An over view on the causes, types and role of hormones in fish migration

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Abstract— In terrestrial and aquatic organisms, migration is a very common phenomenon that occurs both on diel and seasonal bases either for, reproduction, feeding or refuge seeking from predators or adverse climatic conditions. Migration is triggers by various extrinsic factors such as, precipitation, water level, current and discharge, lunar cycle, photoperiod, temperature, dissolved oxygen concentration, turbidity and water color, fish density, hunger and apparition of certain insects. The intrinsic factors such as, thyroxin, prolactin, growth hormone, somatolactin, insulin like growth factor -1(IGF-1), gonadotropin releasing hormone (GnRH), luteinizing hormone, follicle stimulating hormone (FSH), testosterone (T), ll-ketotestosterone (11KT), estradiol-17β (E_2) and 17α, 20β-dihydroxy-4-pregnen-3-one (DHP) has either a direct or indirect role in triggering fish migration. For fish, migration is very essential for their existence, as a single habitat cannot provide abundant of food and ideal environmental conditions for long times. Man has interrupted fish migration by constructing dams, culverts and weirs that break stream continuity. Water pollution and certain toxicant not only altered the physical and chemical properties of water but also negatively affects the olfactory, lateral line organs, metabolism and swimming performance, leading to delay or migration failure. Migration delay or failure is a key factor for species extinction and reduces the availability of fish for human consumption.

Index terms- Lunar, Hormones, Turbidity, Testosterone, Estradiol, Gonadotropin releasing hormone.

1 INTRODUCTION

Migration in many organisms is a very common phenomenon that occurs periodically in aquatic and terrestrial environment. Migration is the orderly movement of animals from one place to another place in search of food, breeding habitat and better climate. Usually fishes live in a constant habitat and restrict their movement with in a particular territorial limit, but there are a few fish species which migrate from fresh water to sea water and vice versa. In nature adult fish migration is mainly for spawning and feeding. Fish migrate to new habitat, thousands of kilometers away from their home land. But in fishes in addition to seasonal migration there is also, diel migration. For a successful fish migration three things such as, motivation, orientation ability and energy storage and locomotory ability are very essentials [1], [3].

Why do fish migrate?

For survival fish migrate to new suitable habitat for feeding and reproduction, as the feeding and spawning grounds are separated in term of space and time. Some fishes migrate in ordered to escape from predators, while other disperses in all directions ensuring their expansion and survival [4].

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When fish start migration?

According to three step model, fish start migration when (1) a fish achieve a certain threshold of body size or age depending on the growth rate and hatching date. In the second step fish achieve certain physiological characteristics such as, energy accumulation, osmoregulation and smoltification. All these physiological functions are regulated by hormones; the most important one is thyroxin. The third step is the reception of exogenous and endogenous triggers that initiate migratory behavior [3].

What is a migratory trigger?

A trigger by definition is anything that initiates a reaction or a process, by analogy to the metallic part of a gun moved by the finger to fire. In case of fish migration, triggers are environmental factors. There are several environmental factors that offer abrupt signals for fish to initiate migration.

Types of migratory triggers

There are two main migratory triggers, (1) extrinsic triggers and (2) intrinsic triggers, each containing sub-categories. Both extrinsic and intrinsic triggers actively participate in migration.

Extrinsic triggers

In migratory biology, the influence of environmental factors on migration is a very important theme. But this study is very challenging because, different environmental factors are correlated with one another, so it is very difficult to conclude that what factor really triggers migration. For example, there is a correlation between photoperiod and

temperature in temperate climate. Some of the extrinsic triggers are as follow;

Water level, current and discharge

Water level is a migration triggers and is correlated to current speed and water discharge. This is why in some fishes migration is triggers by the arrival of monsoon season [5]. Similarly during rainy season a change in water level and current speed occurs that is associated with both lateral and longitudinal migration [6], [7], [8]. About in 26 fish species migrations are triggers by alteration in water level, discharge and water current. Some fishes are *Bangana behri; Paralaubuca typus; Pangasius conchophilus; Hemisilurus mekongensis; Hemibagrus filamentus* (Bagridae); *Cyprinus carpio carpio* etc [9], [10]. In some fishes migration for spawning occurs during seasonal floods when water level rises. Fishes from these flooded areas then move to stable water bodies as water level regresses [11]. If in these areas due to climatic changes floods are delayed, migration will be also delayed. During the spawning season in Upper Paraná failure of fish reproduction was reported due to flood absence [12]. In contrast to adult fishes, juvenile migrates at lower water level [13]. In cat fish juvenile, it is the water current that triggers migration. No migrations in these juveniles were reported when the current speed was below 0.08 ms^{-1} [14].

Precipitation

In the tropics at the start of rainy season, precipitation in association with high water level triggers reproductive and breeding migration [15]. It has been reported that upstream migration after dry season is triggered by the first rain fall. There are about ten species whose migration is linked with early rain falls. Some of them are *Tenualosa thibaudeaui* (Clupeidae); *Barbonymus gonionotus; Pangasianodon gigas; Mekongina erythrospila; Micronema bleekeri* (Siluridae) etc. [7]. This type of migration is also affected by the moon [5]. Rain and floods, both trigger reproductive migration. Raining triggers migration in species which breed in calm water and floods trigger migration in species which breed in running water [16].

Lunar cycle

In certain fishes migration is linked with lunar cycle at a certain time of the year. These fishes sense the lunar cycle through tidal interface, gravitational force or visual cues, acting as direct or indirect trigger of migration. It has been noted that maturing adult eels migrate downstream while juvenile eels migrate upstream during the new moon [17]. Migration in response to moon is affected by storm and falling atmospheric pressure [18]. Migration in certain fishes such as *Cirrhinus microlepis; Paralaubuca typus* and *Tenualosa thibaudeaui* is triggered by the full moon [19]. Migration in *Pangasianodon hypophthalmus* in initiated during or prior to the period of full moon [5].

Apparition of insects

In certain areas such as Mekong River, fishers have observed that when fishes are about to start migration, there is the appearance of large number of mayflies and dragonflies. During this times these fishes comes to the surface and feed on these insects. Thus there is a link between fish migration and appearance of insect populations. Some fishes which migrate when blooms of insects appeared are *Pangasius pleurotaenia; Pangasius conchophilus; Paralaubuca typus* (Cyprinidae) etc. [7], [9].

Turbidity and water color

Alteration in water color and turbidity also triggers migration. Some of the fishes migrate due to change in water color and turbidity are *Tenualosa thibaudeaui* (Clupeidae); *Bangana behri; Pangasianodon gigas; Paralaubuca typus; Pangasius polyuranodon* etc. [10].

Photoperiod

The intensity of light and photoperiod also influences migration of fishes [20]. Similarly meteorological and sidereal influences affect the migratory responses [21]. In a population to synchronize and start the activity of migration, photoperiod offers calendar information. Pacific lampreys (*Lampetra tridentata*) and Pacific salmon during spawning to synchronize the activity of migration, migration totally relies on photoperiod. At the same time other environmental factor such as, temperature is highly variable on a seasonal scale and is less reliable. Migratory activity synchronizes with daily (diel) changing between dark and light phase. These diel activities are divided into three categories- crepuscular, nocturnal and diurnal. This is not investigated yet that, whether this is the light level or true endogenous circadian rhythm that affects the migratory activity. It has been reported that some fishes adjust their diel activities to changing light level. For example some nocturnal fishes become active on a cloudy day or when there is high turbidity.

Temperature

In fishes, temperature has also a role in synchronizing and triggering migration. Migration in response to temperature

can be considered as a form of behavioral thermoregulation. Migration in response to temperature occur under two different conditions. When for a given population of fish, temperature reaches to a limit beyond the tolerance threshold. Such type of fish populations escapes from extreme heat and occupy new thermally suitable habitats. The best example is the sea lampreys. Secondly when the thermal requirements of fish population changes. For example, the thermal requirements for growth and reproductions are not the same. In the Laurentian Great Lakes, migration in *P. marinus* does not start until in the stream temperature exceeds to ~10C^0 [3].

Oxygen concentration

There are some fishes which migrate when oxygen concentration in the water become too low. For example, several centrarchids, three-spined stickleback etc. [22].

Fish density

Fishes can start migration only when sufficient numbers of fishes are waiting below the fault line. These fishes gathered and start migration [3], [22].

Searching for food

Availability of food is one of the most important factors that are responsible for large scale migration of many species of fish going out in search of feeding areas [3].

Intrinsic factors it include the followings;

Instinct

Migration is an innate and instinctive behavior and it is a genetic makeup that develops this instinct in the concerned species.

Physiological factors

The ripening of gonads, secretion of hormones and biological clock etc. are the biological factors influencing fish migration. A number of hormones secreted by the pituitary gland such as prolactin, corticotrophin and growth hormone etc. are responsible for osmo and ion regulation in fishes during migration. The diadromous migrtation is associated with well-marked endocrine changes. Some of the hormones involved in migration are thoroughly discussed as follow;

Hypothalmo pituitary gonadal (HPG) axis

Gonadal maturation which is controlled by different hormones causes the fishes to migrate long distance from sea to rivers or vice versa. In Salmonids there are two different types of gonadotropin releasing hormone (GnRH), chicken GnRH-II (cGnRH-II) and sGnRH [23]. During migration in chum salmon *(Oncorhynchus ketal),* the immunoreactivity and hybridization signals of sGnRH neurons in olfactory nerve (ON) and olfactory bulb (OB) were strong in the coastal sea but all these vanished or diminished on the spawning ground. Similarly on the spawning ground the immunoreactivity and hybridization signals of sGnRH neurons in telencephalon (TC) and preoptic area (POA) were stronger as compared to coastal area [24], [25], [26]. sGnRH of the POA has a role in synthesis and secretion of gonadotropins, luteinizing hormone (LH) and follicle stimulating hormone (FSH) from the anterior pituitary gland. In both sexes gonadotropins are responsible for steroidogenesis in gonads, and finally steroids stimulate gametes formation and its maturation. The hormones active in vitellogenesis are testosterone and estradiol-17β (E_2), in spermatogenesis are ll-ketotestosterone (11KT) and testosterone but, in both sexes 17α, 20β-dihydroxy-4-pregnen-3-one (DHP) is active in gameto-maturation [27]. In female salmon fish during migration, the concentration of serum estradiol-17β (E_2) rises abruptly but falls rapidly when there is upstream migration. In these fishes the concentration of serum 17α, 20β-dihydroxy-4-pregnen-3-one (DHP) at the spawning ground increases sharply but is very low at the pre spawning ground. Similarly in male salmons, during the pre-spawning period the concentration of testosterone (T) and ll-ketotestosterone (11KT) increases rapidly but, were significantly decreased at the spawning ground except DHP [28], [29], [30]. Similarly in lacustrine sockeye salmon *(0. nerka)* males increase T and 11KT is concerned with shortening of homing interval but increase serum level of DHP and reduces T is linked with reduction of homing percentage [31], [32].

Hypothalmo pituitary thyroidal (HPT) axis

Hasler and Scholz [33] suggested that at various stages of life hormones are responsible for olfactory learning and homing. They confirmed this by using artificial odors and found that juvenile coho salmon learn the odor of their homing area during a very sensitive developmental stage called parr–smolt transformation (PST). During PST this sort of irreversible and unconditional learning is indicative of familial imprinting. Latter on Dittman and Jensen and Duncan [34], [35] proved this experimentally, that adult salmon returned to the releasing site when reared at one area but released from another area during or prior to PST. Scholz and Hasler and Scholz [33], [36]. stated that, expo-

sure of presmolt coho salmon to any odor by artificially increasing the concentration of thyroxin were able to sustain the memories of that odor for a long time as compared to untreated group. Dittman, Tilson and Morin and Doving [37], [38], [39], [40] concluded that there is a correlation between increased thyroxin level and increased sensitivity of olfactory sensations during PST. Nevitt and Kudo *et al.* [41], [42] found that as compared to parr, smolting masu salmon (*O. masou*) olfactory epithelium has abundant of thyroid hormone receptors. This thyroxin in other vertebrates has also a role in the regulation of neurogenesis and peripheral olfactory system. HPT-axis is sensitive to various environmental factors such as photoperiod [43] lunar phase [44], water flow rates [45] temperature changes [45] and exposure to novel water [46]. All these environmental factors have a role in increasing the concentration of thyroxin level. During migration, salmon fish have high concentration of thyroxin when compared to non-migrating salmon [47]. Similarly downstream migration in kokanee salmon can be induced by injecting high concentration of thyroxin [48]. HPT activity is also affected during migration because, the migrants swimming rate increases, exposed to new environment where temperature, water flow rate and chemical composition are different. All these factors contribute to increase the production of thyroid hormone [49]. In summary, high thyroxin level during migration has a role in migration and imprinting.

Insulin like growth factor-1 (IGF-1), prolactin, growth hormone and somatolactin

In wild chum salmon, before starting migration the level of IGF-1 was high suggesting that IGF-1 stimulate the HPG-axis as a somatotropic signal. Similarly prolactin and growth hormone, in addition to osmoregulation has an important role in final maturation. Therefore growth hormone- 1receptor mRNA, prolactin mRNA and somatolactin level increases near the spawning ground [50-52].

Methods of fish migration

A fish can make migration or migratory movements by several methods which are as follows;

1. **By drifting**
   In this method fishes are carried passively by water current [53].

2. **Random swimming**
   Fishes released from a point in a uniform environment and spreading out in all directions, the process is called dispersal and leads to uniform distribution of the species [54].

3. **Oriental swimming movement**
   In this method fishes move in a particular direction which may be (i) either towards or away from one habitat or (ii) at some angle to an imaginary line running between them and the source of stimulation [54].

Types of fish migration on the basis of food, spawning, climate and water current

These include the followings;

Feeding migration

Migration of fish in search of food and water is called feeding migration. This migration occurs because the supply of food in any habitat is not constant but, fluctuates from time to time. Fish in order to, survive and reproduce move to an areas with abundant of food supply. Some fishes are; cyprinids, salmonids, *Thymallus thymallus* and percids [3], [55].

Spawning migration

Migration for the purpose of spawning is migration in true sense and is also called spawning migration. This spawning migration is more prominent as compared to feeding or climatic migration because of the aggregation of thousands of fishes to a particular habitat [56]. These include salmonids, osmerids, cyprinids, castostomids etc. [57].

Climatic or refuge seeking migration

This type of migration occurs in response to harsh climatic conditions. For example; arctic and subarctic fishes migrate to separate refuge and feeding areas during their life cycle. These fishes include *Thymallus arcticus* and *Salvelinus alpinus* [58] Similarly *Anguilla anguilla* migrate in ordered to avoid ground ice, surface ice and cold water [59].

Contranatant migration

Movement of migratory fishes against the water current is called contranatant migration.

Detanatant migration

Movement of migrating fishes in the direction of water. Detanatant movement of adult salmon from sea to river is an example of Detanatant migration.

Types of fish migration on the basis of direction

On the basis of direction Myers [60] recognized three patterns of fish migration. They are as followed;

1. Diadromous migration
2. Potamodromous migration
3. Oceanodromous migration

Diadromous migration

Fish migration between fresh water and sea water is known as diadromous migration. This migration is further classified into the following three types.

Anadromous migration

Journey of marine fishes from sea to fresh water for spawning is called anadromous migration. Examples of such fishes are Salmon, Trout, shad and Lamprey etc. Salmon travels thousands of kilometers in the sea and then several hundred kilometers into the fresh water rivers to reach the spawning grounds. They migrate in pairs. Black spots develop on the body of female Salmon and red spots on the body of male Salmon during the journey. The reproductive organs ripen and the alimentary canal shrinks. Females lay the eggs in saucer shaped nests. Then the male releases the sperms and the eggs are fertilized. After egg laying the spent fishes returns to their home. This upstream and downstream journey takes about one year. Salmon attain sexual maturity in about seven years. After attaining full sexual maturity they return to fresh water rivers for breeding purpose. During this migration, they came to many path and turns, water falls etc. but reached to their exact place of origin where they took birth seven years ago. After hatching young Salmon do not return to the sea until their salt secreting cells had developed [60].

Catadromous migration

Fish migration from fresh water to ocean for spawning is called catadromous migration. Fresh water eel is the best example of this type. There are sixteen species of fresh water eel. The yellow color of European eel represents the feeding and growing phase. When the color changes to silver, it represents the breeding phase. 8-10 years old male and10-18 years old female eel prepear for migration. Their feeding stops, digestive tract shrinks and become functionless. Gonads covers the entire coelomic cavity, the eyes become large, lips thinner and the pectoral fins becomes more pointed. They travel 3-4 thousands kilomters. It is belived that the eel spawn at the depth of about 400-500 meters below surface at 16-17c^0. The parents die after spawning. Eggs hatched into a larva known as Leptocephalus. This larva is flat like leaf, transparent and tiny having large eyes with needle like teeth. It takes three years in reaching home. During this journry leptocephalous metamorphose into Elver's larva and attain a length of about eight milimeter. Some other catadromous fishes are *Poramalosa richmondia, Myxus pelardi, Macquaria novemaculeata* etc. [60], [61].

Amphidromous migration

Migration of fishes from sea to rivers and vice versa, but not for breeding purpose is called amphidromous migration. This is mainly for food and change of environment. This travel may occur regularly at some definite stage of their life cycle. The only example is Gobies [60].

Potamodromous migration

Fish migration from one place to another only with in fresh water is called potamodromous migration. Teleosts, cat fishes, trout, carps and perches show migrtaion pattern entirely within fresh water in search of suitable spawning grounds. This migration provides young ones suitable environment, abundant food and are free from predators [60], [62].

Oceanodromous migrtation

Long journey from one place to another with in sea is called oceanodromous migrtaion. Cod, Mackerels and Atlantic herrings take long journey in the sea from deeper hoter ocean water to the shallow colder shores for the purpose of spawning. This is during breeding season. After spawning they return to their original home [60].

Vertical migration

Throughout the oceans, seas, and lakes, many species of fish and invertebrates are found to make diel (with a 24-hour periodicity) vertical migrations usually toward the surface at dusk and toward the bottom at dawn. The most plausible general explanation for such a regular event is that phytoplankton is to be found in the euphotic zone, near the surface. Herbivores must visit these strata in order to feed, and since they can feed in the dark (unlike most carnivores) the best time to visit the surface layers is at night, while by day they are safer dispersed in deeper water. The carnivores follow the migrations of the herbivores, feeding on them at dusk and dawn when they are in dense concentrations and before the illumination has fallen below the carnivores' visual threshold. Thus, vertical migration is

driven by the need to feed and to avoid predators. In particular, it is desirable for many larger species to avoid the surface waters by day where they are vulnerable to avian predators. Upward vertical migration at dusk seems to be triggered by falling light intensity and downward migration at dawn by increasing intensity. In high latitudes, in the polar summer and winter, vertical migration is less evident since there is a much reduced diel cycle of light. Vertical migration is also predictably influenced by bright moonlight (which tends to inhibit upward movement) and lunar or solar eclipses (which cause upward movements during the period of darkening [63].

Horizontal migration

Daily vertical migrations are modulated by small-scale horizontal migration involved in feeding and predator avoidance. Reef fish may move on off the reef with a 24-hour periodicity, feeding by day and hiding at night (some "hide" by drifting in school-like aggregations away from the reef). Much larger seasonal horizontal migrations occur that are related to spawning and feeding. These are often depicted in the form of oscillatory triangular movements. For example, maturing Atlantic cod migrate to the Norwegian coast to spawn in the spring. After spawning they return to the offshore feeding grounds to recover. Herring in the North Sea moves southward in the early summer. After spawning they tend to drift eastward, overwintering in the eastern North Sea. In the spring they migrate offshore to the west and north and start to feed and mature for a repeat of the spawning cycle. Plaice in the southern North Sea have distinct spawning grounds but wider areas in which they feed and recover after spawning [63].

Speed of fish during migration

The average speed of fish during migration is three times the length of fish per second (body length × 3/ sec). For Salmon maximum speed during migration is 49 km day-1 but for grilse it is 47 km day^{-1}. For the same fish, speed is different because of variation in water velocity [64].

Distance traveled during migration

The distance covered by fish during migration varies from species to species and ranges from few hundred kilometers to few thousand kilometers.

Duration of migration

It also varies from species to species and ranges from few months to years.

Anthropogenic impacts on migration

For several thousands of years humans have exploited fishes, during their migration. Humans constructed dams, and other barriers such as culverts and weirs which not only break the river or stream continuity but, also negatively affects migratory movements. These barriers not only physically disturb migratory movements but, also alter chemicals and physical properties of water, indirectly affecting their migrations. In some areas fish ways are present but, they are species specific and are very costly in terms of time and energy. Water pollution and toxicants alters chemicals and physical properties of water, so fishes are unable to identify their homeland as their home land odors are masked by pollutants. Pollutants and toxicants also, destroy olfactory, lateral line organs and negatively affect fish metabolism and swimming performance. All these human activities either causes fish mortalities or Lead to delay or failure of migration [65].

Advantages of migration

Migration has multiple advantages such as (1) better utilization of the new habitat and their resources. (2) one particular habitat do not have enough food to support both adult and offspring's, so due to migration they have separate feeding, breeding and nursery grounds. (3) Providing suitable climatic conditions for breeding and survival of the young's.

Disadvantages of migration

It includes (1) Long journey is wasteful and many migrating fishes get lost while migrating. (2) Numerous migrating fishes are eaten by predators. (3) Dams construction check migration and the concerned fish species become extinct.

Conclusion

To keep a fish within its ecological norm, diel and seasonal migration are very crucial. Especially for commercial fishes, knowledge about migration is necessary. Fish migration in different fishes is triggered by a variety of extrinsic and intrinsic factors. But, dams construction and water pollution may either causes migration delay or failure. Further studies are needed to investigate the molecular pathways for each extrinsic factor that triggers migratory movements.

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