JOURNAL OF ANIMAL BEHAVIOUR AND BIOMETEOROLOGY

RESEARCH ARTICLE
Published Online: January 2, 2023
https://doi.org/10.31893/jabb.23002

Behavior and swimming performance of local fish in the ecosystem waters of rivers, oxbow and peat swamps

Nofrizal[a*] | **Rommie Jhonnerie**[a] | **Alit Hindri Yani**[a] | **Bustari**[a] | **Riska Fatmawati**[a] | **Ramses**[b]

[a]Department of Fisheries Resources Utilization, Faculty of Fisheries and Marine Science, Riau University, Kampus Bina Widya, Km. 12.5, Simpang Panam, Pekanbaru 28293, Indonesia.
[b]Study Program of Biology Education, Universitas Kepulauan Riau, Jl. Pahlawan No.99, Bukit Tempayan, Kec. Batu Aji, Kota Batam, Kepulauan Riau 29425, Indonesia.

*Corresponding author: aan_fish@yahoo.com

Abstract The four fish species, *Trichogaster pectoralis*, *Barbodes schwanenfeldii*, *Osphronemus gouramy*, and *Wallago leeri* have the same body size, representing different habitats. Therefore, this study aimed to determine the four species swimming abilities and speeds, including sustained, maximum sustained, prolonged swimming speed, and burst speed. The four species were brought using oxygenated plastic bags to the Aquatic Resources Utilization Laboratory at Riau University. Then it was acclimated in an aquarium measuring 100×50×50 cm with an aeration and filtering system to maintain water quality. The four groups of species were forced to swim in the swimming channel of the flume tank, with different current speeds for each individual tested. The swimming activity of the fish was recorded using a high-speed video camera (Casio HS Exlim, EX-ZR400, Casio Computer Co. LTD, Japan). The results showed that the swimming speed of *B. schwanenfeldii* was higher than *O. gouramy*, *T. pectoralis*, and *W. leeri*. The maximum sustained swimming speed of *B. schwanenfeldii* is about 5.1 BL/s, and 14.2 BL/s for the burst speed. Meanwhile, the sustained swimming speed of *O. gouramy* (1.6 BL/s) and the burst speed is 7.2 BL/s. The maximum sustained swimming speed of *T. pectoralis* was 1.6 BL/s, and the burst speed was 5.7 BL/s. In addition, the maximum sustained swimming speed of *W. leeri* is only 0.5 BL/s and 2.4 BL/s for the burst speed. The ability of these four fish to swim was influenced by the morphology of the tail fin, body shape, and the habitat where they live.

Keywords: *Barbodes schwanenfeldii, Osphronemus gourami*, swimming endurance, *Trichogaster pectoralis*, *Wallago leeri*

1. Introduction

Rantau Baru has a relatively large area of rivers, oxbows, and peat swamps (Nofrizal et al 2022). The water area also provides considerable fishery potential. There are at least 44 species that have economic value in these waters (Nakagawa et al 2021; Nofrizal et al 2022). Therefore, most of the Rantau Baru people, both men and women, work as fishers to meet their daily needs (Nofrizal et al 2022).

The study of fish behavior plays an essential role in the management of fishery resources (Wardle 1993; Parrish 1999; Winger et al 1999; Nofrizal and Ahmad 2015), especially in the development of fishing methods and techniques (Uyan et al 2006; Nofrizal 2009; Killen et al 2015), as well as in cultivation (Nofrizal and Arimoto 2011). The behavior and swimming performance of fish are also important information in managing aquatic resources for conservation purposes. Most studies on the swimming performance of fish focus on marine fish species (Breen et al 2004; Clark et al 2005; Nofrizal et al 2020a). Meanwhile, the number of studies on freshwater fish is quite limited (Zeng et al 2009; Oufiero et al 2011; Kern et al 2018). Meanwhile, ecosystem management for fish habitat for conservation purposes requires considering specific fish behavior, such as fish swimming speed and endurance.

Meanwhile, reciprocal relationships also occur in aquatic ecosystems, where habitat influences fish behavior, including the swimming performance of these species. Ecosystems can shape the characteristics of the habitat where each species lives. Habitat conditions affect the biology and physiology of fish living there, affecting their ability and swimming behavior (Larsson et al 2006). Therefore, this research must be conducted to add information about the swimming characteristics of fish. Based on the explanation above, research on the swimming performance and speed of fish in different habitats, namely rivers, oxbows, and swamps, must be carried out to enrich the information on these fish species' biology and ethology data.

A little information about swimming behavior and performances, including fish speed and swimming endurance, which is one of the considerations in developing environmentally sound fishing technologies and methods, is

 Received: October 22, 2022 | Accepted: December 23, 2022

the main problem in this study. Meanwhile, information about fish speed and swimming performance is also the basis for consideration in managing fishery resources in inland waters, such as rivers, lakes, reservoirs, oxbows, and swamp waters which are also needed for conservation and cultivation purposes (Nofrizal and Arimoto 2011). This study aims to determine the swimming performance and behavior of fish living in river and swamp ecosystems, especially for *T. pectoralis*, *B. schwanenfeldii*, *O. gouramy,* and *W. leeri*. Meanwhile, the specific purpose is to determine these four species swimming abilities and speeds, including sustained, maximum sustained, prolonged swimming speed, and burst speed. Information regarding these four categories of swimming speed is urgently needed in the utilization and management of fishery resources.

2. Materials and Methods

A series of observations and experimental methods were carried out to observe and identify the four species of fish that were the object of research based on their living habitat, divided into three places: rivers, oxbows, and swamps. In contrast, the experimental method is used to measure and test the swimming speed of fish in the flume tank (Figure 1).

Swimming speed and endurance were observed at the Laboratory of Fishing Gear, Department of Aquatic Resources Utilization, Faculty of Fisheries and Marine Science, Riau University. Observation of fish swimming speed and endurance was carried out in the laboratory so that environmental parameters can be controlled and regulated according to the desired conditions and by the natural conditions in which the test fish habitat lives, such as parameters of water temperature and light intensity when swimming. Experimentation and testing are underway

2.1. The current velocity in a swimming channel of the flume tank

The velocity of the current in the swimming channel has a positive correlation with the rotation of the propellers of the current tank (Figure 2). The faster the impeller rotates, the faster the current speed in the swimming channel; this was indicated by the high coefficient of determination (R^2 = 0.8). Each position of the current speed measurement shows a varying speed. Therefore, the analysis of the swimming speed of fish in this swimming channel uses a linear regression coefficient.

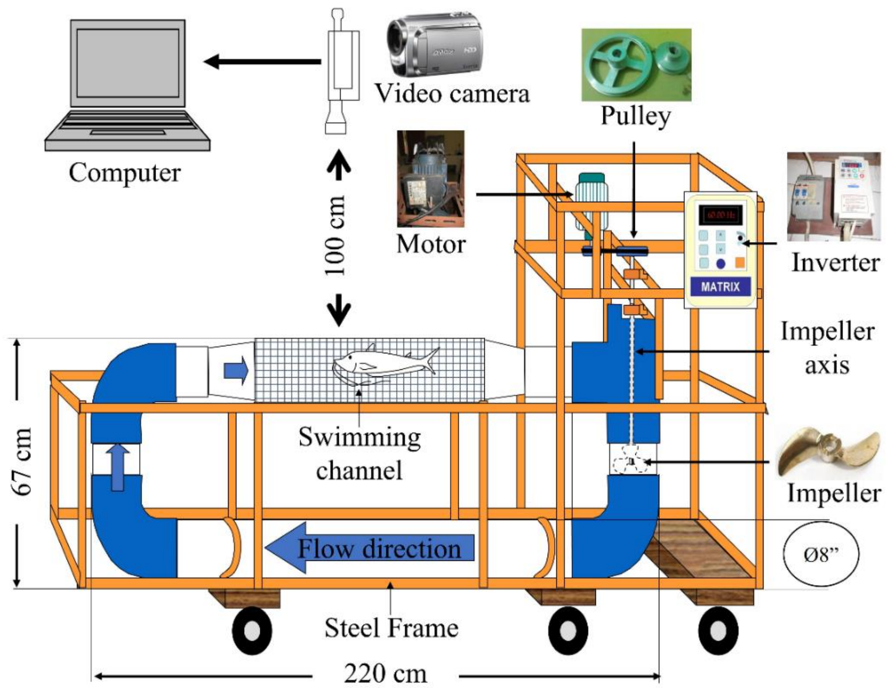

Figure 1 Schematic of observation and testing of fish swimming speed and endurance in a flume tank.

The use of the regression coefficient in observing and determining swimming speed was based on the fact that the swimming position of fish when swimming for 12000 seconds was not in a fixed position in the swimming channel (Nofrizal 2009). So by calculating the regression coefficient, it was expected that swimming speed data analysis would have a relatively high level of accuracy.

2.2. Sample size determination

Sampling was conducted in nature in rivers (mainstream), hoof lakes (oxbows), and swamps around Rantau Baru Village. Fish samples taken were *B. schwanenfeldii*, *T. pectoralis*, *O. gouramy,* and *W. leeri*. As far as possible, the sample size was taken from a relatively same size with the slightest possible standard deviation. Fish of the same size are more likely to come from the same age group. Samples were collected from fishers, then stored for transportation to the Fishing Materials and Equipment Laboratory, Faculty of Fisheries and Marine Science, Riau University in an aquarium measuring 100 x 50 x 50 cm. which is equipped with a portable aerator so that the condition of the dissolved oxygen content in the water in the storage well maintained.

Body length measurements of the four species were taken as Body Length (BL), measured from the tip of the fish mouth to the base of the tail or the tip of the tailbone of the fish. It is because the four species of fish tested for swimming speed and endurance have different tail shapes. The standard length will make it easier to standardize the sizes of the four fish species. Data on fish speed and swimming endurance were taken from a swimming endurance exercise in a flume tank in seconds. This data is taken from experiments with different current speeds for each species and each individual. The swimming channel of the flume tank will be given black square lines (Figure 1) to maintain their position due to the fish optomotor response when the current was given (Nofrizal et al 2009; Nofrizal and Arimoto 2011; Nofrizal et al 2012; Nofrizal 2015; Nofrizal et al 2015; Nofrizal and Ahmad 2015; Nofrizal et al 2020b). Under these conditions, the swimming speed of the fish will be the same as the current speed of the flume tank. Meanwhile, the swimming behavior of the fish was observed and recorded using a high-speed video camera.

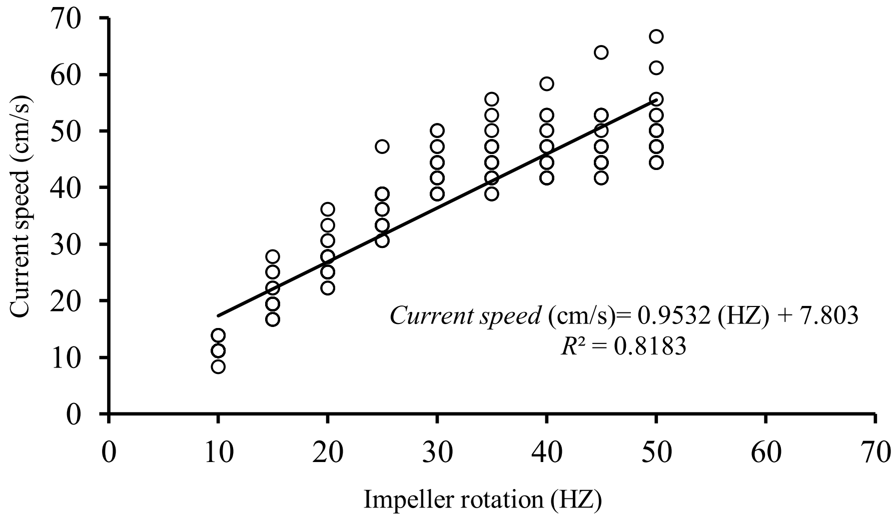

Figure 2 Relationship between impeller rotation and the current speed in the swimming channel of the current tank, which is regulated by the inverter.

Fish swimming speed will be grouped into four categories (Webb 1975), i.e., sustained speed, defined as when fish can survive swimming for more than 200 minutes. The maximum sustained speed is the swimming speed of the fish that exceeds the sustained speed, where the red and white muscles work when swimming. At this speed, swimming endurance decreases drastically because the fish are exhausted (Nofrizal et al 2009; Nofrizal and Arimoto 2011; Nofrizal and Ahmad 2015; Nofrizal et al 2020a). The next is prolonged speed, a faster swimming speed where the fish swim for more than 15 seconds and less than 200 minutes due to fatigue. And the last is the maximum swimming speed (Burst Speed) in which fish can only swim for less than 15 seconds (Nofrizal et al 2009; Nofrizal and Arimoto 2011; Nofrizal et al 2012; Nofrizal 2015).

2.3. Data collection

Data on the speed and swimming endurance were obtained from the following research procedures. First, all fish samples were acclimated in a 100 x 50 x 50 cm aquarium to relieve stress during transport from the fishing area to the laboratory for one week. Both experiments started by adapting the fish in the swimming channel for 10 minutes without current. Continue adaptation with low current speed (2-3 cm/s) for 30 minutes. Third, each individual is tested for swimming endurance at different speeds for 200 minutes. Observations were stopped when the fish was tired and stopped swimming before 200 minutes. Fourth, fish swimming activity was recorded at different speeds using a video camera, recorder, and timer to obtain tail beat frequency data at different speeds moreover, fifth, swimming speed and endurance data for each of the four types. Individual fish were recorded and then analyzed.

2.4. Data analysis

The relationship between fish swimming speed and tail beat frequency was analyzed by linear regression, as follows $U = a + b$ (Hz), where U is swimming speed, a is the slope, b is intercepted, and Hz is a tail flick (tail beat frequency). The swimming endurance data of fish were analyzed to obtain the swimming curve of fish at different speeds using the following equation, $Te = Lon\ (a+b.U)$, where Te is the swimming endurance of fish. Estimated maximum sustained and burst speeds were analyzed by substituting the linear regression equation of the relationship between swimming speed (U) and fish swimming endurance (Te) with the following equation, *U max. sustained/burst* = (*LonE-b*)/*a*, where, *E* = fish endurance time in seconds.

Tail beat frequency analysis was critical in this research. The tail beat plays an important role in fish swimming speed. In addition, it also determines the swimming endurance of fish which can determine the boundary between maximum sustained, prolonged swimming speed and maximum (burst) swimming speed. The tail beat analysis was conducted by calculating one-period frequency (seconds) (Figure 3). Then proceed by using linear analysis, in which the equation is as follows. *Y* = *a*+*bx*, Where *Y* is the swimming speed of the fish, *a* slope, *b* is the intercept, and *x* is the swimming speed of the fish in seconds.

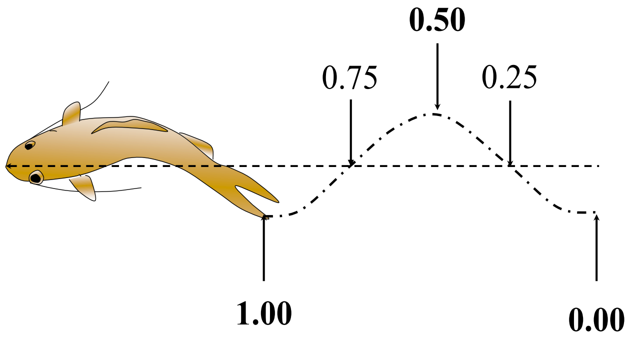

Figure 3 Calculation of tail beat frequency performed using a high-speed camera video camera.

3. Results

The swimming speed of the fish examined is the same as the current swimming speed in the swimming channel of the flume tank, so the swimming endurance of the fish is based on the swimming speed, which is regulated by the current speed in the swimming channel can be adjusted using the inverter found in the flume tank. From the swimming speed and endurance of the four species observed, some differences will be described in this research report in detail.

3.1. Endurance and swimming speed

Figure 4 shows the same swimming speed relationship trend between the four species tested for endurance and swimming speed. The faster the swimming speed of the four species, the lower their swimming endurance. The four species tested showed that the *B. schwanenfeldii* had good swimming ability, with high swimming speed and endurance. Meanwhile, *W. leeri* is a fish with the lowest endurance and speed compared to T. *pectoralis*.

From the regression equation for the relationship between swimming speed and swimming endurance of the fish, it can be estimated that the maximum sustained swimming speed and the burst can be estimated. The estimated maximum sustained swimming speed of *B. schwanenfeldii* has the highest swimming speed of *T. pectoralis*, *O. gouramy*, and *W. leeri,* which is 5.1 BL/sec, and the highest burst speed is 14.2 BL/s. Meanwhile, the maximum sustained swimming speed of *O. gouramy* was 1.6 BL/s, and the maximum swimming speed was 7.2 BL/s. The maximum sustained swimming speed of the *T. pectoralis* is higher than that of *W. leeri*, which is 1.2 BL/s, and a burst speed of 5.7 BL/s. These four species lowest swimming speed and endurance is the *W. leeri*, which is 0.5 BL/s for maximum sustained swimming speed and 2.4 BL/s for burst speed (Figure 4).

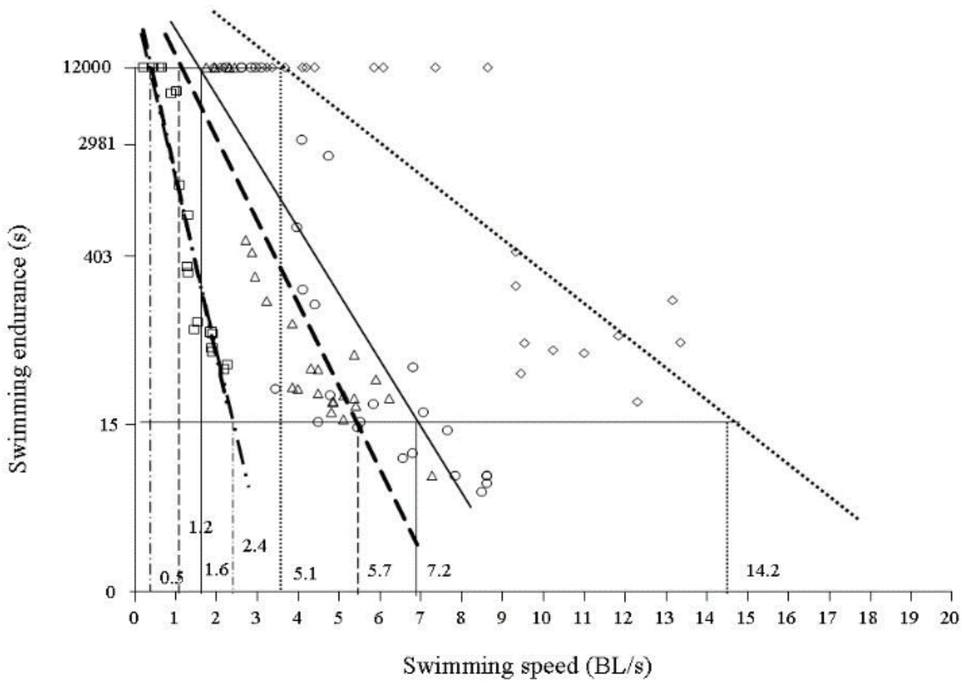

Figure 4 Relationship between endurance and swimming speed of *O. gouramy*, *T. pectoralis*, *B. schwanenfeldii*, and *W. leeri*. Solid line is *O. gouramy*, a broken line is *T. pectoralis*, a dot line is *B. schwanenfeldii*, and the combination between the broken line and dot line is *W. leeri*.

The sustained swimming performance of fish is the range of fish swimming speed that does not affect the physiological conditions of fish for a long time to swim. The swimming curve in Figure 5 illustrates the swimming performance from the aspect of speed and endurance, indicating a range of sustained swimming speeds. *B. schwanenfeldii* has a range of sustained swimming speeds higher than *O. gouramy*, *T. pectoralis,* and *W. leeri*, which is ≤ 5.1 BL/s. *O. gouramy* had a sustained swimming speed range of ≤ 1.6 BL/s, *T. pectoralis* ≤ 1.2 BL/s, and *W. leeri* ≤ 0.5 BL/s. The swimming curve above shows that *B. schwanenfeldii's* swimming performance and endurance are faster and longer than *O. gouramy*, *T. pectoralis,* and *W. leeri* (Figure 5).

3.2. Tail beat and swimming speed

The swimming speed of the fish is closely related to the beat of the fishtail; the faster the beating of the fish tail, the higher the swimming speed (Figure 3). The tail beat activity of the four species observed for their swimming performance in this study positively correlated with their swimming speed. The higher the tail beat activity, the faster the swimming speed. *B. schwanenfeldii's* has a more active tail beat activity when compared to *O. gouramy*, *T. pectoralis,* and *W. leeri* (Figure 6).

The amplitude of the fish's tail beat was the height of the tail fin waving when the fish is swimming. The amplitude of the fishtail waving was positively correlated with the swimming speed of the four species observed. A high swimming speed requires a high amplitude (Figure 7). The tail waving amplitude has a close relationship with the swimming speed of the fish; the higher the tail waving amplitude, the higher the swimming speed of the fish (Figure 7).

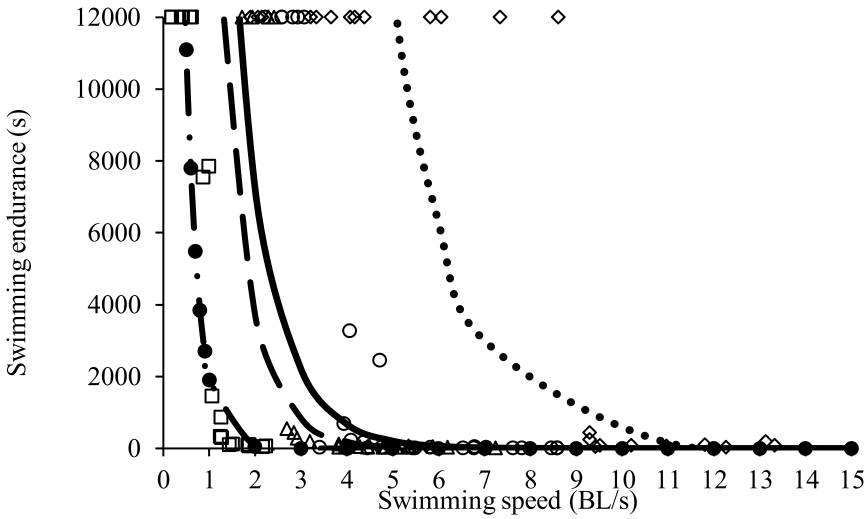

Figure 5 Swimming curves of *O. gouramy*, *T. pectoralis*, *B. schwanenfeldii*, and *W. leeri*. Solid line is *O. gouramy*, a broken line is *T. pectoralis*, a dot line is *B. schwanenfeldii*, and the combination between the broken line and dot line is *W. leeri*.

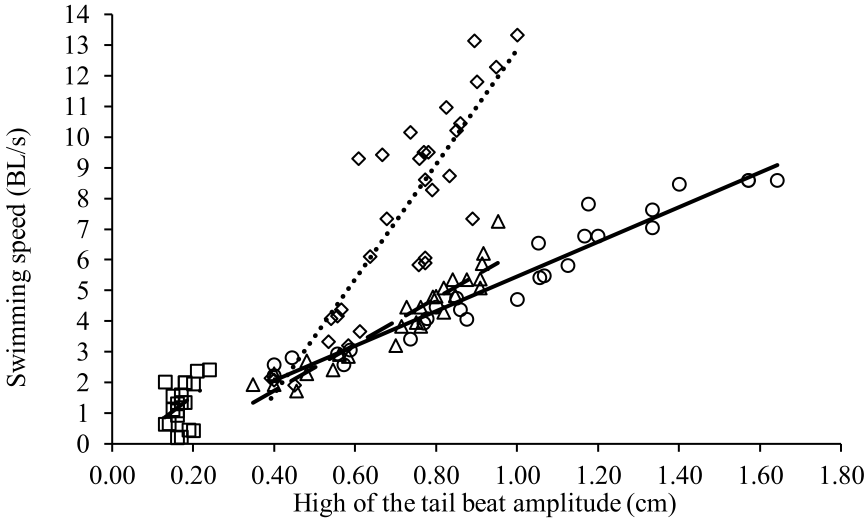

Figure 6 Relationship between tail beat and swimming speed. A solid line is *O. gouramy*, a broken line is *T. pectoralis*, a dotted line is *B. schwanenfeldii*, and the combination between the broken line and the dotted line is *W. leeri*.

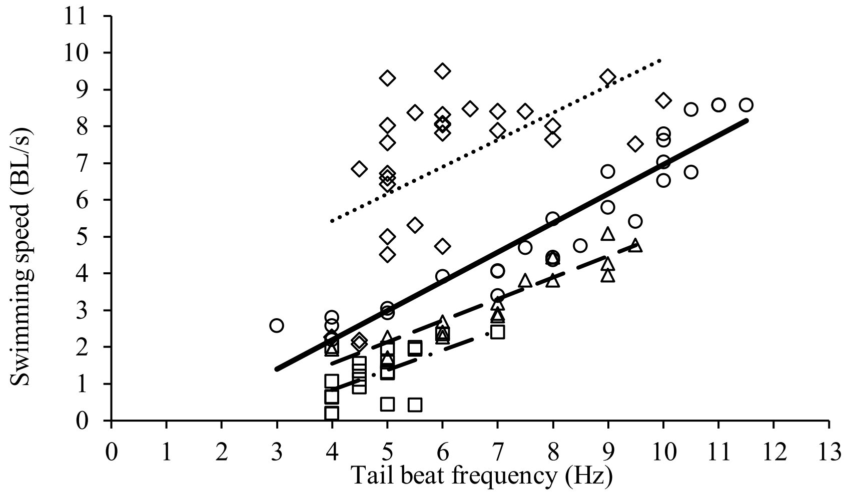

Figure 7 Relationship between tail beat amplitude and swimming speed. A solid line is *O. gouramy*, a broken line is *T. pectoralis*, a dotted line is *B. schwanenfeldii*, and a combination between the broken line and the dotted line is *W. leeri*.

Figure 7 shows that the tail beat activity of the four fish species observed was closely related to their swimming performance, which includes swimming speed and endurance (Figures 4 and 5). *B. schwanenfeldii* had higher tail beat activity than *O. gouramy*, *T. pectoralis*, and *W. leeri*. *W. leeri* had the lowest tail beat activity of the three species observed for its swimming performance.

3.3. Tail wagging amplitude and swimming speed

Figure 7 shows that the tail beat amplitude of *O. gouramy* is the highest of the other four species, reaching a maximum of 1.6 cm for a swimming speed of 8.6 BL/s. The maximum tail beat amplitude of *B. schwanenfeldii* and *T. pectoralis* reached 1.0 cm to obtain a maximum swimming speed of 7.3 BL/s for *T. pectoralis* and 13.3 BL/s for *B. schwanenfeldii*. Meanwhile, the maximum amplitude generated by *W. leeri's* tail waving was 0.2 cm, producing a swimming speed of 2.4 BL/s as the maximum swimming speed observed in a swimming channel.

3.4. Tail beat amplitude and tail beat frequency activity

The fishtail beat activity determines the swimming speed while producing the fishtail beat rhythm is influenced by the high amplitude of the fishtail waving. Figure 8 shows that the higher the amplitude of the fishtail waving, the faster the fishtail waving rhythm. Although *O. gouramy* was not the fastest swimming fish out of the four fish species tested, the tail beat amplitude of *O. gouramy* was the highest, 1.6 cm, which can produce a tail beat of as much as 11.5 Hz. The maximum tail beat amplitude of *B. schwanenfeldii* can reach 1.0 cm to produce a maximum tail beat rhythm of 10 Hz. Meanwhile, *O. gouramy* has a maximum tail beat amplitude of 0.2 cm to produce a maximum tail beat rhythm of 5 Hz (Figure 8).

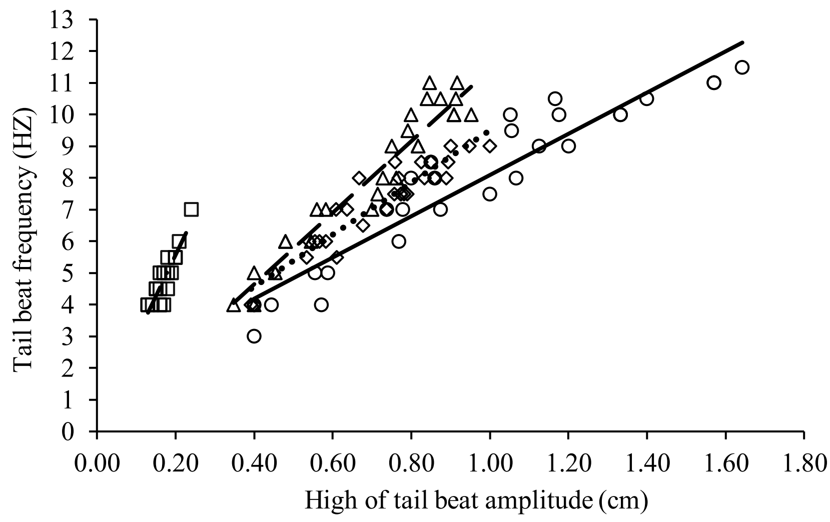

Figure 8 Relationship between tail beat amplitude and tail beat frequency activity. The solid line is *O. gouramy*, the broken line is *T. pectoralis*, the dotted line is *B. schwanenfeldii*, and the combination between the broken line and the dotted line is *W. leeri*.

4. Discussion

Swimming performance data is required to develop fishing methods and techniques (Nofrizal 2009; Nofrizal and Arimoto 2011; Nofrizal et al 2012; Nofrizal 2014; Nofrizal 2015; Nofrizal and Ahmad 2015). The swimming performance of fish determines the drag speed of fishing gear which is efficient and effective in the fishing process. Meanwhile, for the survival of fish and other aquatic animals, the ability to swim determines their survival in their habitat (Burgess et al 2006; Tudorache et al 2008). Fish swimming speed is influenced by body shape (Webb 1984a; Webb 1984b; Walker 2000; Boily 2002), caudal fin morphology (Webb 1984a; Nicoletto 1991; Videler 1993; Plaut 2000; Fulton et al 2005), and the environment or habitat where the fish lives (Campos et al 2018).

B. schwanenfeldii spends most of its life in mainstream waters with faster currents and better swimming speed and endurance than *O. gouramy*, *T. pectoralis,* and *W. leeri*. Fish body shape affects the locomotor of each fish species. According to Fulton et al (2001), locomotor morphology is a good predictor of inter-habitat and micro-habitat utilization. The morphology of the caudal fin of *B. schwanenfeldii* is more effective in making water propulsion higher so that its swimming speed will be faster and longer. The fin morphology of *B. schwanenfeldii* has a lot of stiff and weak hardened bones, so the tail beat is more effective in producing high swimming speeds. The movement of the fish's tail fin plays a vital role in determining the fish's swimming ability. The fishtail movement is also related to fish energy consumption and fish body metabolism. Steinhausen et al (2007) stated that the propulsion of fishtail waving is related to swimming speed and oxygen consumption to maintain aerobic metabolic needs while fish are swimming.

Fulton et al (2005) stated the general functional relationship between fin morphology and swimming performance. Fin morphology correlates highly with swimming speed, suggesting a highly harmonious relationship between fin morphology and wave-induced water movement. *O. gouramy* and *T. pectoralis* have a rounded caudal fin shape with less stiff and weak hardened coccyx bones, making their swimming ability slower than *B. schwanenfeldii*. Meanwhile, the habitats of *O. gouramy* and *T. pectoralis* tend to prefer places to live in calmer waters in rivers and swamps, making their swimming performance adaptation lower than *B. schwanenfeldii*.

Meanwhile, the *W. leeri* had lower swimming ability when compared to *B. schwanenfeldii*, *O. gouramy,* and *T. pectoralis* due to the small shape and size of the caudal fin, so it was not very effective in swimming activities. The living habitat of *W. Leeri,* which tends to choose calm deep waters to stalk their prey, adapts to their swimming movements slower than *B. schwanenfeldii*, *O. gouramy,* and *T. pectoralis*. The tail beat amplitude of *B. schwanenfeldii* is higher because the morphology of *W. leeri's* tail is more elongated and narrows towards the tip of the tail, so that body stride when swimming at high speed causes the amplitude of each tail waving movement to be higher.

The body shape and body length (Cano-Barbacil 2020) of fish affect the hydrodynamics of fish when swimming; the body shape of streamlined and slender fish produces better hydrodynamics when swimming, resulting in high swimming speeds. Yan et al (2013) said that swimming ability is higher with a slimmer body shape and high speed. Although the body shape of *B. schwanenfeldii*, *O. gouramy,* and *T. pectoralis* are the same, the caudal fin morphology and habitat are different. The morphology of the forked fins of the *B. schwanenfeldii* and the structure of the fins with hard and weakly hardened bones make the tail beat of *B. schwanenfeldii* more effective and efficient in producing thrust propulsion in the water for swimming.

5. Conclusions

Habitat and ecosystem affect the ability and behavior of fish. Fish in flowing water habitats have better swimming abilities with high speed and endurance, such as *B. schwanenfeldii*. The body shape and caudal fin morphology also affect the fish's swimming ability. The tail shape of *B. schwanenfeldii*, which is forked and has hard fin bones, is more effective in producing good swimming movements. The activity of *B. schwanenfeldii's* tail beating frequency was more active and faster at each swimming speed level than *O. gouramy*, *T. pectoralis*, and *W. leeri*. The tail beat amplitude of *B. schwanenfeldii* at each swimming speed level was also higher than the other three species in this study.

Acknowledgments

The authors would like to thank the Rantau Baru Village fishing community, who helped collect the fish samples in this study. The authors thanked all staff and students in the Fishing Gear Laboratory, Department of Aquatic Resources Utilization, Faculty of Fisheries and Maritime Affairs, Riau University for the valuable technical assistance. Our gratitude also goes to Masaaki Okamoto, Osawa Takamasa, and Hikaru Nakagawa as a team from the Research Institute Humanity and Nature, Kyoto University, who have inspired us to research peat swamp ecosystems.

Ethical considerations

Not applicable.

Conflict of interest

We declare that the data and discussion in this article have no conflict of interest whatsoever with any party.

Funding

This research was funded by Postgraduate Program, through DIPA-UNRI 2022.

References

Boily P, Magnan P (2002) Relationship between individual variation in morphological characters and swimming costs in brook charr (*Salvelinus* *fontinalis*) and yellow perch (*Perca favescens*). Journal of Experimental Biology 205:1031–1036.

Breen M, Jamie Dyson J, O'Neill GF, Jones E, Haigh M (2004) Swimming endurance of haddock (*Melanogrammus aeglefinus* L.) at prolonged and sustained swimming speeds, and its role in their capture by towed fishing gears. ICES Journal of Marine Science 61:1071-1079. doi: 10.1016/j.icesjms.2004.06.014

Burgess EA, Booth DT, Lanyon JM (2006) Swimming performance of hatchling green turtles is afected by incubation temperature. Coral Reefs 25:341–349.

Clark LD, Leis MJ, Hay CA, Trnski T (2005) Swimming ontogeny of larvae of four temperate marine fishes. Marine EcoLony Progress Series 292:287–300.

Campos DF, Val AL, Almeida-Val VMF (2018) The influence of lifestyle and swimming behavior on metabolic rate and thermal tolerance of twelve amazon forest stream fish species. Journal of Thermal biology 72:148-154. doi: 10.1016/j.jtherbio.2018.02.002.

Cano-Barbacil C, Radinger J, Argudo M, Rubio-Gracia F, Vila-Gispert A, García-Berthou E (2020) Key factors explaining critical swimming speed in freshwater fish: a review and statistical analysis for Iberian species. Scientific Reports 10:18947

Fulton C, Bellwood D, Wainwright P (2001) The relationship between swimming ability and habitat use in wrasses (Labridae). Marine Biology 139:25–33.

Fulton CJ, Bellwood DR, Wainwright PC (2005) Wave energy and swimming performance shape coral reef fish assemblages. Proceeding the Royal Society 272:1565. doi: 10.1098/rspb.2004.3029.

Kern P, Cramp LR, Gordos AM, Watson RJ, Franklin EC (2018) Measuring U_{crit} and endurance: equipment choice influences estimates of fish swimming performance. Journal of Fish Biology 92:237-247. doi: 10.1111/jfb.13514

Killen SS, Nati JJ, Suski CD (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.

Larsson DGJ, 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 PharmacoLony 22:338–340.

Nakagawa H, Osawa T, Binawan A, Dewi HK, Hasegawa T, Mandari ZD, Nofrizal PW, Okamoto M (2021) Local names of fishes in a fishing village on the bank of the middle reaches of the Kampar River, Riau, Sumatra Island, Indonesia. Southeast Asian Studies 10:435-454.

Nicoletto PF (1991) The relationship between male ornamentation and swimming performance in the guppy, *Poecilia reticulata*. Behavioral Ecology and Sociobiology 28:365-370.

Nofrizal (2009) Behavioural physioLony on swimming performance of jack mackerel *Trachurus japonicus* in capture process. Dissertation, Tokyo University of Marine Science and Technology.

Nofrizal, Kazutaka Y, Arimoto T (2009) Effect of temperature on the swimming endurance and post-exercise recovery of jack mackerel *Trachurus 8japonicas* as determined by ECG monitoring. Fisheries Science Journal 75:369-375.

Nofrizal, Arimoto T (2011) ECG monitoring on swimming endurance and heart rate performance of jack mackerel, *Trachurus japonicus* for repeated exercise. The Journal of the Asian Fisheries Science 24:78-87.

Nofrizal, Ahmad M, Syofyan I (2012) Tingkah laku dan kemampuan renang ikan selais (*Cryptopterus* sp.). Jurnal Iktiologi Indonesia 12:99-106.

Nofrizal (2014) Aktivitas jantung ikan nila, *Oreochromis niloticus* (Linnaeus, 1758) pada kecepatan renang yang berbeda dimonitor dengan Electrokardiograf (EKG). Jurnal IktioLoni Indonesia 14:101-109.

Nofrizal (2015) Kemampuan renang ikan patin (*Pangasius sutchi*) di dalam tanki berarus. Jurnal Perikanan dan Ilmu Kelautan 20:43-51.

Nofrizal, Ahmad M (2015) Swimming performance of Asian redtail catfish (*Hemibagrusnemurus*) in the swimming channel of flume tank. Journal Sustainable Science and Management 10:107-113

Nofrizal, Ramdhani F., Arimoto T (2020a) Temperature effect on the maximum swimming speed of jack mackerel Trachurus japonicus through muscle contraction monitoring. Journal of Animal Behaviour and BiometeoroLony 8:160-167.

Nofrizal, Ramdhani F, Oktavia Y, Ramses, Kurniawan R, Arimoto T (2020b) Swimming speed and heart rate of Japanese jack mackerel (*Trachurus japonicus* Temminck Schlegel, 1844), through electrocardiograph (ECG) monitoring in step-up swimming exercise. Journal AACL Bioflux 13:1221-1228

Nofrizal, Jhonnerie R, Thamrin, Raza'i ST, Sa'am Z, Nakagawa H (2022) Fishery in the Rantau Baru and Kampar Rivers, Sumatra, Indonesia. In: Okamoto M, Osawa T, Prasetyawan W, Binawan A (Eds.) Local Governance of Peatland Restoration in Riau, Indonesia: A Transdisciplinary Analysis. Springer (In press).

Oufiero EC, Walsh RM, Reznick ND, Garland JT (2011) Swimming performance trade-offs across a gradient in community composition in Trinidadian killifish (*Rivulus hartii*). ecology 92:170-179. doi: 10.1890/09-1912.

Plaut I (2000) Efects of fish size on swimming performance, swimming behaviour and routine activity of Zebrafsh Danio rerio. Journal of Experimental Biology 203:813–820.

Parrish JK (1999) Using Behaviour and ecology to exploit schooling fishes. Environmental Biology of Fishes 55:157–181.

Steinhausen MF, Steffensen JF, Andersen NG (2007) The Relationship between caudal differential pressure and activity of atlantic cod: a potential method to predict oxygen consumption of free-swimming fish. Journal of Fish Biology 71:957–969.

Tudorache C, Viaene P, Blust R, Vereecken H, De Boeck GA (2008) Comparison of swimming capacity and energy use in seven European freshwater fish species. Ecology Freshwater Fish 17:284–291.

Uyan S, Kawamura G, Archdale VM (2006) Morphology of the sense organs of anchovy *Eugraulis japonicus*. Journal of Fisheries Science 72:540–545.

Videler JJ (1993) Fish Swimming. Chapman and Hall, London.

Wardle CS (1993) Fish behaviour and fishing gear. In: Pitcher, T. J. (Ed). The Behaviour of Teleost Fishes. (2nd ed.). Chapman and Hall, London, pp. 609–643.

Walker JA (2000) Does a rigid body limit maneuverability?. Journal of Experimental Biology 203:3391–3396.

Webb PW (1984a) Form and function in fish swimming. Scientific American 251:72–82.

Webb PW (1984b) Body form, locomotion and foraging in aquatic vertebrates. American Zoology 24:107 –120.

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

Yan GJ, He KX, Cao DZ, Fu JS (2013) An interspecific comparison between morphology and swimming performance in cyprinids. Journal of Evolutionary biology 26:1802-1815. doi: 10.1111/jeb.12182.

Zeng QL, Cao ZQ, Jian SF, Peng LP, Wang XY (2009) Effect of temperature on swimming performance in juvenile southern catfish (*Silurus meridionalis*). Comparative Biochemistry and Physiology 153:125-130 doi: 10.1016/j.cbpa.2009.01.013.