THE INFLUENCE OF PHYSICAL BARRIERS TO FISH ASSEMBLAGE ALONG SUNGAI ENAM IN TEMENGOR RESERVOIR, PERAK

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by

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'Remember, a dead fish can float downstream, but it takes a life one to swim upstream'.

W. C. Fields

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LIST OF SYMBOLS AND ABBREVIATION

ANOVA	Analysis Of Variance
cm	Centimeter
DO	Dissolved Oxygen
g	Gram
GIS	Geographical Information System
GPS	Global Positioning System
H'	Shannon-Wiener Diversity Index
J'	Pielou's Evenness Index
Kn	Relative Condition Factor
L	Litre
LWR	Length-Weight Relationship
mg	Miligram
MVSP	Multivariate Statistical Package
NH_3-N	Ammoniacal-Nitrogen
NO_2-N	Nitrite-Nitrogen
NO_3-N	Nitrate-Nitrogen
PO_4-P	Ortho-Phosphate
r	Pearson Correlation Coefficient
R^2	Regression Coefficient
RCC	River Continuum Concept
s	Second
SE	Standard Error
SL	Standard Length
SPSS	Statistical Package For Social Science
TDS	Total Dissolved Solids
TL	Total Length
UPGMA	Unweighted Pair Group Method
W	Weight
µS	Micro Siemens
b	Growth Coefficient

PENGARUH HALANGAN FIZIKAL TERHADAP PERKUMPULAN IKAN SEPANJANG SUNGAI ENAM DI TAKUNGAN TEMENGOR, PERAK

ABSTRAK

Satu kajian mengenai pengaruh halangan fizikal terhadap perkumpulan ikan (bilangan spesis ikan, relatif faktor keadaan ikan dan pergerakan ikan) telah dijalankan dari Oktober 2014 hingga Jun 2015 di sembilan ruas sepanjang Sungai Enam di Takungan Temengor, Perak. Sembilan ruas tersebut termasuk dua halangan semula jadi (air terjun) dan dua halangan buatan manusia (empangan kecil). Persampelan telah dijalankan sebulan sekali dengan memilih satu kolam secara rawak dari setiap ruas (kaedah persampelan rawak berstrata). Ikan ditangkap menggunakan beg galas pengejut ikan (Smith-Root LR-24 Electrofisher) dengan jaring. Selepas pengecaman ikan dan pengukuran, sirip ikan yang tertentu dipotong berdasarkan ruas sebagai kaedah penandaan untuk menentukan pergerakan mereka di sepanjang sungai. Hubungan antara pembolehubah persekitaran dan ketiga-tiga parameter ikan tersebut juga telah dinilai. Hasil kajian menunjukkan bahawa 13 spesis ikan (3,643 spesimen ikan) yang terdiri daripada enam famili telah dikenal pasti di sepanjang sembilan ruas di sungai ini. Kajian ini juga merekodkan *P. smedleyi* sebagai spesis ikan yang paling kerap dan banyak ditemui di sembilan ruas. *Mastacembelus favus* telah direkodkan buat kali pertama di sungai ini. Bilangan spesis ikan meningkat dengan ketara dari hulu ke hilir sungai. Ikan telah ditemui di kawasan atas air terjun yang tinggi di sungai ini. Berdasarkan pada 515 spesimen ikan yang ditangkap semula selepas proses penandaan, pergerakan enam spesis (28 spesimen) ke hulu sungai dan pergerakan lima spesis (39 spesimen ikan) ke hilir sungai telah direkodkan dan *Poropuntius smedleyi* merupakan spesis ikan yang

paling banyak bergerak di sepanjang sungai ini. Relatif faktor keadaan (*Kn*) *P. smedleyi* menunjukkan bahawa kehadiran halangan fizikal tidak mempengaruhi keadaan *P. smedleyi* di sepanjang sungai ini. Hubungan antara pembolehubah persekitaran dan parameter ikan adalah lemah. Kajian ini telah mengesan bahawa air terjun yang mempunyai tahap kecerunan yang tinggi lebih cenderung mempengaruhi bilangan spesis ikan berbanding dengan air terjun yang mempunyai tahap kecerunan yang rendah. Manakala, halangan buatan manusia yang terdapat di sungai ini tidak memberikan pengaruh yang bererti terhadap bilangan spesis ikan. Walau bagaimanapun, halangan fizikal di Sungai Enam tidak memberikan pengaruh terhadap relatif faktor keadaan *P. smedleyi* dan pergerakan ikan di sepanjang sungai ini.

THE INFLUENCE OF PHYSICAL BARRIERS TO FISH ASSEMBLAGE ALONG SUNGAI ENAM IN TEMENGOR RESERVOIR, PERAK

ABSTRACT

A study on the influence of physical barriers to fish assemblage (i.e., the number of fish species, relative condition factor of fish and fish movements) was carried out from October 2014 to June 2015 at nine reaches along Sungai Enam in Temengor Reservoir, Perak. The nine reaches include two natural barriers (i.e., waterfalls) and two man-made barriers (i.e., small dams). Sampling excursions were carried out once a month by selecting one pool randomly from each reach (stratified random sampling method). Fish were captured using a backpack electrofishing (Smith-Root LR-24 Electrofisher) with scoop nets. After fish identification and measurements, selected fish fin were clipped according to reach as a marking method to determine their movement along the stream. Relationships between environmental variables and the three fish parameters were also assessed. Results showed that 13 fish species (3,643 fish specimens) comprising of six families were identified along the nine reaches of this stream. This study also recorded *P. smedleyi* as frequently and greatest fish species found in nine reaches. *Mastacembelus favus* was recorded for the first time in this stream. The number of fish species significantly increased from upstream to downstream. Fish were present above high waterfalls in this stream. Based on 515 fish specimens that were recaptured after marking process, upstream movement by six species (28 specimens) and downstream movement by five species (39 specimens) were recorded and *Poropuntius smedleyi* was the most travelled fish species along this stream. Relative condition factor (*Kn*) of *P. smedleyi* indicated that the presence of physical barriers has no influence towards the condition of *P. smedleyi* along this stream. The relationships between environmental variables and fish parameters were weak. This study detected that a waterfall with greatest slope is more likely to influence the number of fish species compared to the waterfall with least slope. Meanwhile, man-made barriers that present in this stream did not have significant influence to the number of fish species. However, physical barriers in Sungai Enam have no influence on relative condition factor of *P. smedleyi* and fish movements along the stream.

CHAPTER I

INTRODUCTION

1.1 Background

Malaysia is enriched with natural beauty and resources which are to be proud of. One of the attractions that are well-known in Malaysia is its waterfalls. Waterfalls attract people by their beautiful landscapes and refreshing air, since these area possess greater concentration of negative ions which increase serotonin level (mood chemical) that helps to reduce depression, stress and improve daytime energy (Mann & Nazario, 2002). Besides attraction, waterfall is also one of the natural habitats for aquatic biodiversity. Many endangered and rare species could be found in such secluded habitat compared to other aquatic habitats located near human hotspots, because most of the waterfalls are located deeply in the forest which ensures and secures the presence of those species.

Waterfall is a watercourse that is created when the water falls from high elevation over a cliff or rock. This eventually erodes the river bed and forms a pool. Formation of waterfall often occurs at the upper reach of a river where it flows over different band of rocks (Corrigan, 2007). The presence of waterfall in the river network affects stream communities (Gilliam *et al.*, 1993; Mazzoni *et al.*, 2006), changes the prey-predator dynamics (Reznick & Ghalambor, 2005), and longitudinal abundance of species (Greathouse & Pringle, 2006).

Waterfalls are categorised as natural barriers in a river system. This natural barrier is a dominant factor in determining the composition of regional faunas and in promoting endemism (Ricklefs & Schluter, 1993; Cox & Moore, 2000; Rahel, 2007).

The dominance and abundance of species in a fish assemblage could change with the changes of river gradient. Waterfall which is called as a bio-geographic barrier is able to prevent species exchange among regions and disrupts the movement of an aquatic organism (Rahel, 2007). For example, waterfalls in the Snake River (Idaho, USA) are restricted to certain fish species in upstream colonisation (McPhail & Lindsey, 1986).

Sungai Enam is one of the prominent headwaters that flow into Temengor Reservoir. Several studies have been conducted by ecologists in Sungai Enam such as fish fauna by Zakaria-Ismail and Sabariah (1995), Mohd- Akhir (1999), Berryhill-Jr. and Ahyaudin (2002), Hashim *et al.* (2012), Ismail *et al*. (2013) and Mohd Shafiq *et al.* (2013), hydrology and water quality by Hashim *et al.* (2011) and Wan Ruslan *et al.* (2013), flowering plants by Siti Munirah *et al.* (2013), lianas by Zakaria *et al.* (2013), macrofungal by Kin (2013) and mammals by Shahfiz *et al.* (2013) which proved that Sungai Enam solely able to possess great number of biodiversity and is a crucial headwater for research in the reservoir.

Nevertheless, these studies were only carried out at certain elevation within a short time frame. Therefore, no studies have yet been conducted on the influence of physical barriers to fish assemblages especially in the reaches above and below the waterfalls along Sungai Enam. Since the understanding of the influence of waterfalls to freshwater fish assemblages, especially in the tropical regions are still incomplete, Sungai Enam was selected to determine the influence of physical barriers to fish assemblage in this stream. At the same time, an experiment was carried out to observe fin regeneration.

1.2 Problem statement

Some definitive evidence showed that diversity and distribution of freshwater fish in Malaysia has been disrupted rapidly due to the developmental pressure and modification of fish habitat (Zakaria-Ismail, 1991; Bowen *et al.*, 2003; Chong *et al.*, 2010). One of the reasons that jeopardize freshwater fish diversity and its distribution in Malaysia is through habitat modification of dam constructions or any barriers that possibly will limit fish movement from downstream to upstream reaches or vice versa. The presence of barriers, either man-made or natural, will affect the fish assemblage in the fluvial ecosystem.

Waterfalls may disrupt the stream connectivity and influence the spatial distribution of freshwater fish. Fast-flowing water washes away fish species from upstream to downstream and prevents them from moving upstream as they have no adaptations either in the aspect of morphology or behaviour. It is clearly observed that only a few fish species can survive above the waterfall and move across the barrier. Therefore, the species, which are robust and tolerant against such physical and geographical obstacles hardly face biological competition and predation risks.

It is evident that the fish movement varies between taxa and life-history stages (Baras & Lucas, 2001; Crook, 2004). But complications and difficulties are common phenomenon in monitoring fish movement due to picking out the unfavourable type of tagging/marking method. Some tags or marks such as external tags (e.g., T-bar tag) (Collins *et al.*, 1994), external marks (e.g., dyes) (Dussault & Rodríguez, 1997), internal tags (e.g., PIT tags) (Zydlewski *et al.*, 2006), internal marks (e.g., alizarine) (Simon *et al.*, 2009) and visible implant elastomer (VIE) tags (Younk *et al.*, 2010; Kozłowski *et al.*, 2016), have certain limitations to certain number of species as well as individuals and are only applicable to large sizes of fish species. To reduce bias, tagging/marking techniques should be applied to a wide range of size. Therefore, fin clipping was selected and applied in this study because of its easiness and simplicity. Moreover, this marking method can be used to different types of fin. However, this type of marking method is considered harmful by a few scientists due to the lack of knowledge and practical understanding about the fin regeneration process (Akimenko *et al.*, 2003).

1.3 Significance of study

Fish require unimpeded access along waterways to survive and reproduce. Both types of fishes, either fresh or saltwater, move within the water at different times to access food and shelter, to avoid predators, and to seek mates. Some fish species have to migrate at least once as a part of their life cycle. However, the presence of physical barriers such as dams and waterfalls can disrupt the continuity of river or stream. At the same time, these barriers may limit fish movements, resulting in distinct assemblages on both side of the barriers (Barbosa *et al.*, 2015).

Studies of spatiotemporal patterns of fish diversity, distribution, and composition are beneficial to determine the factors that influence the structure of fish community (Belliard *et al.*, 1997; Galacatos *et al.*, 2004; Khairul Adha *et al.*, 2009). Fish distribution in the habitats is influenced by various factors such as the availability of food, breeding sites, water velocity, depth, topography and physic-chemical properties of water (Harris, 1995).

Disclosing fish-habitat interaction in a habitat is also crucial to understand fish adaptations. Besides, by studying the fish that live in altitudinal variation habitats could provide new insight into how fishes respond to environmental gradients and directly help on freshwater conservation efforts. However, high-altitude streams, such as above the waterfall is one of the habitats that have depauperate fish faunas of less than 15 species (Samat, 1990; Martin-Smith & Laird, 1998). These depauperate areas are hardly investigated by ecologists due to their physical isolation (Matthews, 1998).

To identify the location of any impacts arising in the future, information on upstream progress rates, and longitudinal changes in species movements is important (Bishop *et al.*, 1995). Observation towards the formation of groups between the waterfalls is necessary to confirm that waterfalls are able to produce dissimilar fish community resulting from different capability of fish to move against it.

1.4 Limitations of study

In this study, there were some limitations that may have affected the outcomes of this study. The first limitation is the sampling gears. In this study, only one active gear, electrofishing, was used to capture the fish. The combination of sampling gears either in passive or active gears, are generally able to collect more fish species because of the gear selectivity. Some species like to swim and forage on the surface of water (e.g., danios and rasboras), whereas some species like to swim and forage at the river bed (e.g., catfishes and eels). However, in this study, backpack electrofisher was the only suitable gear, due to shallow and narrow stream reaches.

The second limitation was the lack of manpower for such hard sampling excursions. In the field, sampling activities such as fish measurements and fish markings are needed to be carried out as fast as possible to reduce fish mortality. Along with hiking and other related procedures, the captured fish could be released earlier if there were enough manpower. In such case, a lot of manpower are needed as it is very difficult to manage with only three or four people.

1.5 Objectives

The objectives of this study can be summarized as:

a) To determine fish assemblages and their similarities among reaches in Sungai Enam, primarily between above and below the barriers.

b) To determine and to compare the relative condition factor of selected fish species among reaches in Sungai Enam, primarily between above and below the barriers.

c) To determine fish movement along reaches in Sungai Enam, primarily between above and below the barriers.

d) To correlate environmental variables with fish parameters in Sungai Enam.

CHAPTER II

LITERATURE REVIEW

2.1 Running water

Running waters range from a small stream to large rivers (Allan, 2012). Running waters harbour a diverse and unique collection of species, habitats, and ecosystems, including some of the most threatened species and ecosystems (Allan & Flecker, 1993). However, nowadays, running waters are perhaps the most impacted ecosystems on the planet (Malmqvist & Rundle, 2002; Aura, 2008) due to human settlements and heavy exploitation for water supplies, irrigation, electricity, and waste disposal.

2.1.1 River and stream

Rivers are mostly understood as lotic habitats where the water continuously flow. A river begins at a source (or most often several sources) and ends at a river mouth. Rivers and streams are always being misidentified due to their similar characteristics. Even though both are fast moving water bodies, but in general, a river is larger, deeper, and longer than a stream and is also formed from a collection of many streams (Chiotti, 2004). On the other hand, a stream is much shallower than a river, which sometimes can even be walked across.

Studies on rivers and streams started in Europe (Cushing *et al.*, 2006). Early studies were concerned with the distribution, abundance, and taxonomic composition of lotic organisms. Then, these studies advanced with the development of technology and expertise, as summarized in Figure 2.1.

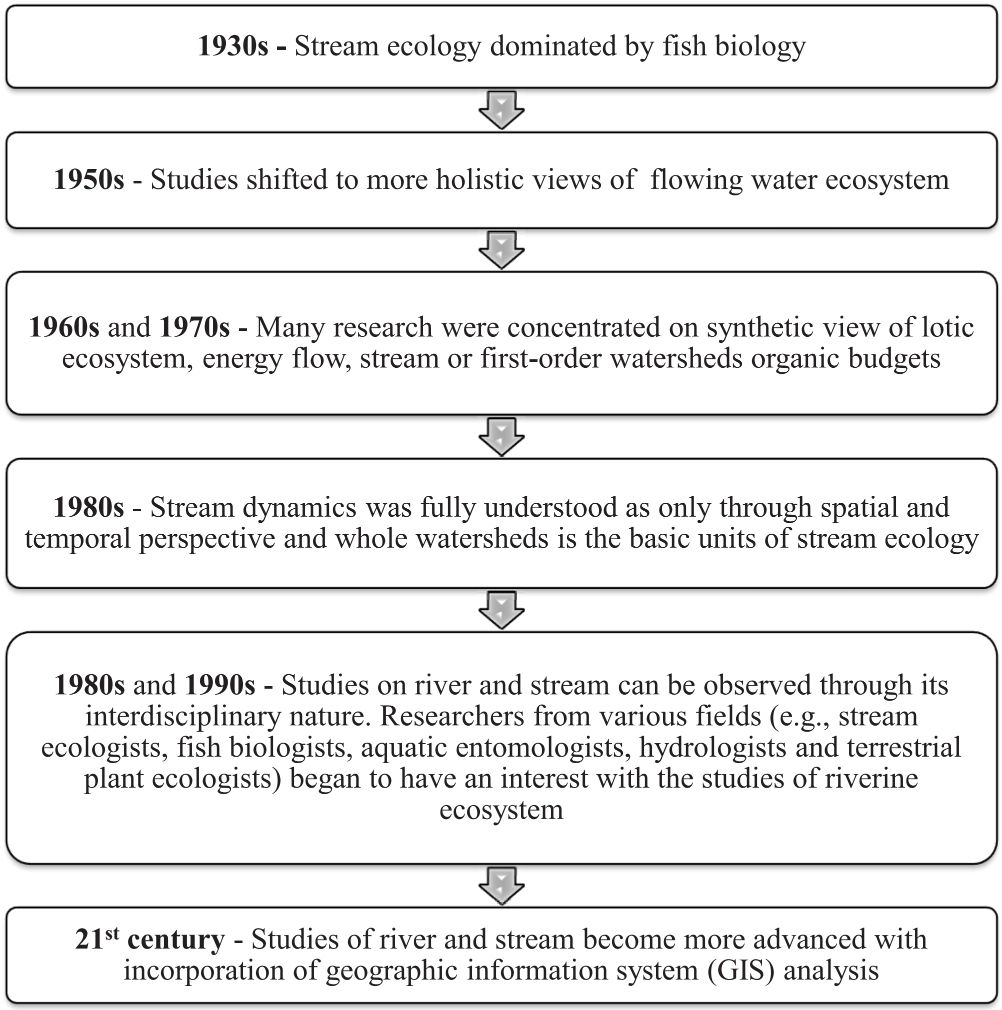

Figure 2.1: Chronology on the studies of river and stream ecosystem (adapted from Cushing *et al.*, 2006)

Generally, rivers and streams are classified by their size according to the Strahler Stream Order (Strahler, 1957). A first-order stream is usually the smallest stream with round flow and no tributaries. Second-order streams are formed when two first-order streams flow into each other. Third order-streams are formed when two second-order streams flow into each other. A river starts to form when all streams are interconnected; this is also known as a fourth-order stream (Chiotti, 2004).

2.1.2 River Continuum Concept

River Continuum Concept (RCC), is a framework that has been proposed by Vannote *et al.* (1980), that is important for the study of running waters. RCC, which has been tested in many countries, is able to describe the function of lotic ecosystems from the source to the river mouth (Allan, 2012). In this concept, geomorphological and hydrological performance changes as a stream order changed (Allan & Castillo, 2007). Allochthonous material was mentioned to be more abundant in the headwaters, whereas autochthonous input plays a greater role in the mid reaches.

According to Johnson *et al.* (1995), River Continuum Concept (RCC) was debated with different views regarding to several issues such as border issue, stochastic issue, human disturbance issue and spatio-temporal variation issue. To make it more realistic, several other concepts have been integrated into the RCC, including on the influence of riparian zone (Cummins *et al.*, 1989) and the Flood Pulse Concept (Junk *et al.*, 1989).

Flood Pulse Concept highlighted the importance of flood pulse, which is responsible for the existence, productivity, and interactions between biota in river and the floodplain systems. This concept was assumed as one of the most innovative concepts in order to adjust some weaknesses in the RCC. However, Ta Fang (2010) concluded that the application of RCC is still valid in order to provide an important model for proper management in riverine functional enhancement.

2.1.3 Malaysian river system with special emphasis on Sungai Enam

Malaysia, a tropical country, has a diverse collection of rivers and tributaries. Out of 150 major rivers, 100 are located in Peninsular Malaysia and another 50 are located in Sabah and Sarawak (Hashim *et al.*, 2011). Sungai Rajang with 51,000 km^2 of catchment area is the largest river in Malaysia, whereas in Peninsular Malaysia, it is Sungai Pahang with 29,000 km^2 of the catchment areas (Chan *et al.*, 2003). Most Malaysian rivers are short, steep (Abdullah, 2002) and located in remote areas (Berryhill-Jr. & Ahyaudin, 2002).

In Malaysia, low order streams are tropical mountain streams which are located deep within the forest and are difficult to be accessed. Basically, this low order stream is classified as oligotrophic with low fish diversity. Sungai Enam is one of the low order and high gradient streams in Malaysia. This stream is located within the Temengor Reservoir watershed, which is enriched with waterfalls at different heights and two small man-made dams. Water quality in Sungai Enam has recovered and was classified as Class I (Hashim *et al.*, 2011).

2.2 Assessment of freshwater fishes in streams

Fish is a crucial inhabitant of an aquatic ecosystem. Fish constitute almost half from the total number of vertebrates in the world due to their ability to live virtually in every conceivable aquatic habitat (Nelson, 2006). Out of 39,900 species of vertebrates, there are 21,723 living fish species recorded (Jayaram, 1999), which is comprised of 8,411 freshwater species and 11,650 marine species (Kar *et al.*, 2006).

2.2.1 Fish assemblages in streams

Fish assemblages play an important role in aquatic ecosystems. Fish assemblage is the term used to describe the collection of fish species in a habitat or fishing ground. Research on freshwater fish in Malaysia had begun in the mid-19th century (Zakaria-Ismail, 1991). However, studies on entire river stretches are still limited and need to be further discovered, especially in the upper reaches of rivers because this river section is the least studied, among other fluvial sections (Kottelat & Whitten, 1996), and possibly has many undiscovered endemic species (Shah *et al.*, 2009).

2.2.2 Previous studies of fish assemblages in the Temengor Reservoir

Temengor Reservoir is one of the four consecutive hydroelectric reservoirs located along Sungai Perak after Chenderoh, Bersia, and Kenering Reservoir. Temengor Reservoir, which has approximately 30 m of mean depth and 152 km^2 of mean surface area (Khairul-Rizal, 2004) receives water from its surrounding water catchment areas that have countless headwaters.

Previous studies on fish diversity of Temengor Reservoir (lotic and lentic) include Zakaria-Ismail and Lim (1995), Zakaria-Ismail and Sabariah (1995), Mohd-Akhir (1999), Berryhill-Jr. (2003), Hashim *et al.* (2012), Hamid *et al.* (2012), Kaviarasu *et al.* (2013), Ismail *et al.* (2013), Mohd-Shafiq *et al.* (2013) and Amirrudin and Zakaria-Ismail (2015). To date, Amiruddin and Zakaria-Ismail (2015) reported that the total number of fish species found in the reservoir and streams that flow into Temengor Reservoir is 42 species compared to the first study on fish fauna in Temengor Reservoir carried out by Zakaria-Ismail and Lim (1995) with only 23 species. However, Hashim *et al.* (2012) recorded only 21 species in Temengor

Reservoir. This finding showed that there were some missing species in comparison with Mohd-Akhir (1999) who found 37 species in the same reservoir.

Meanwhile, in Sungai Enam, the number of fish species recorded for the first study in 1994 was only nine species (Zakaria-Ismail & Sabariah, 1995) followed by 21 species in 1998 (Mohd-Akhir, 1999). Fish species recorded in Sungai Enam declined afterwards to 14 species in 2002 (Berryhill-Jr., 2003), 11 species in 2004 (Hashim, 2006) and ten species in 2012 (Ismail *et al.*, 2013).

2.2.3 Electrofishing

Electrofishing is a common technique used by fish biologists to catch fish in freshwater bodies. It is an active fishing method that establishes an electric field in the water to capture fish. Generally, there are three types of electrofishing unit used: (1) backpack, (2) stream-side or shore, and (3) electrofishing boats. An electrofishing operator typically moves through habitats accompanied by assistants who collect shocked fish with scoop nets (Portt *et al.*, 2006). A backpack unit is carried by an operator and may be powered by either a battery or a small gasoline powered generator. The efficiency of electrofishing in attracting and immobilizing fish is influenced by the characteristics of the electric field that is established. The effectiveness of electrofishing is lower in larger streams than in small streams (Paller, 1995).

Electrofishing is easy to be used in the field compared to other sampling gears that depend on the user's skills which results in different amounts of captured fish for different operators. However, this gear is limited to a certain depth and is only efficient in a specific water condition (Table 2.1).

Table 2.1: Advantages and disadvantages of electrofishing (adapted from Mohd-Akhir, 1999).

Advantages	Disadvantages
• It is selective, whereby unwanted fish can be released back to the habitat alive without any physical injuries. • It is more efficient to be used compared to other sampling gears. • It is safe to be used if operators wear the wader and is also easy to use.	• Most fish will sink, and it is possible that the fish will not leave their habitats when shocked. • It is quite difficult to detect fish that were shocked in cloudy water. • The effectiveness of this gear is limited to a certain depth and certain distance.

2.2.4 Altitude as a key factor in limiting fish distribution in streams

In fish study, most of the changes in diversity are related to altitude (Lomolino, 2001). In Malaysia, studies that show the trend of fish diversity and distribution in high altitude zones include studies conducted at Taman Kinabalu Sabah (Samat, 1990), Danum Valley Field Centre in Sabah (Martin-Smith & Laird, 1998), Taman Negara Pahang (Yahya & Singh, 2012), and Sungai Enam in Perak (Berryhill-Jr. & Ahyaudin, 2002; Hashim *et al.*, 2012; Ismail *et al.*, 2013). Other studies include Madeira River of Amazon basin (Torrente-Vilara *et al.*, 2011), and Agbokum waterfalls in South Eastern Nigeria (Offem & Ikpi, 2012).

The richness of freshwater fishes declines with the increase in altitude (Wootton, 1992; Jaramillo-Villa *et al.*, 2010). This statement is in concordance with a study by Agarwal *et al.* (2011) who found a low number of fish species at the upper stream stretches of Bhilagna river, Uttarakhand, India. Similar results of fish richness and diversity indices that were shown to be greater in downstream than upstream regions were obtained by several researchers such as Chang *et al.* (1999), Offem and Ikpi (2011), and Singh and Agarwal (2013).

Spatial change in fish community resulted from the shifts in the physical gradient of the stream from a shallow and temporally variable area (e.g., upstream and riffles) to a deeper and more stable area (e.g., downstream and pools) (Isaac, 1982). From upstream to downstream, and from riffle to pool, habitat diversity and water volume increased. Fish community also changes from headwaters to downstream, which due to the progressing addition of new species (Rahel & Hubert, 1991).

2.3 Assessment of the impacts of barriers to fish species

In ecology, a barrier is a physical or biological factor that tends to limit the migration, interbreeding or free movement of individuals or populations. Migratory fish require different environments to complete their life cycle phases such as reproduction, juvenile production, growth and sexual maturation (Larinier, 2001). For instance, the life cycle of diadromous fish species partly takes place in freshwater, and partly in seawater, whereas the reproduction of anadromous species, takes place in freshwater. The presence of structures such as dams, weirs, culverts, waterfalls and cascades, fish movement could be restricted and at worst, can disrupt their sustaining habitats (Rahel, 2007).

2.3.1 The influence of man-made barriers to fish species

Most rivers throughout the world have been dammed. Dam construction has its own pros and cons, but usually provides negative effects to fish distribution (Table 2.2). Dam construction affects nutrient dynamics along the system and fisheries in downstream reservoirs (Welcomme, 1985) and river channels (Hess *et al*., 1982). However, a dam also enhances some riverine fisheries, particularly with respect to tailwater fisheries which are located below the dam. For example, tailwater fisheries below Table Rock and Taneycomo dams on the White River (Missouri, USA) received seven to ten times greater value of catch per unit effort (CPUE) than upstream reservoir (Fry, 1965).

Table 2.2: Physical and biological impacts of dams

	Impacts
Physical	• Modifies the flow, temperature regimes, and water turbidity (Chang *et al.*, 1999). • Changes water quality (Chang *et al.*, 1999). • Blocks the passage of young migratory fishes in downstream and dams act as a barrier to upstream migrations (Larinier, 2001). • Breaks the upstream-downstream connectivity for a series of dams (Hashim, 2013). • Changes water discharge and current in some distance off downstream with the presence of impoundment and is able to alter a river's natural periodicity of flow for a series of large dams (Choi *et al*., 2005).
Biological	• Causes permanent biological change when migratory fish species are eliminated (Kanehl *et al.*, 1997). • Reduces the productivity in the rivers with its floodplain in response to reduced and altered river flow (Chen, 2000). • Much more likely to eliminate flora and fauna (Pereira *et al.*, 2010) due to high flows that are being released from dams, especially for the hydroelectric dam. • Blocks the upstream passage of anadromous fish such as salmon, catadromous fish such as eels, and some stream resident fishes, but likely induces migration to spawn, such as the case for catfish (Godinho & Kynard, 2009). • In some cases, water pressures encountered in turbines and spillways damage fishes migrating downstream (Cada, 1990).

2.3.2 The influence of natural barriers to fish species

The blockage of fish passage, resulting from barriers, either man-made or natural, can have negative implications to fish population. The deleterious effects of dams on fish assemblage are commonly noticed because most fish are unable to jump or move against the dams unless fish ladder is provided (Noonan *et al.*, 2012; McKay *et al*., 2013; Ottburg & Blank, 2015). Surprisingly, a natural barrier such as a waterfall is also able to interrupt fish movements along the stream.

A waterfall is one of the obvious natural barriers present in river ecosystem. Waterfalls are generally assumed as a vertical or very steep descent of a watercourse. Waterfalls can be found in the upper course of a river and are created by erosion process (Lamb *et al.*, 2007; Fuller, 2012). The steepness and height of waterfalls are varied between places (Kano *et al*., 2012).

Waterfall increases speciation rates (Dias *et al.*, 2013) through geographical isolation created by this barrier (Rahel, 2007; Cote *et al.*, 2009). High waterfall can be a barrier to the upstream fish movement (Rahel, 2007; Torrente-Vilara *et al.*, 2011; Kano *et al.*, 2012) and prevent species exchange among regions (Rahel, 2007).

Fish diversity decreases above waterfalls (Martin-Smith & Laird, 1998; Carlsson & Nilsson, 2001; Costello *et al.*, 2003) as waterfalls block the upstream movement of some fish species. Above waterfall, the populations will only persist if the fish have special behavioural or morphological adaptations. Adaptability of swimming pattern in order to move against water current may reduce downstream losses (Northcote, 1978; Wootton, 1992). Resident species above waterfalls generally have dispersal mechanisms such as united pelvic fins in some species under genus Gastromyzon, which allows them to ascend these upstream barriers (Martin-Smith & Laird, 1998). Thus, a waterfall, which acts as a bio-geographic barrier, is expected to produce different assemblage structures in riverine ecosystems (Torrente-Villara *et al.*, 2011) and generate freshwater biodiversity in river basins (Dias *et al.*, 2013).

2.4 Assessment of fish condition on the basis of length-weight relationships and relative condition factor

Biometric relationships are often required in research field to transform collected data into appropriate indices (Ecoutin & Albaret, 2003). Both analyses (*i.e.*, length-weight relationships and relative condition factor) are important in fisheries and fish biology to determine the condition or the well-being of fish in their habitat. Generally, the fish well-being indicates their health and suitability with the environment. This is because fish is easily affected by any changes that occur in the environment. Heavier fishes at a specific length are said to be in a better condition (Jones *et al.*, 1999).

Most fish species tend to grow in length and weight after they have reached sexual maturity, even though the growth rate declines as the fish get bigger (Wootton, 1992). Mainly, food availability and temperature always play an important role in affecting their growth. Fish growth depends on the efficiency of fish in obtaining sufficient food and the ranges of prey they have as the fish grows.

2.4.1 Length-weight relationships (LWR)

Many researchers use length-weight relationship (LWR) in their studies to observe the growth pattern for fish species. LWR provides the beneficial information of the growth patterns of fish (Bagenal & Tesch, 1978). LWR of fishes is necessary to evaluate the general well-being of fish species in terms of fatness, breeding, and feeding states and how the environment is suitable enough for them (Schneider *et al.*, 2000; Farzana & Saira, 2008; Mohd Shafiq *et al.*, 2012). LWR can also be an indicator of environmental changes and sustainable stock management (Samat *et al.*, 2008; Mohd-Shafiq *et al.*, 2012). The *b* value in the length-weight relationship of fish depends on biotic and abiotic factors such as water temperature, food availability, and habitat type (Wootton, 1992; Chu *et al.*, 2012).

The *b* value of isometric growth is 3, and values greater or lower than 3 are considered as allometric growth. The *b* value originated from the slope of regression from the length-weight equation. The formula of length-weight relationships of most fish can be described as:

$$W = aL^b$$

Where W = weight, L = length, *a* is a constant and *b* is an exponent that usually ranges between 2.5 to 4.0 (Le Cren, 1951).

2.4.2 Relative condition factor (*Kn*)

Suitability of habitat for fish growth could be determined by the value of relative condition factor (*Kn*) (Samat *et al.*, 2008; Abowei, 2009; Mohd-Shafiq *et al.*, 2012). Expected weight of fish in the formula of relative condition factor (*Kn*) could be identified from the equation of LWR (Isa *et al.*, 2010). Based on Pope and Kruse (2007), formula for the relative condition factor that is widely used such as by Le Cren (1951), Blackwell *et al.* (2000), Mohd-Shafiq *et al.* (2012) and Amani *et al.* (2015) is:

$$Kn = (W/W') \bullet 100$$

where *W*=observed weight of fish individual (g) and *W'*=expected weight of fish individual (g) from LWR.

Fish are assumed to be in a good condition when their relative condition factor (*Kn*) is greater than 100, as 100 is used as a benchmark value in this parameter

(Pope & Kruse, 2007). The greater the value of relative condition factor, the better the habitat suitability in terms of food availability for optimum fish growth (Samat *et al.*, 2008; Abowei, 2009; Isa *et al.*, 2010; Mohd-Shafiq *et al.*, 2012). This *Kn* value also can be used to compare spatial and temporal condition between or among fish species (Samat *et al.*, 2008). The state of their sexual maturity and appetite condition also contributes to different values of the relative condition factor (Williams, 2000; Pervin & Mortuza, 2008; Isa *et al.*, 2010).

2.5 Fish movement over barriers

Fish come and go within habitats (Roff, 1988; Wootton, 1992), and the spatial position of sites within stream provides a chance for fish to move freely to access resources or colonized new habitats (Hitt, 2007). Knowledge of fish movement is particularly important to managers as it provides information on fish's spatial and temporal distribution (Lucas & Baras, 2000). Fish movement studies would also provide a resource to determine specific spawning area and nursery habitat used by offspring and are appropriate for future fisheries management activities to be planned (Landsman *et al.*, 2011).

2.5.1 Importance of fish movement

Movement is a necessary organisms' behaviour, which not only brings beneficial encounters, but also exposes the organism to dangerous encounters (Bianco *et al*., 2014). Movements to a new habitat may increase individual fitness in promoting their reproductive success, which sometimes cannot be obtained from their previous habitat (Hitt, 2007). This movement could also reduce the rate of local extinction (Jackson *et al.*, 2001; Offem & Ikpi, 2011). Fish movement brings the fish into more suitable habitats than the habitats they left (Wootton, 1992). Commonly,