IOP Conference Series: Earth and Environmental Science

Oxygen consumption of *Mugil cephalus* on several temperatures under brackish water conditions

To cite this article: V A Prakoso *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **278** 012060

Oxygen consumption of *Mugil cephalus* on several temperatures under brackish water conditions

V A Prakoso[1*], K T Kim[2], J H Ryu[3], B H Min[2], Y J Chang[4]

[1]Research Institute for Freshwater Aquaculture and Fisheries Extension, Indonesia
[2]National Institute of Fisheries Science, Korea
[3]Ph.D Student on Department of Aquaculture, Pukyong National University, Korea
[4]Institute of Review and Assessment on Fishery and Aquaculture, Korea

*E-mail: vitas.atmadi@gmail.com

Abstract. Two experimental groups were applied to measure oxygen consumption (OC) of young grey mullets *Mugil cephalus* (TL: 27.3±2.1 cm; TW: 187.9±45.8 g) at different temperatures (15, 20, and 25ºC). Specimens of fish from seawater (30 psu) and freshwater (0 psu) were transferred in to brackish water (15 psu). Rate of fish OC after rearing in brackish water, showed significant difference (P<0.05) in that the grey mullets consumed 90.9, 116.8, and 172.1 mg O_2/kg/h at temperatures of 15, 20, and 25ºC, respectively. In fish from freshwater transferred to brackish water, grey mullets consumed 80.5, 114.4, and 161.5 mg O_2/kg/h at 15, 20, and 25ºC, respectively (P<0.05). The results showed that the highest oxygen consumption was found at 25ºC compared to those at 15 and 20ºC. However, the OC from both groups did not differ significantly (P>0.05). It can be concluded, that the OC rate of grey mullets on brackish water has the tendency to increase by temperature rise.

Keywords: grey mullet, *Mugil cephalus*, oxygen consumption, temperature

1. Introduction

Grey mullets *Mugil cephalus* are distributed worldwide, mainly in tropical and subtropical region. This species has potential to be developed as cultured species. Grey mullets are truly cosmopolitan and considered as a commercially important food product [1]. Grey mullets has good osmoregulatory capacity and can tolerate wide ranges of salinity (euryhaline) [2]. Grey mullets live in seawater as their natural habitat. They can migrate from seawater to brackish water to feed and grow from juvenile to adult [3].

The development of aquaculture for this species was required in order to serve the increasing demand for this fish species. One important factor to support aquaculture development is the availability of oxygen consumption (OC) data. Oxygen consumption is one of the most important factors in aquaculture activities, as the oxygen is a vital condition for all organisms living in the water and having an aerobic type of respiration. Oxygen requirement is one of the most important factors for aquaculture maintenance of aquatic species, because it is related to metabolism processes. Recently, metabolism process had become one of the most studied fields on animal physiology [4]. Oxygen consumption can be used to measure the metabolic rate in fish. It will be useful for determining the carrying capacity in aquaculture environments [5].

The metabolism level on aquatic species may be affected by several external factors, such as oxygen availability, temperature, and food intake [6]. The metabolic process in fish is also closely related to temperature. Like most biochemical reactions, the reaction of aerobic metabolism is directly affected by ambient temperature [7]. Thus, fish should have the mechanism to overcome this effect to provide the energy that is required for ambient temperatures. Higher temperatures will escalate the proportion of enzymes that have gained their activation energy levels, which increase the average rate of biochemical reactions to enable more activities [8]. This condition requires more oxygen supply [9]. Therefore, fish metabolism is closely related to temperature. In most aquatic animals, the rate of aerobic metabolism can be estimated indirectly by measuring the level of oxygen consumption.

Besides temperature, many researches investigated the oxygen consumption of various fish species [10-12] on several environmental factors, such as salinity [13-15], photoperiod [16, 17], and stocking density [18-21]. In terms of temperature, it was known that its effects contribute to fish physiological processes. As an example, previous studies regarding the effects of temperature on fish growth have been conducted on marine species such as sea bass *Dicentrarchus labrax* [22, 23], Atlantic cod *Gadus morhua* and common eelpout *Zoarces viviparus* [24], cobia *Rachycentron canadum* [25, 26], golden pompano *Trachinotus ovatus* [27], freshwater species such as African catfish *Clarias gariepinus* [28], Channel catfish *Ictalurus punctatus* [29], nile tilapia *Oreochromis niloticus* [30], white sturgeon *Acipenser transmontanus* [31], mrigal carp *Cirrhinus mrigala* [32], and common carp *Cyprinus carpio* [33]. The impact of temperature on fish growth might vary depending on characteristics of the fish species itself [34]. Research on oxygen consumption in relation to temperature also continues to be developed for aquaculture purposes in various species [35-43].

According to the information above, we need to investigate the oxygen consumption in grey mullets *M. cephalus* according to temperature changes for the development of its rearing management, as currently the information on this remains incomplete. Thus, study on oxygen consumption will be useful to support the aquaculture of grey mullets by providing some information, especially in rearing conditions. In this study, we aim to assess the effects of different water temperatures on oxygen consumption of grey mullets reared under brackish water environmental conditions.

2. Materials and Methods

Thirty one grey mullets *M. cephalus* (total length (TL): 27.3±2.1 cm, total weight (TW): 187.9±45.8 g) which were collected from Suncheon Bay and reared in culture tanks were used for the experiments. Before the experiments, grey mullets were divided and acclimated into two different rearing environments, which were seawater (SW, 30 psu) and freshwater (FW, 0 psu). The fish were reared in recirculating tanks and fed twice a day at 2% of their biomass with commercial food. No food was given to any experimental fish for 24 hours after the experiments started.

As shown in table 1, two experiments were conducted to measure the OC according to water temperature changes (15ºC, 20ºC, and 25ºC) of grey mullets *M. cephalus*. Those two experiments were fish from seawater (SW, 30 psu) reared in brackish water (BW, 15 psu) as known as seawater directly transferred to brackish water (SDB) and fish from freshwater (FW, 0 psu) reared in brackish water (BW, 15 psu) as known as freshwater directly transferred to brackish water (FDB).

Table 1. Experimental conditions in OC measurement

Experiment al groups	Water temp. change (ºC)	Salinity (psu)	Total length (cm)	Body weight (g)	Fish number
SDB	15→20→25	15	29.6±1.8	234.0±31.2	3
FDB	15→20→25	15	27.1±0.5	181.3±18.0	3

Descriptions: SDB: fish reared in SW transferred to BW, FDB: fish reared in FW transferred to BW.

To measure the OC according to water temperature changes, OC measurement system and OC calculation methods were adopted from a previous study [16]. Three grey mullets were put into a respiratory chamber (dimension = 20 × 30 × 20 cm) inside the closed recirculating system with photoperiod of 12 hours light (07:00 - 19:00) : 12 hours dark (19:00 - 07:00). The measurements were conducted with five replicates. Dissolved oxygen (DO) of inflow water was maintained above 7.0 mg/L in each experiment, while the salinity inside the closed recirculating system was kept stable at 15 psu. During experiments, water temperature inside the OC measurement system was increased slowly from 15°C to the target temperature at a rate of 0.5°C/h to avoid any thermal shock. In order to evaluate the fish activities during the experiments, the breathing frequency was also observed during experiments. All statistical analysis were performed by one-way ANOVA method (PASW Statistics 18).

3. Results and Discussion

As shown in figure 1, the OC according to temperature rises for each experiment and showed a linear increase in line with temperature. The OC of grey mullets which was observed every hour clearly showed various types of OC fluctuations. Various rhythm has appeared at each water temperature during continuous measurements from 15°C to 25°C. Sudden increase of OC occured in each experiment during the beginning of the light period and the dark period with various amounts in each experiment.

Based on the OC according to temperature changes in SDB, the grey mullets consumed 90.9, 116.8, and 172.1 mg O_2/kg/h at 15, 20, and 25 °C, respectively, showing significant differences at each temperature ($P<0.05$). Similar patterns with SDB, grey mullets in FDB consumed 80.5, 114.4, 161.5 mg O_2/kg/h at 15, 20, and 25 °C, respectively ($P<0.05$). The OC values in FDB were a bit lower than SDB. However, no significant difference was found ($P>0.05$) (table 2).

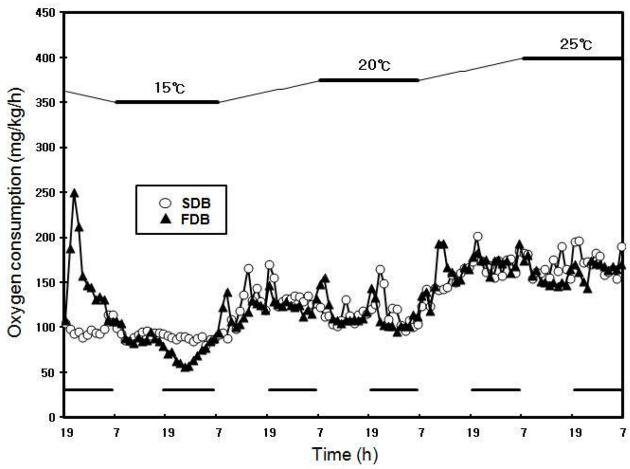

Figure 1. OC of grey mullets *Mugil cephalus* by water temperature. SDB and FDB are the same abbreviations as shown in table 1.

Table 2. Average of OC (mg O_2/kg/h) of grey mullets *Mugil cephalus* in each experiment

Group	Water temperature (°C)			b	a	r^2
	15	20	25			
SDB	90.9 ± 4.4[a]*	116.8 ± 15.5[b]*	172.1 ± 13.3[c]*	8.12	-35.84	0.854
FDB	80.5 ± 13.6[a]*	114.4 ± 16.1[b]*	161.5 ± 10.8[c]*	8.12	-43.26	0.853

Descriptions: All abbreviations are the same as shown in table 1. Each value represent means ± SD (n = 24). Different letters indicate significant differences between water temperatures in each experiment, respectively. Asterisks indicate significant differences between each experiment ($P<0.05$, one-way ANOVA).

Compared to the previous studies [44, 45], OC rate in the present study was lower. However, another study on flatfish Senegalese sole (*Solea senegalensis*) showed lower values of OC compared to this study [18]. Our results were similar with another study [46], which reported from different species at juvenile stage that the OC increased in line with the temperature rise. Another previous studies on different species [16, 47] also reported that OC of fish increased directly with the temperature rise. The results showed that water temperature is considered as one of the important parameters influencing the OC of grey mullets. Breathing frequency and OC per breath were also influenced by temperature rise. The difference of results compared with previous studies was likely to be influenced by different species, density, and body weight.

During light and dark periods, fish in each experiment showed various patterns of OC according to temperatures in both groups. In SDB, the average OC during the dark period was 94.8, 104.9, and 104.4% of that of the light period at 15, 20, and 25°C, respectively. Which means at 20 and 25 °C grey mullets consumed higher amounts of oxygen during dark periods than light periods (P<0.05). Meanwhile, in FDB, the average OC during the dark period was 78.2, 93.2, and 105.0% of that of the light period at 15, 20, and 25°C, respectively. The change in tendency of OC during light and dark periods was found in these experiments. The results from two experimental groups showed that grey mullets on SDB consumed a slightly higher amount of oxygen in dark period at 20°C and 25°C after they consumed a higher amount of oxygen in light period at 15°C, whilst the grey mullets on FDB consumed higher oxygen during dark periods at 25°C after previously consuming more oxygen during light periods in 15 and 20°C. The slope (b) of linear regression in SDB during the light period was higher than FDB. However, the pattern was conversely during the dark period. The slope (b) of linear regression in SDB during the dark period was lower than in FDB (table 3).

Table 3. Average OC (mg O_2/kg/h) of grey mullets *Mugil cephalus* during light and dark periods in each experiment

Group	L : D	Water temperature (°C)			b	a	r^2
		15	20	25			
SDB	L	93.3±4.3^a	114.0±8.2^b	168.4 ± 12.0^c	7.51	-24.97	0.876
	D	88.5±3.0^a	119.6±20.4^b	175.8 ± 14.1^c	8.73	-46.70	0.849
FDB	L	90.3±8.4^a	118.4±17.1^b	157.5 ± 11.5^c	6.72	-12.39	0.827
	D	70.6±10.3^{a}*	110.3±14.5^{b}*	165.4 ± 8.7^c	9.48	-74.13	0.918

Descriptions: All abbreviations are the same as shown in table 1. Each values represent means ± SD (n = 12). Different letters indicate significant difference between water temperature in each experiment, respectively (P<0.05, one-way ANOVA). Asterisk indicates significant difference between light and dark in each experiment, respectively (* : P<0.05, ** : P<0.01,*** : P<0.001, t-test).

Within this study, another parameter that could be considered as an influencing factor to the OC of grey mullets is photoperiod. Results showed that grey mullets consumed a higher amount of oxygen during light periods than dark periods in brackish water. Both groups showed that the energy demand of grey mullets is elevated in the morning. These findings indicated that grey mullets were more active in the morning and sensitive to the light. Another pattern that occurred in the experimental groups was that the OC shifted from lower consumption amount at dark periods to lower consumption amount at light periods or vice versa. These conditions indicated that the OC increase of grey mullets was faster in SDB during light period, whilst in dark period it was faster in FDB. OC of fish reflected the activity of the fish themselves [48]. Similar with other fish species [49, 50], grey mullets seem to be more active during day time. Compared with a previous study according to photoperiod using different species [17], it showed higher results of OC values than grey mullets. The results were likely to show that grey mullets had a lower metabolic rate under a 12 h photoperiod. It could affect their growth, physiological and hematological parameters [17]. Daily variations in OC will have an influence on the water quality requirements of cultured fish. The requirements should be estimated according to peak OC rates rather than the daily average OC [51].

The breathing frequency of grey mullets from whole experiments at 15, 20, and 25°C shown in figure 2. The slope of linear regression of breath frequency according to different water temperatures in SDB and FDB was 2.96 and 2.11, respectively. These values indicated that the breathing frequency in SDB has been rapidly increasing.

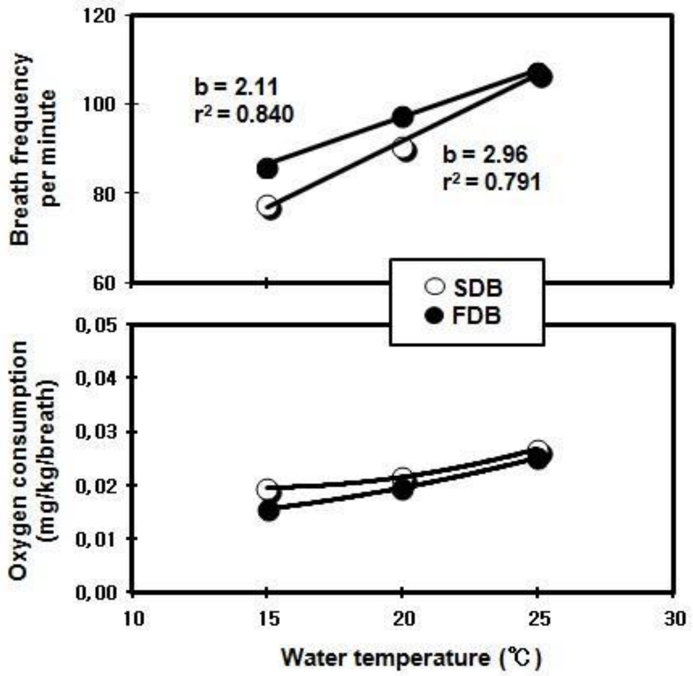

Figure 2. Breathing frequency per minute and OC per breath in grey mullets *Mugil cephalus* in SDB and FDB. All abbreviations are the same as shown in table 1

According to this study, both groups showed that the breathing frequency of grey mullets increased in line with temperature rise. Compared to previous studies [12, 16, 52], the present study has a similar pattern. At higher temperatures, fish required an upsurge of breathing frequency for more oxygen uptake from the ambient water [53]. It means that normally fish will increase their breathing frequency at higher temperatures within their tolerable temperature range.

4. Conclusion

The OC rate of grey mullets in brackish water has shown to have the tendency to increase by temperature rise. Based on our results of OC and behavioral observations, culturing grey mullets in brackish water could be applied at 25°C to optimize aquaculture of this species. We point out that further detailed studies were needed in order to observe the growth of grey mullets in brackish water at several rearing temperatures.

References

[1] Oren O H 1981 Aquaculture of grey mullets (New York: Cambridge University Press)
[2] Saleh M 2008 Capture-based aquaculture of mullets in Egypt pp 109-126 *In*: Capture-based aquaculture Global overview FAO Fisheries Technical Paper No. 508 (Lovatelli A and PF Holthus eds.) Rome: FAO. 298p
[3] Kim S J, Lee Y D, Yeo I K, Baek H J, Kim H B, Nagae M, Soyano K and Hara A 2004 Reproductive cycle of the female grey mullets, *Mugil cephalus*, on the coast of Jeju Island, Korea *J. Envir. Toxicol.* **19** 73-80
[4] White C R, Schimpf N G and Cassey P 2013 The repeatability of metabolic rate declines with time *J. Exp. Biol.* **216** 1763-1765
[5] Lovell T 1998 Nutrition and feeding of fish second edition (Massachusetts: Kluwer Academic Publications)

[6] Rosewarne P J, Wilson J M and Svendsen J C 2016 Measuring maximum and standard metabolic rates using intermittent-flow respirometry: a student laboratory investigation of aerobic metabolic scope and environmental hypoxia in aquatic breathers *J. Fish Biol.* **88** 265-283
[7] Hochachka P W and Somero G N 2002 Biochemical adaptation: Mechanism and process in physiological evolution (New York: Oxford University Press)
[8] Houlihan D and Innes A 1984 The cost of walking in crabs: aerial and aquatic oxygen consumption during activity of two species of intertidal crab *Comp. Biochem. Physiol. Part A* **77** 325-334
[9] Bartholomew G A and Casey T 1977 Endothermy during terrestrial activity in large beetles *Sci.***195** 882-883
[10] Kim I N, Chang Y J and Kwon J Y 1995 Pattern of oxygen consumption in six species of marine fish *J. Korean Fish. Soc.* **28** 373-381
[11] Byun S G, Jeong M H, Lee J H, Lee B I, Ku H D, Park S U, Kim Y C and Chang Y J 2008 Diel rhythm of oxygen consumption of the starry flounder *Platichthys stellatus* by water temperature *J. Korean Fish. Soc.* **41** 113-118
[12] Jeong M H, Kim Y S, Min B H and Chang Y J 2007 Effect of fish number in respiratory chamber on routine oxygen consumption of black porgy *Acanthopagrus schlegeli* reared in seawater or freshwater *Aquac.* **20** 121-126
[13] Marais J F K 1978 Routine oxygen consumption of *Mugil cephalus, Liza dumerili* and *L. richardsoni* at different temperatures and salinities *Mar. Biol.* **50** 9-16
[14] Tsuzuki M Y Strussmann C A and Takashima F 2008 Effect of salinity on the oxygen consumption of larvae of the silversides *Odontesthes hatcheri* and *O. bonariensis* (Osteichthyes, Atherinopsidae) *Braz. Arch. Biol. Technol.* **51** 563-567
[15] Iwama G K, Takemura A and Takano K 1997 Oxygen consumption rates of tilapia in freshwater, seawater, and hypersaline seawater *J. Fish Biol.* **51** 886-894
[16] Chang Y J, Jeong M H, Min B H, Neill W H and Fontaine L P 2005 Effect of photoperiod, temperature, and fish size on oxygen consumption in the black porgy *Acanthopagrus schlegeli J. Fish. Sci. Technol.* **8** 142-150
[17] Ruchin A B 2007 Effect of Photoperiod on Growth, Physiological and Hematological Indices of Juvenile Siberian Sturgeon *Acipenser baerii Biol. Bull.* **34** 583–589
[18] Salas-Leiton E, Anguis V, Manchado M and Canavate J P 2008 Growth, feeding and oxygen consumption of Senegalese sole (*Solea senegalensis*) juveniles stocked at different densities *Aquac.***285** 84-89
[19] Szczepkowski M, Szczepkowska B and Piotrowska I 2011 Impact of higher stocking density of juvenile Atlantic sturgeon, *Acipenser oxyrinchus* Mitchill, on fish growth, oxygen consumption, and ammonia excretion *Arch. Pol. Fish.* **19** 59-67
[20] Bjornsson B and Olafsdottir S R 2006 Effects of water quality and stocking density on growth performance of juvenile cod (*Gadus morhua* L.) *ICES Journal of Marine Science* **63** 326-334
[21] Miller S A, Eric J and Bosakowski T 1995 Performance and oxygen consumption of rainbow trout reared at two densities in raceways with oxygen supplementation *The Proggressive Fish-Culturist.* **57** 206-212
[22] Russell N R, Fish J D and Wootton R J 1996 Feeding and growth of juvenile sea bass: the effect of ration and temperature on growth rate and efficiency *J. Fish. Biol.* **49** 206-220
[23] Person-Le Ruyet J, Mahe K., Le Bayon N and Le Delliou H 2004 Effects of temperature on growth and metabolism in a Mediterranean population of European sea bass, *Dicentrarchus labrax Aquac.* **237** 269-280
[24] Pörtner *et al* 2001 Climate induced temperature effects on growth performance, fecundity and recruitment in marine fish: developing a hypothesis for cause and effect relationships in Atlantic cod (*Gadus morhua*) and common eelpout (*Zoarces viviparus*) *Cont. Shelf Res.* **21** 1975-1997
[25] Sun L, Chen H and Huang L 2006 Effect of temperature on growth and energy budget of juvenile cobia (*Rachycentron canadum*) *Aquac.* **261** 872-878
[26] Sun L and Chen H 2014 Effects of water temperature and fish size on growth and bioenergetics of cobia (*Rachycentron canadum*) *Aquac.* **426** 172-180

[27] Yang Q, Ma Z, Zheng P, Jiang S, Qin J G and Zhang Q 2016 Effect of temperature on growth, survival and occurrence of skeletal deformity in the golden pompano *Trachinotus ovatus* larvae *Indian J. Fish.* **63** 74-82
[28] Britz P J and Hecht T 1987 Temperature preferences and optimum temperature for growth of African sharptooth catfish (*Clarias gariepinus*) larvae and postlarvae *Aquac.* **63** 205-214
[29] Buentello J A, Gatlin III D M and Neill W H 2000 Effects of water temperature and dissolved oxygen on daily feed consumption, feed utilization and growth of channel catfish (*Ictalurus punctatus*) *Aquac.* **182** 339-352
[30] Rodkhum C, Kayansamruaj P and Pirarat N 2011 Effect of water temperature on susceptibility to *Streptococcus agalactiae* serotype Ia infection in Nile tilapia (*Oreochromis niloticus*) *Thai J. Vet. Med.* **41** 309-314
[31] Boucher M A, McAdam S O and Shrimpton J M 2014 The effect of temperature and substrate on the growth, development and survival of larval white sturgeon *Aquac.* **430** 139-148
[32] Singh R K, Chavan S L, Desai A S and Khandagale P A 2008 Influence of dietary protein levels and water temperature on growth, body composition and nutrient utilization of *Cirrhinus mrigala* (Hamilton, 1822) fry *J. Therm. Biol.* **33** 20-26
[33] Desai A S and Singh R K 2009 The effects of water temperature and ration size on growth and body composition of fry of common carp, *Cyprinus carpio J. Therm. Biol.* **34** 276-280
[34] Pepin P 1991 Effect of temperature and size on development, mortality, and survival rates of the pelagic early life history stages of marine fish *Canadian J. Fish. Aquatic Sci.* **48** 503-518
[35] Fry F E J and Hart J S 1948 The relation of temperature to oxygen consumption in the goldfish *Biol.Bull.* **94** 66-77
[36] Franklin C E, Johnston I A, Crockford T and Kamunde C 1995 Scaling of oxygen consumption of Lake Magadi tilapia, a fish living at 37°C *J. Fish. Biol.* **46** 829-834
[37] Wares W D and Igram R 1979 Oxygen consumption in the fathead minnow (*Pimephales promelas* Rafinesque), effects of weight, temperature, group size, oxygen level, and opercular movement rate as a function of temperature *Comp. Biochem. Physiol.* **62** 351-356
[38] Requena A, Fernandez-Borras J and Planas J 1997 The effects of a temperature rise on oxygen consumption and energy budget in gilthead seabream *Aquac. Int.* **5** 415-426
[39] Turker H 2011 The effect of water temperature on standard and routine metabolic rate in two different sizes of Nile tilapia *KAFKAS. Univ. Vet. Fak.* **7** 575-580
[40] Gillooly JF, Brown JH, West GB, Savage VM and Charnov EL 2001. Effects of size and temperature on metabolic rate *Sci.* **293** 2248-2251
[41] Sarma K., Pal A K., Ayyappan S, Das T, Manush S M, Debnath D and Baruah K 2010 Acclimation of *Anabas testudineus* (Bloch) to three test temperatures influences thermal tolerance and oxygen consumption *Fish Physiol. Biochem.* **36** 85-90
[42] Tirsgaard B, Svendsen J C and Steffensen J F 2015 Effects of temperature on specific dynamic action in Atlantic cod *Gadus morhua Fish Physiol. Biochem.* **41** 41-50
[43] Prakoso V A, Ryu J H, Min B H, Gustiano R and Chang Y J 2016. Oxygen consumption of rockbream *Oplegnathus fasciatus* in different salinity levels and temperature degrees *Berita Biol.* **15** 167-173
[44] Lim H K, Jeong M H, Han H K, Lee J H and Chang Y J 2004 Oxygen consumption of hybrid stripped bass (*Morone chrysops* ♀ × *M. saxatilis* ♂) exposed to different temperature, salinity and photoperiod *Aquac.* **17** 258-261
[45] Oh S Y, Park H S and Kim C K 2010 Effect of water temperature and photoperiod on the oxygen consumption rate of juvenile Pacific cod, *Gadus macrocephalus Ocean Polar Res.* **32** 229-236
[46] Oh S Y, Noh C H, Kang R S and Myoung J G 2006 Effect of water temperature and photoperiod on the oxygen consumption rate of fasted juvenile parrot fish, *Oplegnathus fasciatus Ocean Polar Res.* **28** 407-413
[47] Gardner J A and King G 1922 Respiratory exchange in freshwater fish, further comparison of goldfish and trout *Biochem. J.* **16** 729-735
[48] Beamish F W H and Mookherjii P S 1964 Respiration of fishes with special emphasis on standard oxygen consumption. II. Influence of weight and temperature on respiration of goldfish, *Carassius auratus L Can. J. Zool.* **42** 161-175

IOP Conf. Series: Earth and Environmental Science **278** (2019) 012060 doi:10.1088/1755-1315/278/1/012060

[49] Gibson R N 1973 Tidal and circadian activity rhythms in juvenile plaice, *Pleuronectes platessa Marine Biology* **22** 379-386
[50] Muller K 1978 Locomotor activity of fish and environmental oscillations. pp. 1-29 *In*: Rhythmic activity of fishes (Thorpe JE ed.) (London: Academic Press)
[51] Lyytikäinen T and Jobling M 1998 The effect of temperature fluctuations on oxygen consumption and ammonia excretion in under yearling Lake Inari Arctic charr *J. Fish Biol.* **52** 1186-1198
[52] Ao V 2015 Effects of temperature, salinity and fish number on oxygen consumption and blood property of young rockbream *Oplegnathus fasciatus*. Master Thesis. Koica-PKNU International Graduate Program of Fisheries Science, Graduate School (Korea: Pukyong National University)
[53] Farrel A P and Steffensen J F 1987 Coronary ligation reduces maximum sustained swimming speed in Chinook salmon, *Oncorhynchus tshawytscha*. *Comp. Biochem. Physiol. Part A: Physiol.* **87** 35-37