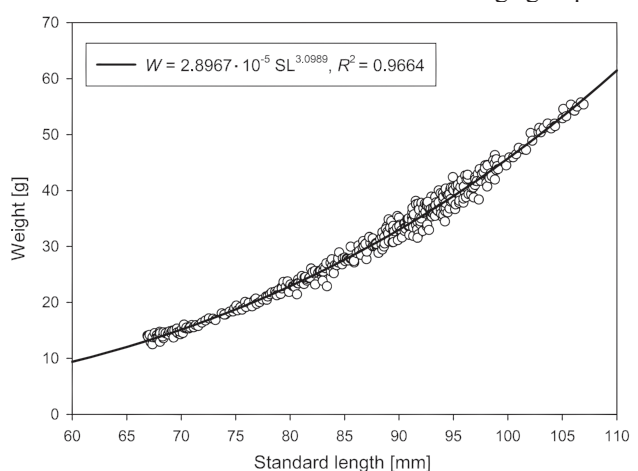

Fig. 2. Length-frequency distributions (absolute numbers) of Jordan's damsel, *Teixeirichthys jordani*, sampled from the southern Taiwan Strait in 2006

Fig 4. The relation between standard length and weight of Jordan's damsel, *Teixeirichthys jordani*, sampled from the southern Taiwan Strait in 2006

In addition, the exponent *b* of LWR, which was the indicator about isometric growth, was higher than those presented in the studies of Al-Zibdah and Kan'an (2009) and Wang et al. (2011) but similar to that of Kulbicki et al. (2005) study, and the species displayed positively allometric growth (*b* > 3). Specific ecological factors, such as distinct population segment, population density, environment temperature, and prey density, may cause the exponent *b* to vary in different sea areas (Ju et al. 2016).

Abundance fluctuation. Many factors, such as fishing (Myers and Worm 2003, Smith et al. 2011), environmental variation (Moran 1953, Fieberg and Ellner 2001) and predator–prey interactions (Rosenzweig and MacArthur 1963, Kareiva 1987), can affect population dynamics, thus cause abundance fluctuations.

However, among all the potential driven factors, fishing is often blamed as a prime reason affecting the quantity fluctuation of fish (Myers and Worm 2003, Smith et al. 2011) and increases population fluctuations (Hsieh et al. 2006) by increasing population growth rates (Shelton and Mangel 2011). The fishing targets a large number of individuals, thus the quantity of fish stock decreases sharply. Moreover, the reduction in stock density relaxed intra-specific competition, enhanced the food availability and increased the growth rates in the remaining stock (density-dependent effect) (Ferreri and Taylor 1996), which increase the abundance fluctuations. For Jordan's damsel

in the MTBFG, abundance (CPUE) sharply decreased with the high level of fishing effort during 1994~1999; then abundance reached a small peak with dramatically decreasing fishing effort and slightly increasing catches from 2000 to 2006; thereafter, abundance continuously declined with the increasing fishing effort under the circumstance of the catches rising (Fig. 5). It indicated that fishing had negative effects on the abundance of Jordan's damsel. Similarly, fishing had a significant negative effect on the CPUE of larval anchovy in the coastal waters of south-western Taiwan (Chu-fa et al. 1996).
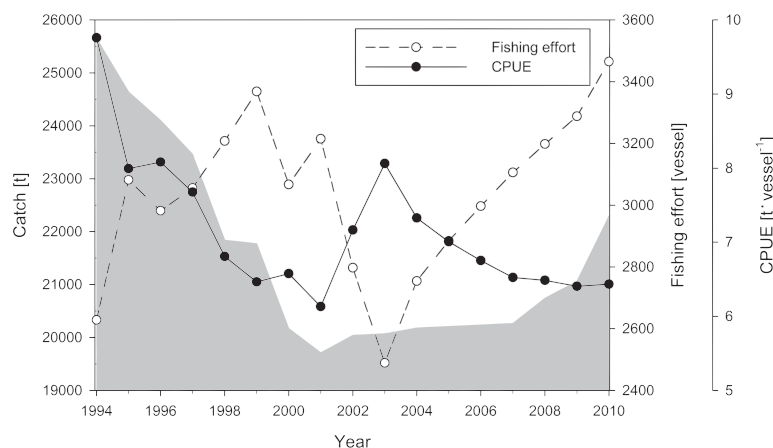
In addition, the fish population dynamics forced by environmental changes are well recorded through comparisons of time-series of catches and the large-scale climatic forcing indices (Beamish 1995, Hare and Mantua 2000, McFarlane et al. 2000, Pörtner and Peck 2010). Climate forcing indexes such as PDO and El Niño-Southern Oscillation (ENSO) can affect biological productivity by changing biophysical processes (Chavez et al. 2003, Yatsu et al. 2005). In the southern Taiwan Strait, climatic forcing indexes affected the physical and biogeochemical processes. For example, in the year of El Niño (EN, warm phase) in summer, the weaker southwest monsoon prevents the warm current from moving northward (Kuo and Ho 2004) and only one weak upwelling occurs in the region (He 1988, Hong et al. 1999). While the reduced northeast monsoon impedes the cold and eutrophic ZMCC from southward spreading into the Taiwan Strait and strengthens the northward invading of the SCSWC and KBW in EN in winter, therefore, the water in EN event of the MTBFG becomes warmer and less nutrient-rich than that in La Niña (LN, cool phase) event (Shang et al. 2005). Correspondingly, primary production and zooplankton biomass were lower in EN event than that in LN event (Shang et al. 2011). When the EN events originated in 1997~1998 and 2002~2003, the SST began to increase and CHL was lower (possibly occurred before or after the EN) in the MTBFG. Similarly, CHL in warm phase (positive PDO) was lower than that in the cool phase (negative PDO) (Fig. 6). As seen in the MTBFG, it is not true that Jordan's damsel abundance was lower in EN event

Table 1

The Akaike's Information Criterion corrected (AICc) of the von Bertalanffy growth function (VBGF), the Gompertz growth function (GGF) and the Robertson growth function (RGF)

Model	*n*	*K*	RSS/*n*	AICc
VBGF	407	3	8.567	385.721
GGF	407	3	8.584	386.071
RGF	407	3	8.605	386.503

n = number of fish, *K* = number of estimated parameters.

Fig. 5. Catch (shaded area), fishing effort, and Catch Per Unit Effort (CPUE) of Jordan's damsel, *Teixeirichthys jordani*, from 1994 to 2010 in the Minnan-Taiwan Bank fishing ground (southern Taiwan Strait)

or in the warm phase (Fig. 6). High primary production (CHL) and zooplankton biomass in the cool phase may lead to Jordan's damsel abundance (CPUE) increase due to the bottom-up effect (Verheye 2000, Hernández-Miranda and Ojeda 2006), however, abundance declines as CHL increase and increase with the positive PDO (warm phase) (Fig. 6). Moreover, fishing effort has a strongly negative effect on abundance (Fig. 5), and the value of abundance is relative higher under the lowest fishing effect even if EN event (2002~2003) or warm phase caused the lower productivity (Fig. 5 and 6). In conclusion, for Jordan's damsel in the MTBFG, fishing may cause abundance fluctuations by affecting population dynamics, and biophysical conditions associated with PDO and ENSO may be not adequate to affect the abundance fluctuation although PDO ($P <$ 0.000, ρ = 0.876), and CHL ($P <$ 0.001, ρ = −0.780) were significant predictors of Jordan's damsel abundance.

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REFERENCES

Ainsley S.M., Ebert D.A., Natanson L.J., Cailliet G.M. 2014. A comparison of age and growth of the Bering skate, *Bathyraja interrupta* (Gill and Townsend, 1897), from two Alaskan large marine ecosystems. Fisheries Research **154**: 17–25. DOI: 10.1016/j. fishres.2014.02.002

Al-Zibdah M., Kan'an N. 2009. Aspects of growth, reproduction, and feeding habit of three pomacentrid fish from Gulf of Aqaba, Jordan. Jordan Journal of Biological Sciences **2** (3): 119–127.

Anderson C.N.K., Hsieh C.-H., Sandin S.A., Hewitt R., Hollowed A., Beddington J., May R.M., Sugihara G. 2008. Why fishing magnifies fluctuations in fish abundance. Nature **452** (7189): 835–839. DOI: 10.1038/nature06851

Barreto R.R., Lessa R.P., Hazin F.H., Santana F.M. 2011. Age and growth of the blacknose shark, *Carcharhinus acronotus* (Poey, 1860) off the northeastern Brazilian Coast. Fisheries Research **110** (1): 170–176. DOI: 10.1016/j.fishres.2011.04.003
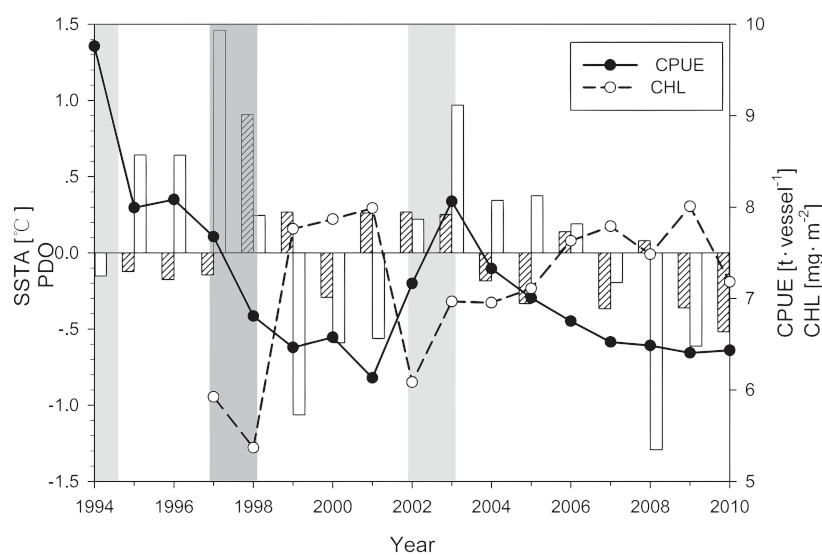
Beamish R.J. 1995. Climate change and northern fish populations. Canadian Special Publication of Fisheries and Aquatic Sciences No. 121.

Chavez F.P., Ryan J., Lluch-Cota S.E., Ñiquen M. 2003. From anchovies to sardines and back: Multidecadal change in the Pacific Ocean. Science **299** (5604): 217–221. DOI: 10.1126/science.1075880

Chu-fa T., Chen P.-y., Lee M.-a., Hsia K.-y., Lee K.-t. 1996. Effects of fishing effort on stock size and catch of larval anchovy in coastal waters of southwestern Taiwan. Fisheries research **28** (1): 71–83. DOI: 10.1016/0165-7836(96)00474-2

Clark C.W. 2010. Mathematical bioeconomics: The mathematics of conservation. 3rd edn. John Wiley and Sons, Hoboken NJ, USA.

Davis S., Calvet E., Leirs H. 2005. Fluctuating rodent populations and risk to humans from rodent-borne

Fig. 6. Sea surface temperature anomalies (SSTA), Pacific Decadal Oscillation (PDO), Catch Per Unit Effort (CPUE), and chlorophyll-a (CHL) in the Minnan-Taiwan Bank fishing ground (MTBFG); the diagonally striped bars indicate SSTA; the white bars indicate PDO; the dark-grey bars indicate the strong El Niño-Southern Oscillation (ENSO) occurred in 1997~1998 (El Niño); the light-grey bars indicate the weak ENSO events occurred in 1993~1994 (La Niña) and 2002~2003 (El Niño)

zoonoses. Vector-Borne and Zoonotic Diseases **5** (4): 305–314. DOI: 10.1089/vbz.2005.5.305

Ferreri C.P., Taylor W.W. 1996. Compensation in individual growth rates and its influence on lake trout population dynamics in the Michigan waters of Lake Superior. Journal of Fish Biology **49** (5): 763–777. DOI: 10.1111/j.1095-8649.1996.tb00077.x

Fieberg J., Ellner S.P. 2001. Stochastic matrix models for conservation and management: A comparative review of methods. Ecology Letters **4** (3): 244–266. DOI: 10.1046/j.1461-0248.2001.00202.x

Froese R. 2006. Cube law, condition factor and length–weight relationships: History, meta-analysis and recommendations. Journal of Applied Ichthyology **22** (4): 241–253. DOI: 10.1111/j.1439-0426.2006.00805.x

Froese R., Pauly D. (eds.) 2019. FishBase. [Version 02/2019] http://*www.fishbase.org*

Gompertz B. 1825. [XXIV.] On the nature of the function expressive of the law of human mortality, and on a new mode of determining the value of life contingencies. In a letter to Francis Baily, Esq. F.R.S. & c. Philosophical Transactions of the Royal Society of London **115** (2): 513–583. DOI: 10.1098/rstl.1825.0026

Gong Y., Suh Y.-S. 2012. Climate change and fluctuations of pelagic fish populations in the Far East region. Journal of Ecology and Environment **35** (1): 15–25. DOI: 10.5141/JEFB.2012.003

Hare S.R., Mantua N.J. 2000. Empirical evidence for North Pacific regime shifts in 1977 and 1989. Progress in Oceanography **47** (2–4): 103–145. DOI: 10.1016/S0079-6611(00)00033-1

He F.X. 1988. [Evolution of upwellings in Minnan-Taiwan Bank fishing ground and its relationship with fishery.] Acta Oceanologica Sinica **10** (3): 346–351. [In Chinese.]

Hernández-Miranda E., Ojeda F.P. 2006. Inter-annual variability in somatic growth rates and mortality of coastal fishes off central Chile: An ENSO driven process? Marine Biology **149** (4): 925–936. DOI: 10.1007/s00227-006-0249-9

Hong H.S., Qiu S.Y., Ruan W.Q., Hong G.C. 1991. Minnan-Taiwan Bank fishing ground upwelling ecosystem study. Pp. 1–17. *In*: Xu B.Z., Xia S.R. (eds.) Minnan-Taiwan Bank fishing ground upwelling ecosystem study. Science Press, Beijing, China.

Hong H.S., Wang H.L., Huang B.Q. 1999. Primary production processes in the Taiwan Strait—Spatial and temporal variations of phytoplankton biomass and productivity. Acta Oceanologica Sinica **18** (3): 423–433.

Hsieh C.-h., Reiss C.S., Hunter J.R., Beddington J.R., May R.M., Sugihara G. 2006. Fishing elevates variability in the abundance of exploited species. Nature **443** (7113): 859–862. DOI: 10.1038/nature05232

Hu J., Kawamura H., Hong H., Pan W. 2003. A review of research on the upwelling in the Taiwan Strait. Bulletin of Marine Science **73** (3): 605–628.

Jan S., Wang J., Chern C.-S., Chao S.-Y. 2002. Seasonal variation of the circulation in the Taiwan Strait. Journal of Marine Systems **35** (3–4): 249–268. DOI: 10.1016/S0924-7963(02)00130-6

Ju P.-L., Yang L., Lu Z.-B., Yang S.-Y., Du J.-G., Zhong H.-Q., Chen J., Xiao J.-M., Chen M.-R., Zhang C.-Y. 2016. Age, growth, mortality and population structure of silver croaker *Pennahia argentata* (Houttuyn, 1782) and red bigeye *Priacanthus macracanthus* Cuvier, 1829 in the north-central Taiwan Strait. Journal of Applied Ichthyology **32** (4): 652–660. DOI: 10.1111/jai.13053

Kareiva P. 1987. Habitat fragmentation and the stability of predator–prey interactions. Nature **326** (6111): 388–390. DOI: 10.1038/326388a0

Katsanevakis S. 2006. Modelling fish growth: Model selection, multi-model inference and model selection uncertainty. Fisheries Research **81** (2–3): 229–235. DOI: 10.1016/j.fishres.2006.07.002

Katsanevakis S., Maravelias C.D. 2008. Modelling fish growth: Multi model inference as a better alternative to a priori using von Bertalanffy equation. Fish and Fishery **9**: 178–187. DOI: 10.1111/j.1467-2979.2008.00279.x

Khalaf M. 2004. Some fishes from the Jordanian coast of the Gulf of Aqaba. Journal of King Abdulaziz University, Marine Sciences **15**: 23–50.

Khalaf M.A., Al-Horani F.A., Al-Rousan S.A., Manasrah R.S. 2006. Community structure of the family Pomacentridae along the Jordanian coast, Gulf of Aqaba, Red Sea. Zoology in the Middle East **37** (1): 47–62. DOI: 10.1080/09397140.2006.10638148

Kulbicki M., Guillemot N., Amand M. 2005. A general approach to length–weight relationships for New Caledonian lagoon fishes. Cybium **29** (3): 235–252.

Kuo N.-J., Ho C.-R. 2004. ENSO effect on the sea surface wind and sea surface temperature in the Taiwan Strait. Geophysical Research Letters **31** (13): L13309. DOI: 10.1029/2004GL020303

Lin X.Q., Lin G.L., Lin J.H., Yang F.L. 2000. [Studies on seasonal changes of species components of fishes caught by bottom trawl in coastal waters of Nanpeng Islands.] Journal of Oceanography in Taiwan Strait **19** (4): 511–522. [In Chinese.]

Liu K.-M., Lee M.-L., Joung S.-J., Chang Y.-C. 2009. Age and growth estimates of the sharptail mola, *Masturus lanceolatus*, in waters of eastern Taiwan. Fisheries Research **95** (2–3): 154–160. DOI: 10.1016/j.fishres.2008.08.013

Liu K.-M., Lin C.-P., Joung S.-J., Wang S.-B. 2011. Age and growth estimates of the blacktip sawtail catshark *Galeus sauteri* in northeastern waters of Taiwan. Zoological Studies **50** (3): 284–295.

Maunder M.N., Punt A.E. 2004. Standardizing catch and effort data: A review of recent approaches. Fisheries Research **70** (2–3): 141–159. DOI: 10.1016/j.fishres.2004.08.002

McFarlane G.A., King J.R., Beamish R.J. 2010. Have there been recent changes in climate? Ask the fish. Progress in Oceanography **47** (2–4): 147–169. DOI: 10.1016/S0079-6611(00)00034-3

Moran P.A.P. 1953. The statistical analysis of the Canadian lynx cycle. Australian Journal of Zoology **1** (3): 291–298. DOI: 10.1071/ZO9530291

Myers R.A., Worm B. 2003. Rapid worldwide depletion of predatory fish communities. Nature **423** (6937): 280–283. DOI: 10.1038/nature01610

Pardo S.A., Cooper A.B., Dulvy N.K. 2013. Avoiding fishy growth curves. Methods in Ecology and Evolution **4** (4): 353–360. DOI: 10.1111/2041-210x.12020

Pörtner H.O., Peck M.A. 2010. Climate change effects on fishes and fisheries: Towards a cause-and-effect understanding. Journal of Fish Biology **77** (8): 1745–1779. DOI: 10.1111/j.1095-8649.2010.02783.x

Ricker W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of Fisheries Research Board of Canada No. 191.

Rosenzweig M.L., MacArthur R.H. 1963. Graphical representation and stability conditions of predator-prey interactions. American Naturalist **97** (895): 209–223. DOI: 10.1086/282272

Shang S., Dong Q., Lee Z., Li Y., Xie Y., Behrenfeld M. 2011. MODIS observed phytoplankton dynamics in the Taiwan Strait: An absorption-based analysis. Biogeosciences **8** (4): 841–850. DOI: 10.5194/bg-8-841-2011

Shang S., Zhang C., Hong H., Liu Q., Wong G.T.F., Hu C., Huang B. 2005. Hydrographic and biological changes in the Taiwan Strait during the 1997–1998 El Niño winter. Geophysical Research Letters **32** (11): L11601. DOI: 10.1029/2005GL022578

Shelton A.O., Mangel M. 2011. Fluctuations of fish populations and the magnifying effects of fishing. Proceedings of the National Academy of Sciences of the United States of America **108** (17): 7075–7080. DOI: 10.1073/pnas.1100334108

Smith A.D.M., Brown C.J., Bulman C.M., Fulton E.A., Johnson P., Kaplan I.C., Lozano-Montes H., Mackinson S., Marzloff M., Shannon L.J., Shin Y.-J., Tam J. 2011. Impacts of fishing low-trophic level species on marine ecosystems. Science **333** (6046): 1147–1150. DOI: 10.1126/science.1209395

Sparre P., Venema S.C. 1992. Introduction to tropical fish stock assessment, Part I: Manual. FAO Fisheries Technical Paper 306/1, Rev. 2.

Spearman C. 1906. 'Footrule' for measuring correlation. British Journal of Psychology **2** (1): 89–108. DOI: 10.1111/j.2044-8295.1906.tb00174.x

von Bertalanffy L. 1938. A quantitative theory of organic growth (inquiries of growth laws II). Human Biology **10** (2): 181–213.

Van Beveren E., **Bonhommeau S., Fromentin J.-M., Bigot J.-L., Bourdeix J.-H., Brosset D., Saraux C.** 2014. Rapid changes in growth, condition, size and age of small pelagic fish in the Mediterranean. Marine Biology **161** (8): 1809–1822. DOI: 10.1007/s00227-014-2463-1

Verheye H.M. 2000. Decadal-scale trends across several marine trophic levels in the southern Benguela upwelling system off South Africa. AMBIO: A Journal of the Human Environment **29** (1): 30–34. DOI: 10.1579/0044-7447-29.1.30

Wang X.H., Qiu Y.S., Zhu G.P., Du F.Y., Sun D.R., Huang S.L. 2011. Length–weight relationships of 69 fish species in the Beibu Gulf, northern South China Sea. Journal of Applied Ichthyology **27** (3): 959–961. DOI: 10.1111/j.1439-0426.2010.01624.x

Wells R.J.D., Kohin S., Teo S.L.H., Snodgrass O.E., Uosaki K. 2013. Age and growth of North Pacific albacore (*Thunnus alalunga*): Implications for stock assessment. Fisheries Research **147**: 55–62. DOI: 10.1016/j.fishres.2013.05.001

Xiao F.S. 2007. [The catch composition analysis of a single trawler in Minnan and Taiwan Bank fishing ground. Journal of Fujian Fisheries **3**: 30–34. [In Chinese.]

Yatsu A., Aydin K.Y., King J.R., McFarlane G.A., Chiba S., Tadokoro K., Kaeriyama M., Watanabe Y. 2008. Elucidating dynamic responses of North Pacific fish populations to climatic forcing: influence of life-history strategy. Progress in Oceanography **77** (2–3): 252–268. DOI: 10.1016/j.pocean.2008.03.009

Yatsu A., Watanabe T., Ishida M., Sugisaki H., Jacobson L.D. 2005. Environmental effects on recruitment and productivity of the Japanese sardine *Sardinops melanostictu*s and chub mackerel *Scomber japonicus* with recommendations for management. Fisheries Oceanography **14** (4): 263–278. DOI: 10.1111/j.1365-2419.2005.00335.x

Zhang Q.Y., Zhang Y.Z. 1982. [Preliminary study on seasonal changes of species compositions of demersal fishes in South-Fujian Taiwan Bank fishing ground. Journal of Xiamen University (Natural Science) **21** (1): 68–83. [In Chinese.]

Zhu Y.D. (ed.) 1985. [Fishes of Fujian Province. Part 1.] Fujian Science and Technology Press, Fuzhou, China. [In Chinese.]