Swimming speed and heart rate of Japanese jack mackerel (*Trachurus japonicus* Temminck & Schlegel, 1844), through electrocardiograph (ECG) monitoring in step-up swimming exercise

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Abstract. The purpose of the study was to observe the heart rate of Japanese jack mackerel (*Trachurus japonicus* Temminck & Schlegel, 1844) and the swimming speed level during the simulation of the capture process in a flume tank. This was monitored on 11 samples of 19.1 ± 0.6 cm body length (BL) (mean ± S.D., *n*=11), during swimming experiments in the flume tank at 24ºC. The observations were conducted at speeds ranging from 1.3 BL/s to 5.9 BL/s, where a gradual increase was applied for each consecutive test session of 10 minutes (step-up protocol). In addition, electrocardiograph (ECG) monitoring was performed to analyze changes in heart rate at each speed level by implanting a pair of electrodes in the pericardial cavity, through the ventral side of the fish body and by a connector to the bio-amplifier and oscilloscope. The results showed an insignificant increase within the swimming speed range of 1.3-2.8 BL/s, from the average control heart rate of 78.5 beats/minute in still water. Meanwhile, a higher value was reported in the elevated speed range of 2.8-4.4 BL/s and the heart rate stabilizes in the speed range of 4.4-5.9 BL/s, at a heart rate of 174.8-182.5 beats/minute. The recovery times monitored through ECG measurements showed similarity in the time taken to attain the control heart rate from the peak heart rate (maximum), of 204.3 ± 81.7 minutes. The heart rate increases when the swimming speed of the fish is increased. Meanwhile, swimming endurance decreases when the swimming speed is increased. Under these conditions, fish required more than 120 minutes for recovery time.
Key Words: *Trachurus japonicus,* Japanese jack mackerel*,* electrocardiogram (ECG), heart rate, recovery time.

Introduction. Japanese jack mackerel (*Trachurus japonicus*, Temminck & Schlegel, 1844) is one of the most important commercialy exploited fish (Dragon et al 2018). Understanding the swimming performance and behavior of fish plays an important role in determining the selectivity and efficiency of fishing with the use of active equipment, like trawl and danish seine (Winger et al 1999). This is evidenced by direct observation, achieved during experiments with various parts of the fishing gear, like the board and wing tips of trawlers (Wardle 1980). Also, trawler fishing shows the fish tendency to maintain a position against the gear for a long period, subsequently preventing the attainment of the codend (Nofrizal et al 2009; Killen et al 2015). Nofrizal et al (2009) stated that the fish escaping from trawls could not be neglected, although the fish were not able to show their optimal swimming performance due to fatigue. Meanwhile, swimming speed is increased with anaerobic muscle activity, hence a supply of additional energy through the respiratory and aerobic metabolic systems is required. Higher swimming speed may lead to a higher probability of avoiding the net (Killen et al 2015). A study using an underwater camera showed the tight relation between swimming speed and fishing gear towing speed, as swimming speed declined alongside a decrease in the ship momentum during the capture process (Inoue et al 1993). Regarding the capture process, heart rate is a highly sensitive indicator of the fish response to any treatment given (Larsson et al 2006). This sparks an interest in observing fish swimming performance in these conditions.

The heart rate of fish is important in the respiratory and metabolic systems during swimming (Briggs & Post 1997; Altimiras & Larsen 2000; Sundstrom et al 2005). Previous studies indicated the presence of a positive significant relationship between heart rate and swimming speed (Nofrizal et al 2008; Nofrizal 2009; Nofrizal et al 2009; Nofrizal & Arimoto 2011). Therefore, this study hypothesizes heart rate is a good indicator for providing information related to the physiological condition and performance of fish during the capture process, while swimming to avoid the active fishing gear. This study also emphasizes swimming speed attained by the fish to maintain relative position toward water flow momentum. The purpose of this research is to measure by eloctrocardiograph observation the changes of heart rate, through an experiment that gradually steps up the swimming speed level, in an attempt to understand its swimming performance.

Material and Method

Experimental fish. A total of 11 adult Japanese jack mackerel measuring 19.1±0.6 cm in body length (BL) (mean±S.D., n=11) were obtained from farmers in Suruga Bay, Japan. The transportation process required the use of a tank truck for conveying the live fish to a maintenance tank, characterized by a length of 2.0 m, width of 0.9 m and a depth of 1.0 m at the Laboratory of Fish Behavior, Tokyo University of Marine Science and Technology. Furthermore, the samples were then maintained at 24°C for one week and fed everyday with fish meal pellets during the period of acclimation and experiment, while the water condition through the study was always monitored and controlled.

ECG monitoring. This research involved the use of a flume tank and an observation system to measure the fish swimming speed. In addition, the tank (West Japan Fluid Engineering Laboratory, PT-70) is specially designed with a length of 70 cm, width of 30 cm and a depth of 20 cm and is accompanied with stable water flow (Figure 1), while one side is covered by a square box panel, expected to function as a marker (visual cue) during testing. This experiment provides information on the possible optomotor responses of fish (Nofrizal 2009; Nofrizal et al 2009; Nofrizal & Arimoto 2011; Wardle 1993; He & Wardle 1988; Xu et al 1993), hence the swimming speed is equivalent to the water flow momentum, as the fish maintains a relative position at the time of trial. The flow velocity within the flume tank was gradually increased, using the axial pump, with which the flume tank is equipped, while observing the fish heart rate. This was set to 24.9, 53.9, 82.9 and 111.8 cm/s, according to the sample average swimming speed, including 1.3, 2.8, 4.4 and 5.9 BL/s.

Data analysis. The swimming speed was calculated according to flow speed of flume tank and then divided to the body length of fish. Meanwhile, the heart rate of the fish was averaged every minute for ten minutes. All the data were analyzed by statistic descriptive and presented in graphs.

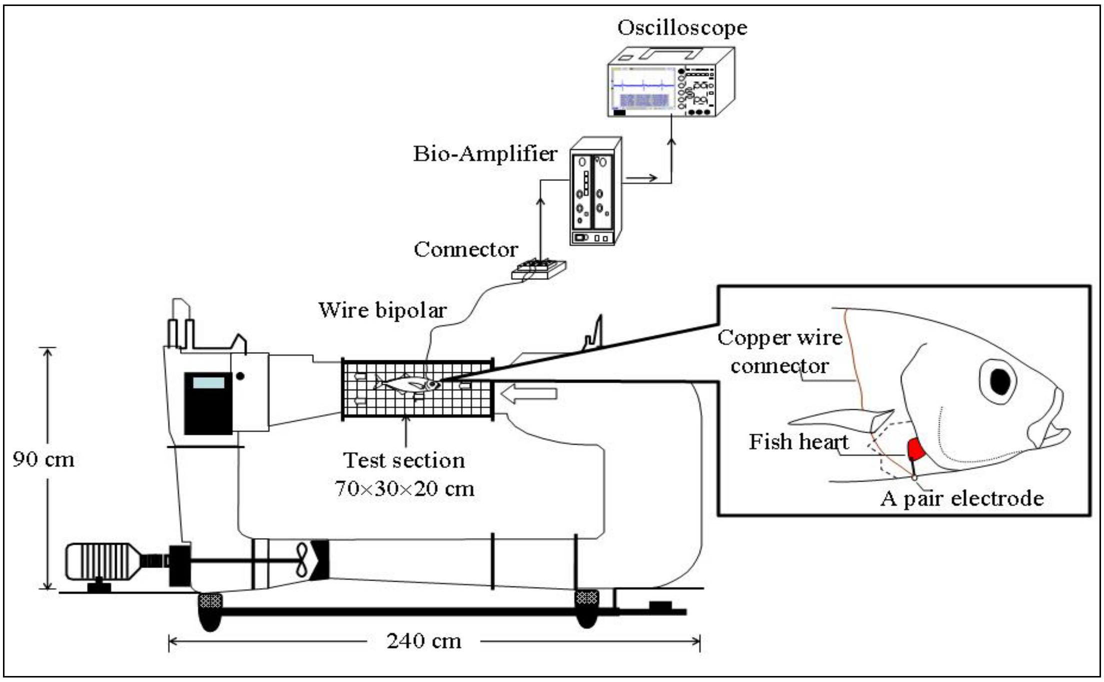

Figure 1. Experimental scheme for swimming endurance and electrocardiogram monitoring used during trials.

The application of electrocardiogram monitoring (ECG) for fish heart rate measurement was performed using a pair of electrodes implanted in the pericardial cavity (Figure 1). Furthermore, anesthesia was initiated by administering a dose of 107 mg FA100 per unit 1 liter of sea water (0.008%) for 15-20 minutes. The electrodes were made up of enamel insulated tungsten pins (MT Giken), characterized by a length of 15 mm and diameter of 0.2 mm or 0.3 mm, while the outer isolation was removed from both ends along 1 mm. This was then inserted into the pericardial cavity from the side of the stomach, with one side connected to copper wire (Tsurumi Seiki, T-GA XBT cable) and covered with super glue (Aron Alpha, Toa-gosei). Conversely, the other end of the cable was attached to a digital oscilloscope (Iwatsu, DS-5102) through an amplifier (Nippon Kohden, Bioelectric Amplifier AB-632J).

During the trial, measurements for heart rate were obtained at 24°C in still water for 30 minutes and also following a recovery period of 180 minutes (3 hours) from anesthesia, induced through the administration of FA 100. Therefore, the average number of beats/minute was calculated to obtain a comparison between the normal (control) and the investigated condition, at a specified water flow rate ranging between 1.3-5.9 BL/s, with increments every 10 minutes (step-up protocol) on each fish. In addition, data collection during the recovery process was measured post-trial, characterized by the experience of fatigue and continuously observed to the point where the heart rate is stabilized to control value (normal) (Ito et al 2003). This was further analyzed based on the average motion obtained at every 10 minute interval.

Results. The swimming speed test increases the fish’s body endurance level and the observations showed that all samples participated actively in this exercise for over 10 minutes at speeds less than 4.5 BL/s (1.3-4.4 BL/s). Furthermore, a decline in endurance (from 0.8 to 9.1 minutes) was identified at higher swimming speeds between 4.5-6.3 BL/s, while none of the specimen exceeded 6.3 BL/s, as described in the graph below (Figure 2).

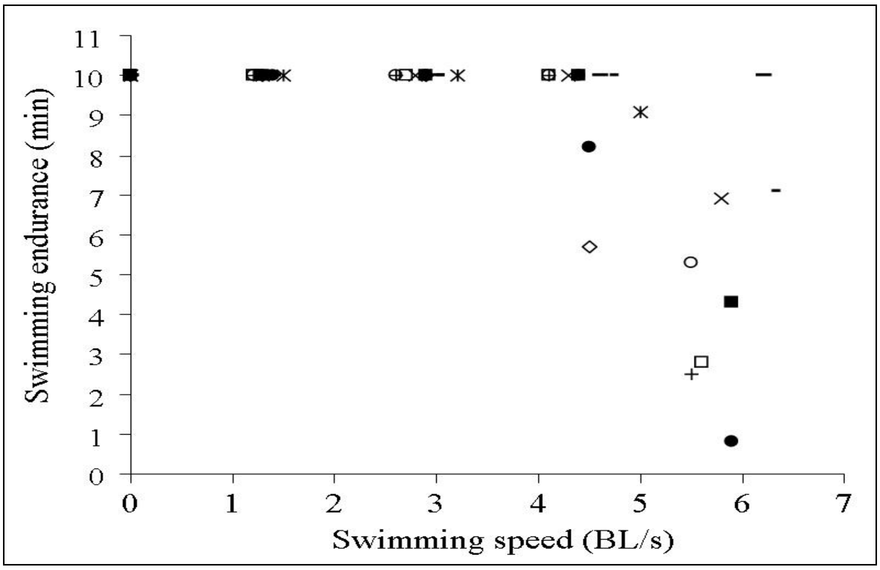

Figure 2. Speed and endurance of fish swimming during trials to increase swimming speed, with each marker representing an individual experimental sample.

Figure 3 shows a similarity in the pattern of heart rate activity for all fish samples, characterized by increased values, following the step-up of the swimming speed level. There were no marked difference in the pattern recorded between the conditions of swimming exercise and control for each sample. Also, there were no changes in the heart rate at a speed of 1.3±0.1 BL/s, although an increase was observed at 2.2±0.2 BL/s, which further elevated at 4.3±0.3 BL/s. Furthermore, the highest peak was attained at 5.9±0.4 BL/s, where a condition characterized by the inability for fish to swim for 10 minutes appeared. Therefore, the experiment protocol was exceeded as the sample experienced fatigue and are unable to transit against the flow within the flume tank.

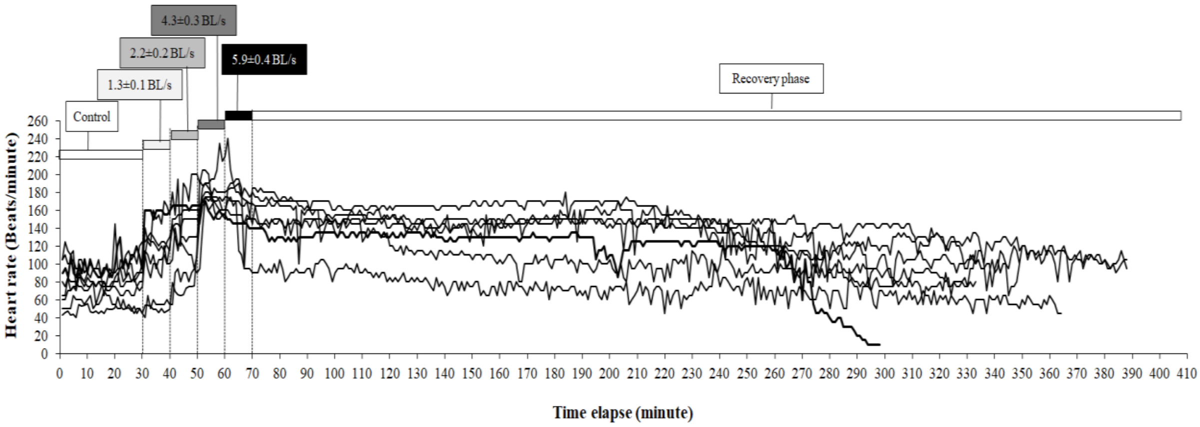

Figure 3. The heart beat pattern of the fish was set according to the step-up swimming speed tested in the flume tank through electrocardiograph monitoring.

There was a similarity between the heart beat pattern in the control and recovery phase, which ensued gradually and is also characterized by fluctuating changes per sample (Figure 3).

The average heart rate increased at higher swimming speeds, where 78.5±19.3 beats/minute was recorded as the control (normal), which increased to 108.1±39.2 beats/minute at 1.3±0.1 BL/s. In addition, an elevation to 2.2±0.2 BL/s and subsequently 4.3±0.3 BL/s lead to a simultaneous increase in heart rate to 131.7±37.6 and 174.8±14.9 beats/minute, while the peak value of 182.5±10.5 beats/minute was reached at 5.9±0.4 BL/s (Figure 3). In addition, there were differences in the average values for each individual, which occurred within the swimming speed range of 1.3±0.1 to 2.2±0.2 BL/s, although the tendency for converging was observed at intervals of

4.3±0.3 to 5.9±0.4 BL/s. Therefore, the rate of heartbeats recorded during trials increased with each step up of speed, as shown in the following figure (Figure 4).

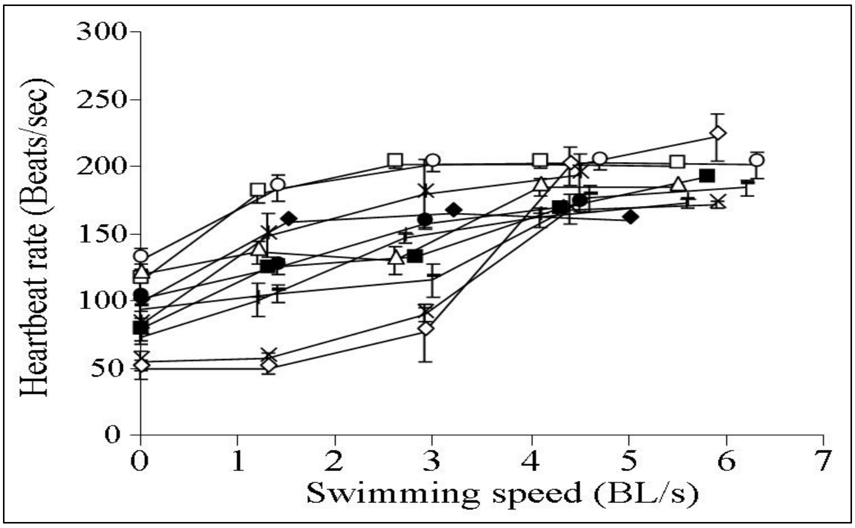

Figure 4. Average heart rate activity at each step-up of the swimming speed during a trial, where each marker represents a sample.

The heart rate recovery at the termination of the trial was evaluated based on the time interval between the highest speed and when the heart rate returned to a similar value with the control. This process ensued within a period of 120 to 360 minutes (Figure 5), where the specimens are generally recovered from 180 to 360 minutes.

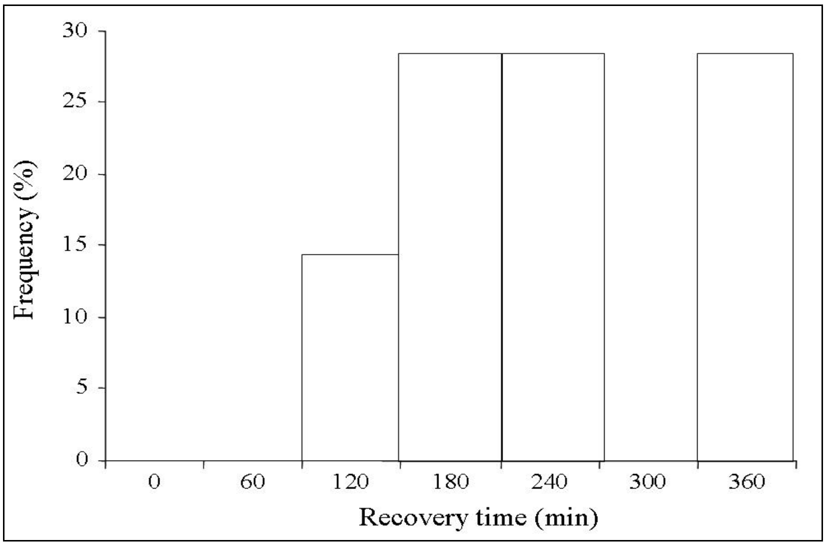

Figure 5. Frequency of the recovery time for Japanese jack mackerel after step-up swimming exercise.

Discussion. At swimming speeds lower than 4.5 BL/s, Figure 2 shows that Japanese jack mackerel have the necessary swimming endurance to complete the 10 minute trial protocol. This is a normal or continuous speed range, characterized by the absence of fatigue, (Nofrizal 2009; Nofrizal et al 2009; Nofrizal & Arimoto 2011), which is also observed in tilapia (*Oreochromis niloticus*) (Nofrizal 2014). Following an increase in swimming speed to over 4.5 BL/s, a decline was observed in individual performances. Previous studies have associated a decrease in the endurance of Japanese jack mackerel (*Tachurus japonicus*) with instances where speeds above 3.5 BL/s are attained (Nofrizal 2009; Nofrizal et al 2009; Nofrizal & Arimoto 2011). Another report showed similar reduction in the endurance of Asian red catfish (*Hemibagrus nemurus*) at 2.5 BL/s

(Nofrizal 2014), while the observations in this current investigation affiliated this manifestation with the incidence of fatigue during the trial session.

The heart rate of Japanese jack mackerel increases gradually with the elevating of the swimming speed, in a similar pattern with the rainbow trout (*Oncorhynchus mykiss*) (Priede 1974). Generally, fish need additional energy to compensate for an increased swimming speed, as well an increased metabolic rate, in order to replenish previous losses, while cardiac activity is physiologically related to metabolic and respiratory processes. Therefore, the heartbeat serves various functions, which includes pumping blood, nutrients and oxygen circulation for biochemical activities within the body and is subsequently needed for continuous metabolism. Also, it is possible to hasten or slow down the pace of this process, which is dependent on the heart rate and speed of samples being tested. Korsmeyer et al (1997) reported on the increase in blood flow of yellow fin tuna (*Thunnus albacares*) by 13.6±3.0%, based on the relative heart rate during swimming trials at an average speed of 1.2-2.1 BL/s. This trial initiated an upsurge of 18.8±5.4%, at a temperature of 24±1°C. Meanwhile, the heart rate of Japanese jack mackerel increased from 34.9±29.8% at the control swimming speed of 1.3±0.0 BL/s to 177.9±79.7% at 5.9±0.1 BL/s, resulting from the demand of oxygen in the blood, which is needed by the myotomal muscle, in order to operate intensively through the aerobic metabolic pathway.

Modern trawlers are made in various sizes and aimed at facilitating various types of fishing vessels and subsequently attracting fish with maximum speed, particularly between 3 and 4 knots or 154.2 and 205.6 cm/s (Wardle 1993). The towing speed of the fishing gear corresponds to the size and momentum of the fish during swimming, even though in the protocol of this study the maximum swimming of all samples is between 4.2-6.3 BL/s. According to Nofrizal (2009) and Nofrizal et al (2009) this range of swimming speed is a prolonged swimming speed which at this swimming speed the fish tend to maintain a stable or a higher than normal swimming speed, that makes it possible to avoid fishing gear, during the capture process. However, the incidence of heartbeats is an indicator of pressure or stress, which increases with the struggle to avoid the gear, hence the need for longer recovery time from fatigue. Cophin & Arimoto (1995) reported on the propensity to use the fish swimming in the trawl tip as samples for trials, as this possibly increases the likelihood of death due to stress experienced in the fishing process, despite the tendency of an escape. This study established a relationship between the amount of pressure exerted on fish during trials, including swimming speeds above 3 BL/s, and the sustained increase in heart rate. This is a highly probable condition attained when using active fishing gear.

Based on the observations, it is necessary to provide fish with over 180 minutes (3 hours) interval for post-trial recovery, following swimming speeds of 1.3-5.9 BL/s, conducted within approximately 40 minutes. Previous studies on the heart rate of largemouth bass (*Micropterus salmoides*) showed less variable patterns, hence the maximum outcome were obtained in samples arranged at several different speeds and times. In addition, the results identified 135 minutes as the appropriate time needed for recovery to normal at 13-25°C (Cooke et al 2004). Meanwhile, Japanese jack mackerel (*Trachurus japonicus*) requires a recovery time range of 103-543 minutes, after attaining the maximum heart rate at 5-7 BL/s at 22°C (Nofrizal et al 2009; Nofrizal & Arimoto 2011). This process features the pumping of oxygen in the blood by the heart for both aerobic and anaerobic metabolic processes during trials, leading to fish fatigue with an increase in oxygen consumption. According to Brett (1964) this phenomenon and a reversion to normal conditions ensue for up to 6 hours in sockeye salmon (*Oncorhynchus nerka*), following the experience of oxygen deprivation that results from fatigue. This explains the fish display of inactivity for several hours, after an exposure to pressure and stress during a capture or escape process, hence there is a higher tendency of being attacked by predators or to be caught again by the fishing gear. Therefore, further evaluation and research is needed to ascertain the swimming performance of fish after complete recovery.

Conclusions. The swimming endurance of Japanese jack mackerel is observed to have decreased at speed ranges higher than 4.5 BL/s, while the heart rate increases, with a record of 108.1±39.2 beats/minute at 1.3±0.0 BL/s. Subsequently, 131.7±37.6 and 174.8±14.9 beats/minute were reported at 2.8±0.1 BL/s and 4.4±0.1 BL/s, respectively a maximum of 182.5±10.5 beats/minute was documented at 5.9±0.1 BL/s. The results also demonstrated an average complete recovery phase of 120 minutes, although 180 to 360 minutes was observed in most samples, after the maximum trial rate was attained.

References

Altimiras J., Larsen E., 2000 Non-invasive recording of heart rate and ventilation rate in rainbow trout during rest and swimming. Fish go wireless! Journal of Fish Biology 57:197-209.

Brett J.R., 1964 The respiratory metabolism and swimming performance of young Sockeye salmon. Journal of the Fisheries Research Board of Canada 21:1183-1226.

Briggs C. T., Post J. R., 1997 Field metabolic rates of rainbow trout estimated using electromyogram telemetry. Journal of Fish Biology 51:807-823.

Cooke J. S., Bunt M. C., Ostrand G. K., Philipp P. D., Wahl H. D., 2004 Angling-induced cardiac disturbance of free-swimming largemouth bass (*Micropterus salmoides*) monitored with heart rate telemetry. Journal of Applied Ichthyology 20:28-36.

Cophin S. F., Arimoto T., 1995 The condition of fish escaping from fishing gear - a review. Fisheries Research 21:315-327.

Dragon A. C., Senina I., Hintzen N. T., Lehodey P., 2018 Modelling South Pacific jack mackerel spatial population dynamics and fisheries. Fisheries Oceanography, 27(2):97-113.

He P., Wardle C. S., 1988 Endurance at intermediate swimming speeds of atlantic mackerel *Scomber scombrus* L., herring *Clupea harengus* L., and saithe *Pollachius virens* L. Journal of Fish Biology 33:255-266.

Inoue Y., Matsushita Y., Arimoto T., 1993 The reaction behavior of walleye pollock (*Theragra chalcogramma*) in a deep/low-temperature trawl fishing ground. ICES-Marine Science Symposium 196:77-79.

Ito H., Akiyama S., Arimoto T., 2003 Heart rate change during exercise and recovery for carp *Cyprinus carpio*. Nippon Suisan Gakkaishi 69(2):192-196.

Killen S. S., Nati J. J., Suski C. D., 2015 Vulnerability of individual fish to capture by trawling is influenced by capacity for anaerobic metabolism. Proceedings of the Royal Society B (Biological Sciences). The Royal Society 22 August 2015.

Korsmeyer K. E., Lai N. C., Shadwick R. E., Graham J. B., 1997 Heart rate and stroke volume contributions to cardiac output in swimming yellow fin tuna: response to exercise and temperature. Experimental Biology 200:1975-1986.

Larsson D. G. J., Fredriksson S., Sandblom E., Paxeus N., Axelsson M., 2006 Is heart rate in fish a sensitive indicator to evaluate acute effects of β-blockers in surface water? Environmental Toxicology and Pharmacology 22:338–340.

Nofrizal, 2009 Behavioural physiology on swimming performance of jack mackerel *Trachurus japonicus,* in capture process. [PhD Dissertation]. Tokyo University of Marine Science and Technology. Tokyo.

Nofrizal, 2014 Heart rate activity of nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758) at various swimming speed by electrocardiograph (ECG) monitoring. Jurnal Iktiologi Indonesia 14(2):101-109. [in Indonesian]

Nofrizal, Arimoto T., 2011 ECG monitoring on swimming endurance and heart rate of jack mackerel *Trachurus japonicus* during repeated exercise. Asian Fisheries Science 24:78-87.

Nofrizal, Yanase K., Arimoto T., 2008 Swimming exercise and recovery for jack mackerel *Trachurus japonicus*, monitored ECG measurements. Proceedings of the 5th World Fisheries Congress (CD-Rom).

Nofrizal, Yanase K., Arimoto T., 2009 Effect of temperature on the swimming endurance and post-exercise recovery of jack mackerel *Trachurus japonicus* as determined by ECG monitoring. Fisheries Science 75:1369-1375.

Priede I. G., 1974 The effect of swimming speed activity and section of the vagus nerves on the heart rate in rainbow trout. Journal of Experimental Biology 60:305-319.

Sundstrom L. F., Petersson E., Johnsson J. I., Dannewitz J., Hojesjo J., Jarvi T., 2005 Heart rate responses to predation risk in *Salmo trutta* are affected by the rearing environment. Journal of Fish Biology 67:1280-286.

Wardle C. S., 1993. Fish behaviour and fishing gear. In: Pitcher TJ, editor. The behaviour of teleost fishes, 2nd edition. London, Chapman and Hall. 609-643 pp.

Wardle C. S., 1980 Effect of temperature on the maximum swimming speed of fishes. In: Ali AM. Editor. The environmental physiology of fishes. New York, Plenum Press, 519-531 pp.

Winger D. P., He P., Walsh S. J., 1999 Swimming endurance of American plaice (*Hippoglossoides platessoides*) and its role in fish capture. ICES-Marine Science Symposium 56:252-265.

Xu G., Arimoto T., Inoue M., 1993 Red and white muscle activity of the jack mackerel *Trachurus japonicus* during swimming. Nippon Suisan Gakkaishi 59(5):745-751.

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