Unit 1 ☐ Diversity, structure and function of insects with reference to their pest status

Structure

1.1 Introduction

Insects appeared about 200 million years ago during the course of evolution of life on earth, during the carboniferous epoch, but man came on the scene only half a million years ago. It seems that insects have utilized every possible opportunity to colonize almost all habitats available on the earth, and now they exhibit the greatest diversity of all life forms. From an anthropocentric interest the amazing diversity of insect species is generally categorized into ***Beneficial, Harmful and Neutral groups***. This categorization is made broadly considering their economic importance.

The common examples of beneficial insects are the silkworms, honeybees, lac insects etc, although a great range of other groups of beneficial insects, from species of natural enemies like predators and parasitoids of pest insects to those insects that provide important clues to forensic scientists, are also known. The examples of harmful insects that are often cited are the agricultural and household pests, forest pests, insects of medical importance (mosquitoes, flies, ectoparasites etc) and other such groups. However, considering the unfathomable diversity of insects, most of the insect species fall within the Neutral group of this rather artificial categorization, that is, they are neither beneficial, nor harmful from an economic point of view.

In this unit a very basic discussion on some aspects of insect structure and function has been made.

1.2 Major Insect orders of agricultural importance

For this part please consult unit 2 of this paper.

1.3 External structures

I. Head including mouthparts

The insect head is a strongly sclerotized capsule. It is joined to the thorax by the flexible, membranous neck. The head bears the mouthparts - the *labrum, mandible, maxillae* and *labium*, and some important sense organs like a pair of *compound eye,* usually three ocelli and a pair of *antennae.* The head consits of six segments.

Orientation of head : The orientation of the head in respect of the rest of the body varies in different insects. Basically three types - *hypognathous, prognathous* and *opisthognathous* or *opisthorhyncous* types are observed. In hypognathous condition the mouthparts hang ventrally form the head capsule, in a continuous series with the legs. This type is very common with the phytophagous (plant feeding) insects and is considered to be most primitive of the three. In prognathous condition the mouthparts are directed forward, a position suitable for predacious insects who pursue their prey, and in larvae who use their mouthparts for burrowing (e.g., coleoptera). In opisthognathous condition the mouthparts are postero-ventral in position, and an elongate proboscis extends backwards between the legs. This type is found mainly among the Hemiptera and Homoptera.

Sutures and divisions of the head (cranium) : A number of markings are present on head. Those markings which represent the original segmentation are called sutures. But on the head there are several marking which arise for functional purpose but not representing original segmentation of the head are caued sulcus. True sutures on head are epicranial and occipital. The following are the sutures and surcia found on insect head.

Epicranial suture : It has the shape of an inverted Y; its stem forms the dorsal midline of the cranium and called the coronal suture, and the arms diverge ventrally across the anterior part of the head, and are termed as the *frontal sutures.* The epicranial suture is also known as *ecdysial line*, because it is along this line that the cuticle splits during ecdysis.

Occipital suture : It begins as a line from the posterior termination of the coronal suture and ends just above the mandibles on either side of the cranium.

Postoccipital suture : It lies posterior to the occipital suture, but in the same plane with the later, and surrounds the foramen magnum, the posterior opening of the head capsule. It also serves to separate the maxillary and labial segments.

Subgenal (Subgenual) suture : These are lines on insect head located immediately above the bases of mandibles and maxillae.

Epistomal (Frontoclypeal) suture : It lies just beneath the frontal suture and connects the subgenal sutures across the front of the cranium.

The other sutures that are present on the cranium are : *circumocular sulcus* surrounding the compound eyes; *antennal sulcus* surrounding the base of each antenna; *subocular sulcus* that may be present running vertically beneath the compound eyes; and a transverse *labial sulcus* connecting prementum and postmentum.

Areas of the head :

Vertex : It lies on the dorsal aspect of the posterior part of the cranium, which is bisected by the coronal suture.

Frons : The frontal region of cranium delimited by the frontal suture.

Gena : The area of the cranium lying above each subgenal sulcus and anterior to the occipital suture.

A postgena lies adjacent to the gena, being located posterior to the occipital sulcus. The postgenae are delimited by postoccipital suture. The region of the head between occipital and postoccipital sutures are called occiput. The head sclerite posterior to the postoccipital sulcus, which surrounds most of the foramen magnum, is called the postocciput. It bears a pair of occipital condyles to which the anterior cervical sclerites are attached.

Clypeus : It is a lobe-like structure located on the anterior part of the head just beneath the epistomal suture. In many insects it is hinged with the labrum. The clypeus is often divided into a postclypeus and an anteclypeus.

Foramen magnum : It is the posterior opening of the head capsule through which the internal organs (alimentary canal, dorsal nerve cord etc.) pass to the thorax of insects.

II. Mouthparts of insects

Insects subsist on an amazingly wide variety of food and exhibit a varied way of feeding, and so their mouthparts also show modifications appropriate for ingesting a particular type of food. It is important to first understand a generalized pattern of mouthparts, which pertains to the mandibulate or chewing type. This type is considered to be the most primitive from which different modifications were achieved.

Mandibulate type of mouthparts consist of :

1. A **Labrum** (*or upper lip*)
2. The **Hypopharynx** (*or tongue*)
3. A pair of **Mandibles** (*or jaws*)
4. A pair of **Maxillae**
5. A posterior **Labium** (*or lower lip*)

The **labrum** is a broad lobe-like structure that articulates by a narrow membrane with the clypeus, and remains suspended from it - thus forming the upper lip. The inner side of the labrum is membranous, and may be produced into a median lobe called the *epipharynx.*

The **hypopharynx** arises as a median, membranous lobe lying on the floor of the pre-oral cavity, much in the same way as the tongue does. It divides the pre-oral cavity into anterior and posterior parts. The anterior part, between the hypopharynx and the labrum, is called the *cibarium*; the posterior part, between the hypopharynx and labium, forms the *salivarium.*

The **mandibles** are strongly sclerotized, unsegmented, compact structures, generally with a dicondylic attachment, a posterior attachment with the postgena, and an anterior attachment near the tentorial pit. Each mandible has a proximal molar, or grinding, region, and a distal incisor, or cutting region.

The **maxillae**, which act as accessory jaws, are little more complex as compared to the mandibles. Each maxilla has the following component parts:

i) A proximal or basal *cardo*, which is strongly articulated with the head.

ii) A flat plate, the *stipes*, which is hinged to the cardo.

iii) Two lobes, an inner, relatively unsclerotized *lacinia* and an outer, more sclerotized galea, which are borne distally on the stipes. The lacinia bear teeth on its inner side.

iv) A five-segmented *maxillary palpus* borne on a palpifer.

This basic structure however may be modified in some forms in which the lacinia, galea or the palp may undergo reduction or loss.

The lacinae are structures that help in holding and masticating the food, and the galeae and the palps are mainly sensory structures baring mechano- and chemosensilla.

The **labium** is similar in structure to the maxilla. It is composed of:

i) A basal, or proximal, *postmentum* attached to the cervix (the "neck" or the membranous region connecting the head and the thorax). The postmentum is generally transversely divided into a proximal *submentum* and distal *mentum.*

ii) An apical, or distal, *prementum*, which is hinged to the postmentum by a labial suture.

The prementum bears a lateral pair of segmented *labial palpi* attached to palpigers, and four distal or terminal lobes. Of these four lobes two inner lobes called the *glossae* are situated between two outer lobes called *paraglossae.* Sometimes the glossae and paraglossae are fused together collectively forming the *ligula.*

III. Thorax

Functionally, the thorax is called the locomotory center of the insect as it bears the legs and the wings. Structurally the thorax consists of three segments - **prothorax, mesothorax** and **metathorax**. Each of the thoracic segments bears a pair of legs. However, legs are absent in larval Diptera, larval Hymenoptera Apocrita, some larval

Coleoptera and in a few adult insects which are apodous (a = without; *podos* = leg). Wings, if present, are borne on either or both of the mesothoracic and metathoracic segments (depending on whether two or one pair is present), and these two segments are called the pterothorax (*pteron* = wing).

Each thoracic segment can be typically divided into four regions: a dorsal **tergum** or **notum**, a pair of bilateral **pleura** (sing., **pleuron**) and a ventral **sternum.** The legs arise from the pleura, and the wings articulate between the notal and pleural regions.

Thoracic appendages : The thorax in insects gives rise to two types of appendages - legs and wings.

Legs : Insects have three pairs of legs, and due to this characteristic feature they are often referred to as 'hexapods'. The legs are typically used for walking and running, although the legs perform a number of other specialized functions as mentioned below.

Each leg typically consists of six segments, viz. coxa, trochanter, femur, tibia, tarsus and pretarsus.

Modifications of legs : The basic function of insect leg is walking, but the legs are modified for a variety of functions in different insects. The principal functional modifications of legs are for:

i) Jumping (e.g., orthoptera and a few coleoptera)
ii) Swimming (e.g., aquatic coleoptera)
iii) Grasping (e.g.. giant water bug, praying mantis, ectoparasitic lice)
iv) Pincers (e.g., praying mantis)
v) Hanging (e.g., in males of various species, for hanging onto female during mating)
vi) Digging (e.g., mole cricket, cicada, many coleopterans)
vii) Cleaning (e.g., honey bee, some coleoptera)
viii) Pollen collection (e.g., hind legs of honey bees)
ix) Suctorial pads (e.g., *dytiscus*)
x) Sound production (e.g., orthoptera)

IV. Wings

Wings of insects, when fully developed, are thin, rigid flaps arising dorsolaterally as outgrowths from between the pleura and the nota of the meso- and metathoracic segments. Each wing is made up of a thin membrane, formed by two layers of closely apposed integument, and the membranes are supported by a system of veins. A nerve and a trachea invade each of the major veins, and haemolymph can enter into wings because the cavities of the veins are connected with the haemocoel.

The majority of the adult pterygota have one or two pairs of wings. Wings are primarily absent in Apterygota (e.g., Orders - Collembola, Diplura, Protura and Thysanura). Also, in pterygota complete absence of wings may occur as a secondary condition, as an adaptation to the habitats of the concerned group of insects (e.g., parasitic groups, some soil dwelling groups etc.).

Wings in insects develop in two ways - externally as **wing pads** in **Hemimetabola** (immatures develop following *larva-nymph-adult plan*), hence also called *Exopterygota*, and internally in *Holometabola* (immatures develop following *larva-pupa-adult plan*), hence also known as *Endopterygota*. The Apterygota (primarily or truly wingless insects) belong to Ametabola.

Structure, veins and venation of insect wings : It is generally assumed that the pattern of extremely varied arrangement of veins that is observed in different orders of insects is derived from a common primitive pattern, or an archetype venation. The venations in wings bear an infinite importance in the study of phylogeny and taxonomy of insects. **The Comstock-Needham system** is the most dependable system of study of wing venation, which is based on the assumption that tracheae are always present in particular veins, and that the pattern of tracheae develops in a particular manner and thus determine the venation pattern.

Areas, margins and angles of wing : Insect wing is approximately triangular in shape having three margins - the anterior *Costal margin,* lateral *Apical margin* and posterior *Anal margin*. Three angles are formed by these margins - the *Humeral angle* at the base, the *apical angle* between the costal and apical margins, and the *Anal angle* between apical and anal margins. The insect wing has two major areas, the anterior, more rigid *Remigium*, and the posterior, flexible *Vannal* (*Anal*) *lobe*. In some orders of insects a pigmented area, the *Pterostigmata*, exists near the costal margin of the wing.

Two major types of veins are recognized : Longitudinal veins that run across the wing originating from their bases, and Cross veins that connect the longitudinal veins. An area enclosed by longitudinal veins and cross veins, or and area formed when longitudinal veins reach the wing margin, is called a *Cell*.

The following are the principal longitudinal veins in insect wing, their notations are given within parenthesis: *Costa* (C); *Subcosta* (Sc); *Radius* (R); *Sector* (S) ; *Media* (M); *Cubitus* (Cu); *Anals* (1A, 2A etc.) and *Plicas* (P) and *Empusal* (Em)

Wings may be variously modified in different insects.

i) In some insects the fore and hind wings may be coupled together by the presence of groups of hairs or *frenulum* on the anterior basal margin of the hind wing and hairs or curved spines or *retinaculum* attached to the various veins of the forewing. Interlocking of these two structures is the basis of the coupling mechanism.

ii) A two-winged condition has been achieved in by the functional loss of either the forewing (e.g., male Strepsiptera) or the hind wing (e.g., Diptera). In these insects the 'lost' wings are in fact modified into a drumstick-like structures called the **haltere**, which act as the sense organs concerned with the maintenance of stability in flight.

iii) Wings of male orthoptera are commonly modified for sound production.

iv) Wings may have hairs, scales etc. on their surface. The scales provide colours to the wings.

V. Abdomen

The abdomen in insects is quite simple and uniform in structure as compared to the head and thorax. The segments are quite distinct, and most of them lack appendages. Each abdominal segment comprises a dorsal tergum and a ventral sternum, these two being separated by a pleural membrane.

The insect abdomen varies both in number and size. The primitive number is 12 (including the periproct), but among the extant insects this number is present only in adult protrura and in the embryos of some higher insects. The more generalized pterygotes have 11 abdominal segments, and the higher pterygotes usually have 10 segments. In some insects a few posterior segments may be telescopic. The size of the abdomen relative to the rest of the body ranges from a very tiny abdomen of parasitic wasps to the unusually large, distended abdomen of the gravid termite queen.

Abdominal appendages : The adults of Collembola, exhibit two rather unique abdominal appendages - the *collophore* on the ventral aspect of the first abdominal segment and *furcula* originating ventrally from the fifth segment. The collophore (meaning 'glue') are probably organs of adhesion, while the fercula, which is held in place by a tentaculum, is released when required so that the insect can spring, or be propelled into air (hence the name springtail). The Thysanura have a pair of cerci and a median caudal filament borne on the terminal abdominal segment. Another structure, the *styli*, which are simple abdominal appendages, is found in first three abdominal segments of adult protrura, and in many abdominal segments of Thysanura.

In pterygotes the abdominal appendages may be variously modified. The cerci may be forceps-like (e.g., earwig), the cerci, epiproct and paraproct may be long, bearing anal gills (e.g., damselfly). Bilateral abdominal appendages of mayfly may serve as gills. Aphids have a pair of *cornicles* or lobe-like projection on the dorsal side of the posterior part of abdomen. In the larvae of lepidoptera the first four or five and the tenth abdominal segments generally bear appendages called *prolegs*.

VI. External genitalia

The morphology of external genitalia, especially that of the male insects, is so varied that Snodgrass (1957) commented that "the great structural diversity in the male genitalia of insects is the delight of taxonomists, the despair of morphologists".

Female : The female genitalia are derived from the eighth and ninth abdominal segments. In females the aperture through the eggs pass is called a *gonopore.* Many female insects with a genitalic opening on the posterior margin of the eighth abdominal segment display an appendicular *ovipositor*. The ovipositor is a structure that develops from modified abdominal appendages or segments. Its function is the precise placement of eggs. In many insects this structure has been lost during the course of evolutionary adaptation to a particular lifestyle.

In *Lepisma* the ovipositor has a basal part and a shaft. The basal part consists of two pairs of *Gonocoxae (Valvifers)* on the eighth and ninth segments.

An elongate process, the *Gonopophysis*, projects ventroposteriorly from each gonocoxa. In pterygote orders the first valvula attached with 8th segment and second and third valvula are attached to 9th segment that form the female genitalia attached to the *Gonangullum* is a small sclerite articulated with the second gonocoxa and the ninth tergum.

Male : The male genitalia are derived from the ninth abdominal segment. The male genitalia are composed of two sets of structures. First, there are basic structures that are common to all insects. Second, there are structures that are peculiar to groups or even a species.

In all male insects the basic genitalia are derived from a pair of Primary Phallic Lobes belonging to the tenth segment. Exceptions are observed in Ephemeroptera, Odonata etc. In most of the insect orders the primary lobes are divided into secondary lobes, the *phallomeres*. Between the median pair, mesomeres, the ectoderm invaginates to form ejaculatory duct. The outer pair, parameres, elongates to form claspers. The mesomeres unite to form a tubular intromittent organ, the *aedeagus*, whose inner passage is called the endophallus. The distal opening of the endophallus is called the *phallotreme*. Sometimes the parameres and aedeagus unite at their bases to form *phallobase*.

1.4 Anatomy : cuticle and sensory system

Cuticle : The integument in insect has three basic divisions : (i) the epidermis (ii) the basement membrane or basal lamina and iii) the cuticle. The second one is a cellular layer, while the other two are non-cellular.

The amorphous ***basal lamina*** is selectively porous., generally 0.5 μm thick, and is composed of mucopolysaccharide, glycoprotein and collagen.

The ***epidermis***, which is one cell layer thick, secretes the cuticle and also the basal lamina. Epidermal tissues are most active during molting and it determines the time of molting, the type of cuticle to produce during a molt, and also the type of specialized structures to be produced. Some of the dermal glands that remain interspersed in the epidermal cells have a role to play in secreting a portion of the cuticle.

The cuticle is a rigid, elastic, flexible structure, generally impermeable, but permeable where necessary. Under light microscope the cuticle can be seen to consist of different layers. Two major layers have been identified: a very thin outer epicuticle, which is 0.03-4.0 μm thick, and a much thicker procuticle, which is up to 200 μm thick. The procuticle forms the bulk of the cuticle and it is again divided in to an outer exocuticle and an inner endocuticle (Fig. 1.1).

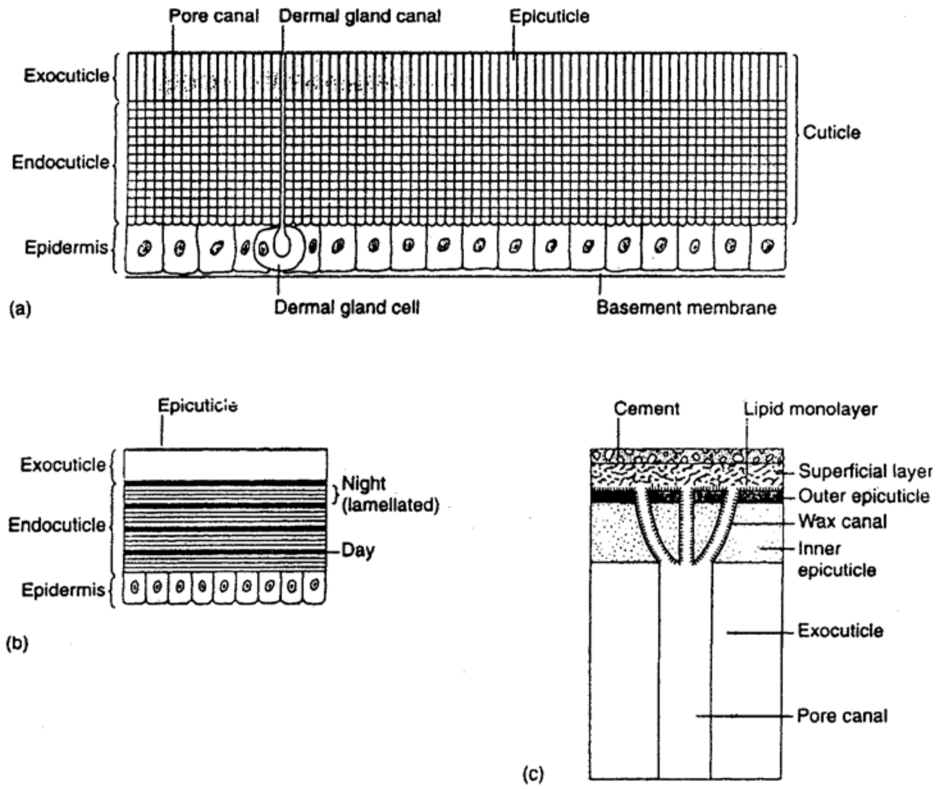


Fig. 1.1 : Structure of the integument (diagrammatic). (a) Section of generalized integument. (b) Daily growth layers and lamellar patterns. (c) Generalized epicuticle.

The exocuticle lies just beneath the epicuticle. It is a greatly stabilized layer of the procuticle and is so resistant in nature that it is left unaffected by the molting fluid and is shed with the exuviae during ecdysis. Exocuticle is however absent in some areas of the integument, like the joints and intersegmental membranes where flexibility is important.

The endocuticle, when observed under light microscope, gives a lamellar structure showing many successive layers of light and dark appearance. Electron microscope studies helped in developing models explaining the lamellae and striations. The helicoidal model suggests that the lamellae are resulted from orientation of layers of microfibrils of chitin and possibly also of protein embedded in a protein matrix. The vertical striations seen under microscopes are in fact tiny ribbon-like tubes known as pore canals, which run from the epidermal layers down to near the external surface of the epicuticle: These canals are 1 micrometer or less in diameter and serve as the connecting tubes between cellular and cuticular layers.

An additional layer of mesocuticle has been identified in the cuticular structure and it lies between the exo- and endocuticle.

The epicuticle, although much thinner when compared to the procuticle, is an important layer. It is a multilayered structure, impregnated by wax canals (60-130 Å in diameter) containing wax filaments. The epicuticle generally comprise of the following four layers:

1. The outer cement layer (< 0.1 micrometer thick)
2. The superficial or wax layer
3. The outer epicuticle or cuticulin layer
4. The inner epicuticle

Functions of cuticle: The cuticle has an enormous importance in insect organization, and most of the functions of the insect integument can be related to the physical structure of the cuticle. The cuticle may additionally serve as a source of metabolites during periods of starvation. The principal functions of the cuticle are the following:

1. It has important role to play in supporting the insect, and providing strength and hardness. These features are most essential for terrestrial organisms.
2. The cuticle controls the permeability of water, gases, insecticides etc.
3. Accurate movement of hard jointed appendages is made possible and at the same time the cuticle ensures the requirement of minimum muscle.
4. The cuticle provides the rigidity of wings, which is necessary for flight.
5. It also gives protection from external threats.
6. The fore-and hind guts have cuticular lining that protects the epithelium from abrasion by food.
7. Parts of the cuticle are modified to form sense organs.
8. Finally, the physical structure of the cuticle produces the colour of insects which has a great adaptive value.

Sensory structures : Various sense organs in insects collect information from the environment. The basic function of any sense organ is to receive some form of energy or stimulus from the environment. These organs then initiate a series of events that ultimately produce the nerve impulse. Various types of sensory systems are recognized in insects, which can be broadly categorized into the following:

Mechanoreception : When insects receive energy in the form of mechanical changes in their environment the sensation of these changes fall under the category of *mechanoreception*. They perceive their environment by their hairs or sensilla, or by stretching a portion of their body or through molecular movements occurring through sound waves propagated through solid, liquid or gaseous medium.

Photoreception : This is achieved when a certain organ, e.g., the eye, is stimulated by electromagnetic waves or photons. In other words, it refers to reception of stimuli in the form of light.

Chemoreception : The perception of potential energy causing mutual attraction and repulsion of particles making up atoms is referred to as chemoreception. Briefly stated, it refers to the perception of atoms and molecules as stimuli.

Hygroreception : When the molecules referred to above are water, the type of sensory system is called hygroreception, i.e., it is the perception of moisture in the air.

Thermoreception : Thermoreception occurs when insects collect information from the environment through thermal cues or heat.

In most instances the sense organs are composed of two types of cells : *receptor cells and accessory cells*. The receptor cells are generally bipolar neurons that detect the stimuli and generate nerve impulse. Receptor cells remain surrounded by accessory cells, and the accessory cells secrete the specialized cuticular structures that actually give shape to a sense organ.

Mechanoeception : It can be of two morphological types: Type I or cuticular, and Type II or multipolar.

Type I : These ciliated receptors are associated with the cuticle with the nerve cell bodies lying to the periphery close to the sensory endings. The Type I mechanoreceptors can be subdivided into the following principal types:

1. **Hair sensilla :** These are formed by two cells, the 'hair forming' trichogen cells surrounded by 'socket forming' tormogen cells. A simple sensillum comprises the following: a rigid pore-less hair set in a socket and four associated cells, trichogen or generative hair cells, tormogen or membrane-producing cell, neurilemma cell and a sensory neuron including a terminal cuticular scolopel.
2. **Campaniform sensilla :** They are found on the outer surface, mostly in compact groups near the joints, where they detect stress on the cuticle. These receptors are bell-shaped, and the stress moves the bell inward, so that the dendritic tip is compressed.
3. **Chordotonal receptors :** They are usually found far beneath the integument, but

may be connected to the integument by attachment structures. They serve several purposes including hearing, detection of joint movement etc.

Type II : This type of mechanoreceptors is nonciliated neurons lacking the detailed structures as found in Type I receptors. In this type the central cell bodies have many fine dendritic endings, each being mechano-sensitive. This type of neurons is found in internal structures like mesodermal tissues.

Photoreception : Photoreception can be defined as the *ability to perceive light energy in the visible or near visible (near ultraviolet)* range of electromagnetic spectrum. Specialized photo-sensory structures like compound eyes, ocelli, stemmata enable insects to detect light energy. However, some species, like those living inside caves, lack these structures and they perceive light through the general body surface.

Compound eyes : The major photoreceptive organs in insects are the compound eyes located on either side of the head and bulging out to provide a wide visual field. A compound eye comprises a variable number (from 1 in an ant of the genus Ponera to more than 28,000 in some Odonata) of individual photosensory units called ***ommatidia*** (sing. Ommatidium) (Fig. 1.2).

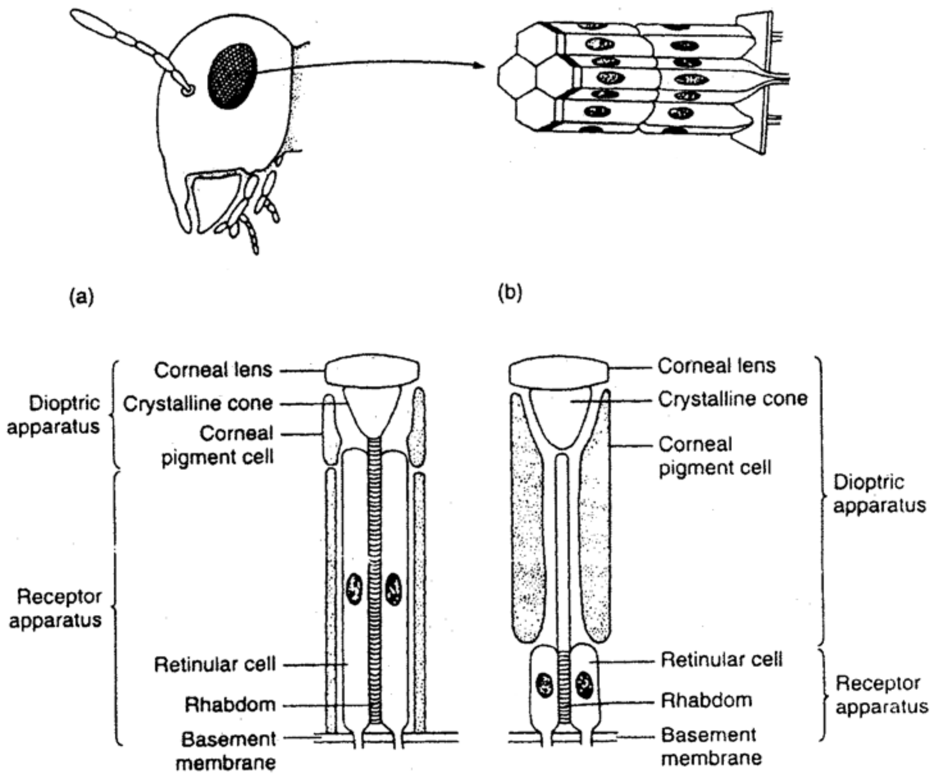


Fig. 1.2 : Compound eye structure (diagrammatic). (a) Head with compound eye. (b) Four ommatidia removed and magnified (c) Apposition ommatidium. (d) Superposition ommatidium.

Structure of the Compound eye : An individual ommatidium has two component parts: the dioptric apparatus or the 'lens', and the receptor apparatus, which plays the necessary role to initiate nerve impulses.

The following structures comprise the dioptric apparatus:

1. The Cornea: It is of cuticular origin, being continuous with the cuticle of the integument. It has a planoconvex shape, the outer surface being formed by the convex portion. In many insects corneal nipples' or conical projections in hexagonal sequence are found on the outer surface of cornea. These projections are considered to form an antireflection coating that reduces deflection of light at the air-corneal surface.

2. *The Crystalline cone :* Immediately below the cornea lies the crystalline cone, which is made up of translucent material. The cornea focuses light to the receptor apparatus through the crystalline cone. Its periphery usually bears the darkly pigmented corneal pigment cells. The crystalline cone is a clear, hard material and is produced by four Semper's cells. The ommatidia of insects show variations with regard to the crystalline cone and on this basis they can be grouped into :

   a) *Eucone type :* In some Apterygota, e.g. Thysanura (Lepisma), Collembola (Orchesella) the crystalline cone is very simple, this type being known as Eucone type.

   b) *Pseudocone type :* In most Diptera the Semper's cells produce liquid-filled or gelatinous cones, but not true crystalline cones. This type is known as pseudocone.

   c) *Acone type :* The Semper's cells do not form a crystalline cone and are transparent. The ommatidia of this type undergo only a little modification. Such ommatidia are found in some Hemiptera Coleoptera, Diptera and in many Apterygota.

   d) *Exocone type :* In some Coleoptera (e.g., *Lampyris*) the lens is formed from an inward extension of cornea. This type is known as Exocone type.

The receptor apparatus is composed of the following :

1. *Retinular cells :* There are seven (sometimes six, primitively eight) retinular or nerve cells which may be arranged in one or two layers. These cells are surrounded by darkly pigmented cells known as pigment cells. A nerve axon arises

from the base of each retinular cells, and the axons pass through the basement membrane to enter the brain.

2. *Rhabdome :* Each retinular cell contributes to the formation of a rhabdom or centrally located retinal rods. The part of the rhabdom contributed by each retinular cells is known as rhabdomere, which is the receptor surface of the retinular cells. Electron microscope studies revealed that rhabdomeres comprise tiny, finger-like, closely packed projections from the retinal cells. It has been suggested that the microvilli contain the light absorbing pigments like rhodopsin, metarhodopsin etc, that are important for photoreception.

The ommatidia can be distinguished into two types according to the arrangement of retinular and pigment cells:

a) *Apposition or Photopic ommatidia :* When retinular cells lie immediately beneath the crystalline cone, the ommatidia are of 'apposition' type. These are characteristic of diurnal insects.

b) *Superposition or Scotopic or Clear-Zoned ommatidia :* When there is a clear space between the retinular cells and the pigment cells, the ommatidia are of superposition' type. This type is found d in nocturnal and crepuscular insects.

Apart from the dioptric and receptor apparatus the light sensitivity of ommatidia is increased due to a double exposure to light which is ensured by a group of tracheal branches that are present near the basement membrane. These branches form a surface which reflects back the light along the rhabdoms that reach through the rhabdoms from distal to proximal ends. These tracheal branches are often collectively called 'tapetum', as their function is considered to be similar to the tapetum in the vertebrate eyes.

Image formation : The process of image formation by compound eyes was explained by Muller (1826) through his 'mosaic theory', which was expanded by Exner (1891). This theory proposes that through a single ommatidium an insect perceives the image of only a small portion of their surroundings. Thus the sum total of the entire object being viewed by an insect is in fact a combination of images sensed by each single ommatidium, and the total image forms a composite or mosaic view of their surroundings.

The type of image formed differs according to the type of insect eye. In apposition type of eye the pigment in the pigment cells surrounding the crystalline cone shows little or no movement in response to changes from light to dark or dark to light conditions.

The pigments in apposition eye remain uniformly distributed. On the other hand, in case of superposition eyes considerable pigment movement occurs in response to changes in light/dark conditions. In a light-adapted condition the pigments in pigment cells migrate proximally, and in dark-adapted condition the pigments migrate distally.

The mosaic theory suggests that light rays enter parallel to the long axis of an individual ommatidium in apposition and in light-adapted superposition eye, and adjacent ommatidia are optically isolated from one another because any ray entering obliquely is absorbed by the pigment. The image thus formed is called an apposition image. In such cases only the dioptric apparatus of the same ommatidium allows light to reach the concerned rhabdom. But such optical isolation does not occur in the dark-adapted superposition eye due to the distal movement of the pigment. In this type the light reaching the rhabdom of a particular ommatidium enters via several ommatidia. This type of image is known as *superposition image.*

Unit 2 ❐ Life history, population, structure and management of insect pests

Structure

2.1 Insect orders of agricultural importance

The insects are represented by the largest number of species belonging to 27 existing orders. Only 9 orders comprise species which are problems in crop production and storage.

I. Hemimetabola (Incomplete metamorphosis)

Eggs hatching into nymphs resembling adults. Wings develop externally.

Order -Orthoptera : Foliage feeders with chewing (mandibulate) mouth parts. Head hypognathus. Forewing forming thickend tagmina. Example : Acridid (Short-horned grasshoppers and locusts), *Hieroglyphus banian* on rice, *Locusta migratoria* on cropfields ; Gryllotalpid (Mole crickets), *Gryllotalpa africana* on grassland ; Tettigonid (Long-horned grasshoppers), *Mecopoda elongata* on rice field ; Gryllid (Crickets), *Brachytrypes portentosus* on orange nursery.

Order-Isoptera : Field pests. Subterranean with biting mouth parts. Both pairs of wings similar with fine network of veins in mating forms. Polymorphic and colony forming. Example : Termitid (Termites), *Odontotermes asmuthi* on Sugarcane.

Order-Hemiptera : Sap feeders with piercing and sucking mouth parts. Basal portion of frontwing thickened and leathery, apical portion membranous or uniform in feature. Beak arises from the front part of head. Example : Mirid, 'Tea mosquito'—*Helopeltis theivora* on tea ; Pyrrhocorid, 'Cotton stainer'—*Dysdercus cingulatus* on bhindi ; Coreid, 'Paddy stink' bug *Leptocorisa varicornis* on rice ; Pentatomid (Shield bugs), *Nezara viridula* on vegetables. Cercopid (Spittle bugs), *Clovia* sp., on jack fruit; Membracid (Tjreehoppers), *Otinotus oneratus* on *arhar ;* Cicadellid (Leafhoppers), *Nephotettix virescens* on rice ; Delphacid (Planthoppers) *Nilaparvata lugens* on rice ; Psyllid (Jumping plant lices), *Diaphorina citri* on orange ; Aleyrodid (Whiteflies), *Bemisia tabacci* on brinjal ; Aphid *lipaphis erysimi* on mustard ; Margarodid (Giant coccids), *Drosicha mangiferae* on mango ; Pseudococcid (Mealybugs) ; *Pseudococcus* sp., on brinjal ; Coccid (Soft scales), *Coccus hesperidium* on rose ; Diaspid (Armoured scales), *Aonidiella aurantii* on orange.

Order-Thysanoptera : Asymmetrical piercing mouthparts. Small and elongate insects. Wings narrow, fringe-like. Example : Thrips, *Thrips tabaci* on onion.

II. Holometabola (Complete metamorphosis)

Eggs hatching into larvae distinctly differing from adults, pupa present. Wings develop externally.

Order-Lepidoptera : Body and wings covered with scales. Adults siphoning sucking habit, larvae are caterpillars with mandibulate mouth parts, 5 pairs of abdominal legs, with crochets. Examples : Gelichiid (Grain moths), *Sitotroga arealella* on rice grain in storage ; Gracillariid (Leaf miners), *Phyllocnistis citrella* on *citnus* plants ; plutellid (Diamond back moth), *Plutella xylostella* on cabbage ; Limacodid (Slug caterpillars), *Parasa lepida* on orange ; Eucosmid, *Eucosma critica* on *Calotropis ;* Nymphalid, *Danais chrysippes* on *Calotropis ;* Hesperiid (Skippers), *Parnara mathias* on rice ; Satyriid, *Melanitis ismene* on rice ; Lycaenid (Blues), *Virachola isocrates* on *daeim* ; Pierid (Whites), *Pieris brassicase* on cabbage ; Papilionid (Swallow-tails), *Papilis demoleus* on orange ; Pyralid (Stem borers), *Scirpophaga incertulas* on rice ; Sphingid (Hawk moths), *Acherontia styx* on sesamum ; Arctüd (Tiger moths), *Spilosoma obliqua* on jute ; Lymantriid (Tussock moths), *Euproctis* sp., on castor ; Eupterotid, *Eupterote mollifera* on '*Sajna'*, Noctuid (Plant feeders), *Helicoverpa armigera* on tomato ; Geometrid (Loopers), *Biston supressaria* on tea.

Order-Diptera : Front pairs of wings discernible. Adults sucktorial mouth parts, larvae apodous maggots. Example : Cecidomyid (Gall midges), *Orseola oryzae* on rice ;

Chloropid *Chlorops* sp. on rice ; Trypetid (Fruit flies), *Dacus cucurbitae* on cucurbitacious fruits ; Agromyzid, *Melanagromyza phaseoli* on pulses. Syrphid (Hoverflies) are predators and Pipunculids are parasites of crop pests.

Order-Hymenoptera : Mouth parts primarily Liting and often lapping-Membranous wings with fewer cells. Abdomen basally constricted, ovipositor distinct. Example : Tenthredinid (Sawflies), *Athalia proxima* on mustard plant ; Cynipid (Gall wasps) on mango stem ; Formicid (Ants), *Dorylus orientalis* on sugarcane. Megachilid, *Megachile* sp. on rose plant. Ichneumonid, Braconid and Chalcid (egg ransites) comprise vast groups of parasites of crop pests.

Order-Coleoptera : Mouth parts biting, larvae are grabs. Forewings modified into horny elytra which meet to form mid-dorsal suture. Examples : Cicindelid (Tiger beatles), *Cicindela* sp., Carabid (Ground beetles), *Ophionea indica ;* & Staphylinid (Rove beetles), *Paederus fuscipes,* are predators of important pests of cultivated crops. Scarabaeid (Chafers), *Oryctes rhinoceros* on coconut, 'white grabs'—*Holotrichia* sp., on sunflower nursery ; Elaterid (Click beetles), *Drasterius* sp., on potato ; Dermestid, *Trogoderma granarium* on wheat grains ; Bostrichid (Rice beatles), *Rhizopertha* sp., on rice grains ; Coccinellid (Ladybird beetles), *Epilachna* sp., on brinjal and *Aspidomorpha* sp., on sweet potato ; Meloid (Blister beetles), *Mylabris pustalata* on Malvaceous plants ; Cerambycid (Longicorn beetles), *Batocera rufomaculata* on mango trunk ; Bruchid (Pulses beetles), *Callosbruchus chinensis* on stored pulses ; Chrysomelid (leaf eating beetles), *Aulacophora foveicollis* on cucurbits ; Apionidae (Jute weevils), *Apion corchori* on jute crop ; Curculionid (Weevils), *Sitophilus orygae* on rice grains.

Besides, there are some hamimetabolans belonging to orders like Odonata (Dragonflies and Damselflies), Dermaptera (Earwigs) and Neuroptera (Ant-lions) who are exclusive predators and one holometabolan order Strepsiptera (Stylops) who are exclusive parasites of agricultural crop-pests.

2.2 Pests : Definition, causes of outbreak, types, assessment of pest status, EIL

Definition

The word 'pest' comes from the Latin '*pestis*' meaning plague, i.e., outbreak of great proportion. Pests are those organisms which compete with man for his food supply, damage his possossions and attack his person. Organisms that conflicts with our economy, aesthetics and / or causing nuisance may be called a past

Causes of outbreak

The factors upsetting the natural balance and causing the outbreak of pests are (a) monoculture with crop varieties of narrow genetic base at the cost of the loss of biodiversity in agroecosystems, (b) adoption of agronomic practices with high inputs, favouring the growth of pest population, (c) indiscriminate use of chemical pesticides adversely affecting natural beneficial agents and development of resistence in pest species, and (d) catastrophic environmental change due to flood or prolonged drought.

Types of outbreak

The outbreak is *endemic* when a particular ecological configuration of an area favours recurrent occurrence of a pest species. Usually few components of an agroecosystem such as unrestricted floor irrigation in canal command area, cronic flood-proneness, etc, are associated with regular outbreak, such as BPH problem and swarming caterpillar problem in Dinhata.

The outbreak is *sporadic* when sudden change in the normal environment conditions, like hail-storm, prolong dryness, heavy rainfall, etc., trigger off the biotic potential of a species, causing serious damage in field crops, such as earcutting caterpillar of rice, indigo caterpillar in jute seedeings, gallmidge in rice, etc.

Assessment of pest status

Pest Status is determined on the basis of the damage potential of a pest. An individual insect has to multiply by reproduction to attain numerical growth as population to assume pest proportion except the insect-vector of diseases where a single puncture of a viruliferons insect may cause transmission of disease. Objective assessment of pest status requires rigorous sampling to sort out other concomitant variables inflicting damage. Subjective assessment from previous experience plays crucial role in assigning pest status. To an average farmer only severe outbreaks such as invasion of locust swarms, or onslaught of armies of caterpillar, hispa, brown planthopper, etc., would probably make a striking impression, as they would result in a clean sweep of his crops within a short time and lead to severe loss. In case of other damage in the form of loss of harvestable produce or deterioration of quality, farmers rely on their eye estimation or guessing rather than economics of pest control. Sometimes, investment determines pest status. So, the pest status of an insect is highly variable depending on various factors.

Concepts of economic levels

In 1959, V.M. Stern and colleagues proposed the concepts of bioeconomics and used the terms — economic damage, economic threshold, collectively called the economic injury level (EIL) concept. Rational use of insecticide is the background of developing such concept.

Economic damage was originally defined as the amount of injury which will justify the cost of artificial control measures. Injury is related to the activity of pest and damage is centered on the crop, its measurable loss of utility.

As the concept is applied in pest management, economic damage begins to occur when money spent for suppressing insect injury is equal to the potential monetary loss from a pest population. The term *gain threshold* has been used to express this beginning point of economic damage. The gain threshold = $\frac{\text{Cost of plant protection (let, Rs. 300 / acre in paddy)}}{\text{Market value of crop (let, Rs. 600/quintal of paddy)}} = 0\cdot5\text{q/acre}$ i.e., at least 50 kg paddy per acre would need to be saved with insecticide applications for the activity to be economically viable.

The economic injury level (EIL) is defined as the lowest number of insects per unit area that will cause economic damage or the minimum number of insects (or their stages) that would reduce yield equal to the gain threshold. If one eggmass of stemborer per sampling unit of one square metre causes 50 kg/acre paddy loss, the EIL for the pest is eggmass m^{-2}. Such an insect number per unit area is considered economic, and management activities are justified. This can be expressed as :

$\mathbf{EIL} = \frac{\mathbf{C}}{\mathbf{PDK}}$ where C is cost of plant protection, P Price of produce per acre, D loss of yield in q | acre associated with number of insect per unit area, and K is a constant (.8)-the level up to which pest number can be reduced

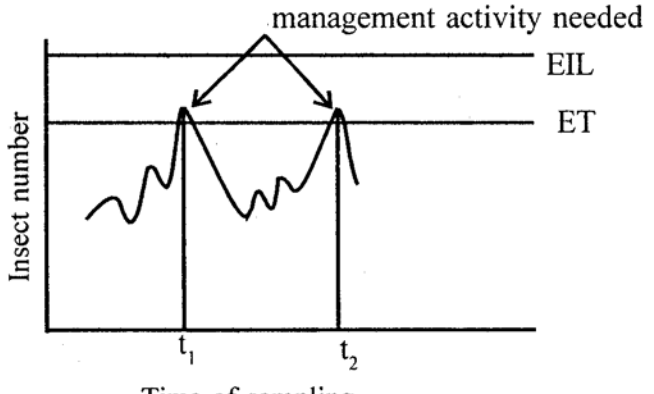
$$= \frac{300}{600 \times \cdot5 \times \cdot8}$$

$= 1\cdot25$ eggmass m^{-2}

Sometimes, D is replaced by the regression co-efficiant, *b*, representing loss in yield per insect (here, eggmass) per acre and can be worked out as

Y = a + *b* X where Y = yield / acre, X = number of insect per acre, *b* = yield loss per insect per acre, and a = Y intercept

The **economic threshold** (ET) is widely used in pest management decisions. ET indicates the number of insect when management action should be taken. For this reason, it is sometimes called the *action threshold.* Although expressed in insect numbers, the ET is in practice a time factor, as will be shown :

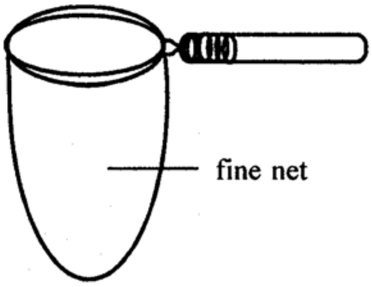


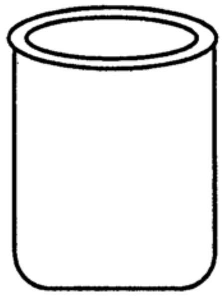
If a pest population is growing as the season progresses, growth rates can be determined in subsequent sampling, and the ET is set below EIL on the assumption that once the population reaches the ET, it is likely that it will touch or exceed EIL. It is judicious to take action on ET, i.e., earlier time, before losses are accured in EIL. Knowledge on population dynamics is pre-requisite, otherwise ET may nearly equal to EIL.

2.3 Methods of estimation of pest populations

The condition of a crop from the stand point of its vulnerability to damage is judged by periodical sampling of insect numbers on the crop and plotting the dynamics of the pest species in question. Depending on the nature of the crop field or orchard, many sampling devices are adopted such as direct count, knockdown, sweep net collection, trapping, extraction from soil, etc., to know either the qualitative or the quantitative aspects of insect populations.

Direct counts are practiced in on-field sampling. *Knockdown* may be on-field or in orchard. Insect are dislodged from the subtrata and then quickly counted. In case of *sweep net collection,* a net with a handle is swung into the crop canopy. Small insect will be collected in the net, subsequently transferred in small bag of fine net, then killed by chloroform and counted on blotting paper. It is suitable for sampling small insects from the nursery buds which apparently show no sign of insect occurrence. There are behaviroural *traps* like light traps, water pan traps and pitfall traps, and attractant traps like pheromone traps. Only adult insects are collected in traps. Different traps are used for different purproses such as phenology study, migration study, occurrence prediction, etc., Count data can be used for relative population estimates and then can be statistically processed in some cases to determine absolute population. Berlese funnels are used for extracting soil insects for taxonomic and ecological studies.





Different sampling techniques are used in on-field crop sampling. Most commonly used techinque is *random* sampling with a quadrat or any other suitable sampling unit. For extensive field sampling—sample size (n) may be 10 to 15. Sometime damage index such as rolled up damaged leaves, bored stems or fruits, etc., are used in stead of insect which may be hidden from sight. The sampled data give the estimate of sample mean and standard error (S.E.), the latter show the variability which is inherent in field pests.

Computation (as an example) : Estimation of number (x) of jassid per rice hill by random sampling.

Sample number (n)	**Number of jassed per hill** (X)	**Number squired** (X^2)
1	4	16
2	5	25
3	7	49
4	0	0
5	5	25
6	7	49
7	0	0
8	2	4
9	2	4
10	1	1
11	1	1
12	4	16

13	1	1
14	0	0
15	2	4
n = 15	Sum $\left(\sum X\right) = 41$	Sum $\left(\sum X^2\right) = 195$

Mean, $\bar{x} = \frac{41}{15} = 2{\cdot}7$

Sum of Squares (S.S.) $= \sum X^2 - \frac{\left(\sum X\right)^2}{n}$

$= 195 - \frac{(41)^2}{15}$

$= 195 - 112{\cdot}1$

$= 82{\cdot}9$

Variance, $s^2 = \frac{S.S}{df}$

$= \frac{82{\cdot}9}{15-1}$

$= 5{\cdot}92$

Standard error (S.E.), $s_{\bar{x}} = \sqrt{\frac{s^2}{n}}$

$= \sqrt{\frac{5.92}{15}}$

$= \pm\ 0.63$

Number of jassid per hill $= \bar{x} \pm S.E$

$= 2.7 \pm 0.63$

2.4 Strategies of pest management : Chemical, biological, cultural, behavioral, microbial, aterile male technique, other strategies ; Integrated Pest Management : philosophy and its application

Chemical control

Strategies of pest management evolve from single tactic chemical control to the culmination in multitactic options and their integration in pest population regulation in integrated pest management. Chemical control implies the use of insecticidal chemicals for pest control. The discovery of the insecticidal property of DDT, a chlorinated hydrocarbon, in 1939 was a revolutionary event in the development of insecticides. Since then thousands of synthetic molecules having pest killing property have been produced and the era of insecticide started. Chlorinated hydrocarbons or organo chlorin like DDT, BHC, dieldrin, aldrin etc., are very popular for their persistence nature but for this character majority of them are eliminated now. Most of the **organo-phosphates** like parathion, phorate, etc., are highly toxic but are biodegradable. Some of them like dimethoate, phosphamidon, etc., have systemic properties. *Carbamates* like carbaryl and carbofuran have wide applicability in agriculture. *Synthetic pyrethroids* like cypermethrin, fenvalerate, etc., are very popular for their quick knock-down-effect. The chemical control approach entailed identifying the pest and finding the most 'effective' chemical to apply, with little concern for other factors. Spraying or dusting was made according to a calender schedule and without knowledge of pest occure, density or damage potential. Gradually, it has been felt that only dependence on insecticides has very serious limitations, especially the growing of resistence in insects which makes the insecticides useless. The repeted spraying dusting/operations disrupt the ecosystem with adverse effect on the beneficial parasites and predators which keep the numbers in check, and on wild life which maintains delicate natural balance. Residues remaining on treated products pose problem in food wave and human health.

Biological control

Biological control means the deliberate use of natural enemies such as parasites predators and pathogens for pest control. The natural enemies are host-specific and self-perpetuating barring natural catastrophes or the unwise human interference. Biological control can be achieved by :

1. Introduction of exotic species of parasites and predators (classical biolgical control) by mass rearing and release. Example : *Trichogramma japonicum* against rice stem borer.

2. Conservation of natural enemy resources which require adjustment of pesticide use to avoid destruction of beneficial fauna. Example : Spider conservation in BPH endemic rice growing areas.

3. Augmentation of parasites and predators by mass-rearing and inundated release or innoculation in specific field, Example : *Tricho* egg-cards for Paddy stem borer, and *Chrysoperla* egges and larvae against aphid.

Biological control as a single tactic is not always reliable due to the nonavailability of specific natural agents. Favourable microclimates for fairplay of natural agents are not precisely known. Bio-control seems to be helpless in sporadic outbreaks.

Cultural control

Cultural control is purposeful manipulation of the crop environment to make it less favourable to the pest species or reducing their rate of increase and damage. It requires a thorough knowledge of the life history and habits of insects and their plant hosts. Some of the practices are :

(1) Modification of planting, growing or harvesting time of crops are aimed at prevention of insect damage rather then destruction of an existing infestation.

(2) Sanitation practices like destruction of crop refuse, clean field borders, etc., are to prevent or reduce insect infestation through removal of breeding and hibernating sites.

(3) Tillage may expose the pupae to be preyed by birds or bury some insects so deeply that they can not emerge.

(4) Rotation with unfavourable crop.

(5) Balanced fertiligation influences the longevity, fecundity, and damage of insects.

The practices *per se* are not suffice to give full crop protection against pests but helps to reduce the damage potential of pests.

Behavioral control

Insects are involved in many interactions with individuals of own species and others in the environment. Attraction, repellency and deterrence are mediated by chemicals from excrine system or their analogues are chemically synthesized.

Attraction : Sex pheromones are produced by females or males, depending on the species concerned, to attract opposite sex for mating. It is highly developed in Lepidoptera and produced by glands at the tip of abdomen. Pheromone traps are used to gain information on pest occurrence. It can also be used for mass trapping and killing. Such phero-lures are used against the adults of *Scirpophaga incertulas, Leucinodes orbonalis, Helicoverpa armigera, Spodoptra litura etc.*

Ocfactory stimulant such as rotten gourd or methyl engenol are used to attract fruitflies and subsequent killing by contact with insecticide.

Repellents : Repellents are volatile chemicals either synthesized or natural essential oil that cause insects to orient their movements away from a source. Example : Citronella oil.

Deterrents : Deterrents are natural plant constituents that prevent feeding or oviposition by insects. Example : Azadirachtin from neem seed kernel extract.

Microbial control

Microbial control is the use of microorganisms like bacteria, virus, fungus, etc., to control insect pests. The usual routes of invasion are oral, and through integument or trachea. Contact with the host insect is pre-requisite and early stages of insect are vulnerable. Example : *Bacillus thuringiensis,* Nuclear poly hedrosis, *Bauveria bassiana* etc., The micro-organisms are extremely host and stage specific effective within a limited range of temperature and humidity and these may limit their wide use for crop pests.

Sterile male technique

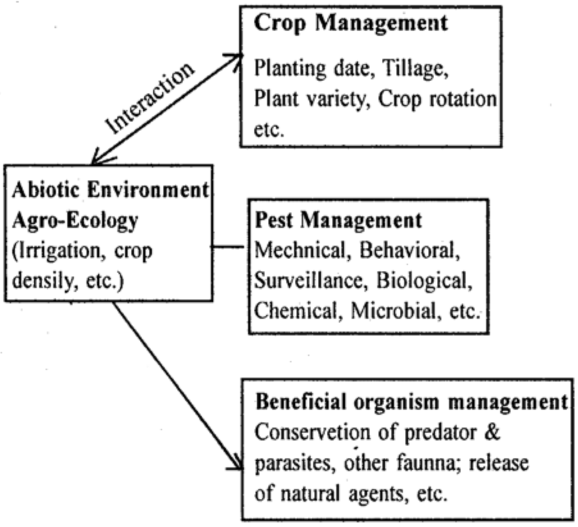
Melon fly and oriental fruitfly were eradicated by the release of males sexually sterilized by gamma radiation. Chemicals can also induce sterility in the natural populaion. Sexually sterilized insects mate with normal insects in the population, thus neutralizing their reproductive potential, decreasing the population in subsequent generations. Ionizing radiation produces cytological abnormalities in the germ cells of both sexes. Chemostrilants such as apholate, TEPA and METEPA are alkylating agents. They have utility in controlling such insects where insecticidal chemicals can not be used. Example : Oozyfly in silkworm industry.

Other Strategies

Mechanical control : Hand-picking is the most effective control measure for the congregated early caterpillars stages of hairy caterpillar and cabbage butterfly. Mustard sawfly and potato cutworm can be hand-picked with little searching. Hand nets can be employed for the *Epilachna* beetles of soyabean, grasshoppers in rice nursery and *Pyrilla* in sugarcane. Mechanical barrier around the host tree or trenching on the ground to prevent insect migration as in case of the giant coccid in mango and swarming caterpillar in rice, respectively, are widely practiced strategy.

Integrated Pest Management : philosophy and its application

In 1967, the FAO pannel of experts on Integrated Pest Control defined Integrated Pest Management (IPM) as 'A pest management system that, utilizes all suitable techniques and methods in as compatible manner as possible and maintains the pest population at levels below those causing economic enjury.' The following chart depicts the different categories of management options their interaction with factors and agro-ecology, and their resultant effect on the adoption of preventive or curative measures.



Preventive Practice

1. Choice of crop growing season
2. Choice of variety
3. Planting time
4. Ploúging
5. Spacing
6. Fertilizer & Irrigation use
7. Surveicillance & behaviour of pest & predators,
8. Immigration of pests

Curative measures

1. Traps setting
2. Sequential Sampling
3. Fixation of action threshold for key pests
4. Plant protection measures, Mechanical Biological, Microbial chemical (if absolutely needed)

Integrated pest managment is necessary to tackle the development of pesticide resistant populations, to prevent resurgence of treated populations, not to elevate secondary pests to a status of major pests, to have no deleterious effect on populations of non-target organisms, viz., parasites, predators, other faunistic composition, and to have no pollution of the environment with pesticidal residues.

Selection of tactices : Design of the insect pest management programme calls for selection of a set of tactics to achieve both prevention and therapy. Keeping in view of the factors which necessiate the IPM, the curative tactics should be such as to protect the beneficial organisms and maintain environmental quality. Besides, they must be compatible with one another and cost effective.

Application : After the proper tactics for prevention and curative measures have been chosen, the next step is integrating them in a complementary manner to achieve environmentally safe stable solutions to pest problems. Actual integration involves proper choice of compatible tactics and blending them so that each complements the other. Sometimes the tactics are required to be applied in a sequential manner, like a relay race, so that a particular tactic will be operated when the utility of the previously used tactic loose significance with regard to crop growth, environment and economic considerations.

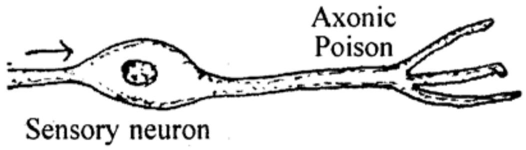
2.5 Types of insecticides according to mode of entry and mode of action

Stomach poisons

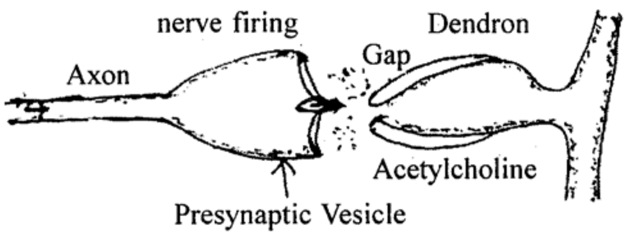
In case of stomach poisons, the target insects are toxified by consuming insecticide contaminated food. Insects having biting mouth parts and sponging or lapping habit of food-ingestion are vulnerable. True stomach insecticides are inorganic compounds like lead arsenate. Arsenic binds to the — SH (thiol) groups of engymes and proteins and acts as a protoplasmic poisons for insects. The biopesticides of bacterial and viral origin are also true stomach poisons. The caterpillar when ingest bacterial spores along with food, the delta-endotoxins are liberated in the midgut and this causes puncture in the epithelial wall. The insects die by septicemia. The virons likewise liberated in case of virus. The synthetic chlorinated hydrocarbons like DDT, BHC and few organo-phosphates have mixed function of stomach and contact actions.

Contact poisons

Contact poisons are chemicals which kill insects by contact when the material is spread over on the body of insects by spraying or dusting. Their mode of action may be plugging of the spiracles or absorption of the cuticular lipids causing dessiccation such as the insecticides of mineral oil and dust derivatives. Chlorinated hydrocarbons like DDT,



BHC, Dieldrin, etc., and Synthetic pyrethroids like cypermethrin, deltamethrin, etc., have contact properties. They are nerve poisons acting on the axon of sensory neurons which carry impulses to the ganglia of central nervous system. The insecticides affect the permeability of axonic membrance bringing about uninterrupted impulses. Repetative discharges occur in axonic nerve fiber resulting in convulsions, paralysis and ultimately death of insect. Some organo-phosphates like methyl parathion, quinalphos, etc., and carbamate like carbaryl are also good contact poisons having knockdown effect. Their mode of action is chemically initiated in nerve-synapses. The



insecticides inhibit the release of the enzyme, acetylcholinesterase for which acetyl choline accumulates in synaptic gap. Rapid nerve firings occur, producing symptoms of restlessness, hyperexcitability, etc., leading to death of insect. In organo-phosphates the inhibition is irreversible and in carbamate reversible.

Systemic poisons

Some organo-phosphates like phosphamidon, dimethoate, etc., and a carbamate like carbofuran when applied on plant or in the soil, are absorbed by roots and foliage and are translocated to all parts of plants and can kill piercing and sucking insects and mites at points distant from the site of application. They remain in active condition for number of days. They act as nerve poisons.

Fumigants

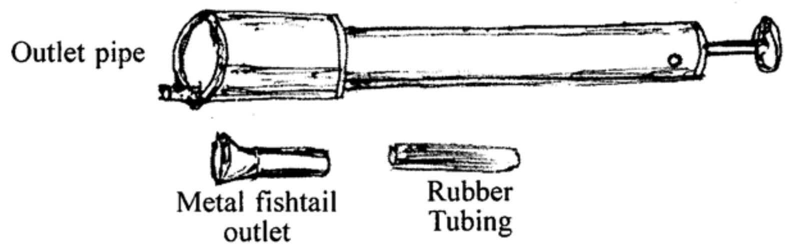
Fumigants are volatile chemicals which are used in gaseous state to destroy insect life. Their fumes enter the insect body through spiracles or trachcae and act upon the nervous and circulatory system. The process is known as fumigation and is applied for stored grain pests, soil insects and trunk borer holes. Examples : methyl bromide, hydrogen phosphide (phosphine), ED-CT mixture, etc.

2.6 Appliances for the use of insecticides

I. Dusting machinery

Plungertype duster

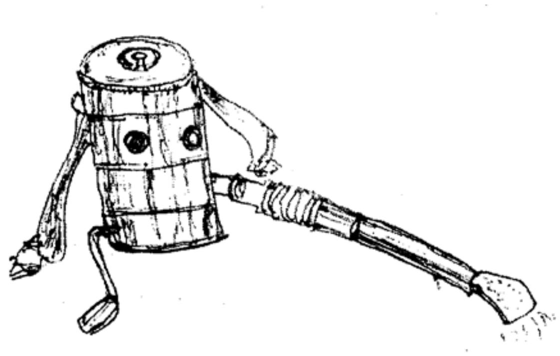
It has a metal cylinder, a part of which contains a movable plunger with a handle. Dusting materials are put in the cylinder. An upward stroke of the plunger helps to take in air, and downward stroke pushes a blast of air into the dusting materials. The air blast



agitates the dust and at the same time blows it out through a spout. Such type of dusters are used in flower tubs.

Rotary hand duster

Fan is enclosed in a small chamber and is rotated by a hand crank, which sends a



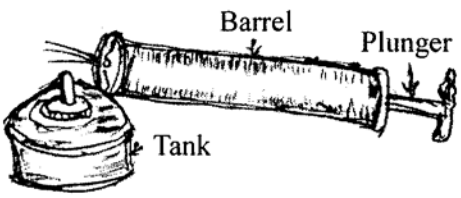
continuous current of air through a small discharge chamber. Dust flows out of the hopper into this chamber and is blown out with the air current. The hopper contains a stirrer, which not only keeps the dust stirred but also feeds the discharge chamber continuously. Thus, a regular flow of dust is ensured. This is suitable for dusting field crops.

Power dusters

Large scale dusting operations are carried out by engine (petrol) - driven machines, called power dusters. The machines have arrangements for mixing a blast of air current with the powder, the mixed stream flowing out at high velocity. There is a provision in the hopper for keeping the dust properly stirred so that it many not clog.

II. Spraying machinery

Hand syringes



It consists of a barrel and a plunger. During outer stroke it takes in the spray material from the tank and during the inward stroke it forces the liquid through the small hole. It is very useful for kitchen garden, flower beds or household purposes.

Hand - compression domestic sprayers

A pneumatic pump generates pressure inside a small tank containing spraying materials which are ejected through the orifice in front of a horizontal tube the end of which can be regulated by the thumb.

Knapsack sprayers

Air is continuously pumped into an air-tight barrel (knapsack) containing the spray liquid, by working a cycle type of pump fitted in the barrel. The air cushion helps in ejecting the spray material through the nozzle. It is widely used for spraying field crops.

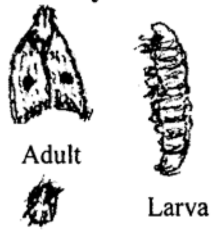
Preumatic sprayers

Air is pumped into an airtight cylindrical barrel with the help of a pump fixed in the barrel. The air cushion built on the liquid help in ejecting the spray material through the nozzle. Periodical pumping necessary to maintain a level of pressure.

2.7 Life history studies of pests (including their importance) : selected pests of cereals, fiber crops, vegetables, fruit trees, oilseeds, plantation crop, stored grains

I. Pests of rice

A. Paddy stem borer, *Scirpophaga incertulas* (Walker)



Order : *Lepidoptera, Family : Pyralidae.*

This is a monophagous insect feeding on rice. This species is distributed in all rice growing asian countries.

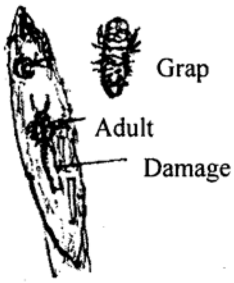
The full grown caterpillar measures 20 mm and is dirty white or greenish yellow having brown head and pronotum. The adults have a wing span of 25-45 mm and are yellow white with orange-yellow front wings. The female have a prominent tuft of brownish yellow silken hairs at the tip of their abdomen.

Damage : The newly hatched larvae after wandering for one or two hours on the plant surface enter the leaf sheath and feed upon the green tissue of the two or three days. Then, they bore into the stem near nodal region. They disperse from one plant to another with the help or silken thread. Its infestation causes drying of central shoot or 'dead-heart' in young plants and 'white ears' of drying of panicle in older plants.

Life cycle : The pest hibernates as a full-grown larva after making silken hibernacula in rice stubbles from November to March. Its activity starts from April and continues breeding till October. The larvae pupates sometimes in March and moths start emerging in April. The female mate after dusk and lay about 120-150 eggs on the undersurface of leaves in 2-5 clusters of 60-100 eggs each. The eggs are oval, flattened, pearly-white covered with yellowish brown hairs of female tuft. The incubation period is 6-7 days. Freshly hatched caterpillars bore into the stem from growing points downwords. The larval period is 16-46 days having 6 moultings. Before pupation the emergence hole is constructed which is always located above water level and pupate inside the attacked plant. Pupal period is 6-12 days. Adults live for 4-5 days.The total developmental period lasts for 31 70 days. There are 3-5 generations in a year from April to October.

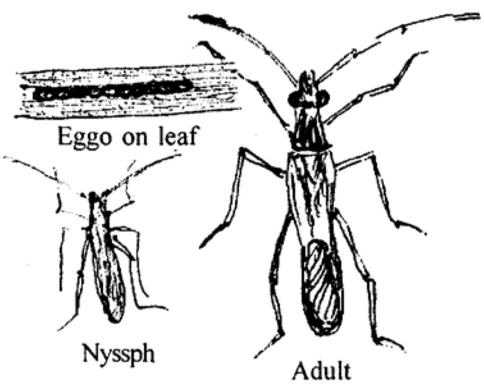
Control : Spray 250 ml of Phosphamidon or 560 ml of Monocotophos or 1 litre or Chlorpyriphos 20 EC in 100 litres of water per aere 3 times at 30, 50 and 75 days after transplantation. Removing and destroying stubbles where the larvae and pupae mbernate proves good result. The egg parasitold, Tricogramma japonicum is censidered as a good agent for biological control of this pest.

B. Rice hispa, *Dicladispa armigera* (Chrysomelidae : Coleoptera)



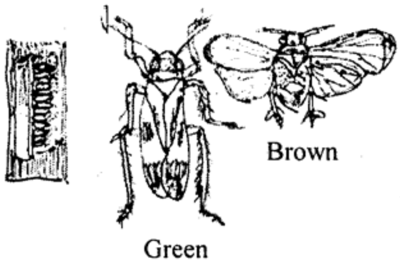
Life history and importance : The eggs, laid singly, into the tissue of the young leaf close to the tip. The grub burrows into the leaf tissue, feeding on the green matter, producing characteristic blister patches in leaf tips. The pupa is found in the same burrow. The adult is small bluish black, fringed with numerous short spines on its body, causing parallal white lines on the leaf surface. Damage is considerable when outbreaks occur on nursery and early crop stage.

C. Paddy stink bug, *Leptocorisa varicornis* (Coreidae : Hemiptera)



Life history and importance : The bugs appear in the field when the crop is in panicle bearing stage. Eggs are laid in rows on any surface of leaves. The eggs are browns oval and slightly depressed. The nymphs are pale green. The bug is slender, elongated, greyish green. It causes heavy damage when the grain is in 'milky stage' and it sucks the young grain content, leaving a brown scar on seed coat.

D. Green leaf hopper, *Nephotettix virescens* (Cicadellidae : Homoptera) and Brown Plant Hopper, *Nilaparvata lugens* (Delphacidae : Homoptera)



Life history and importance : Green leaf hopper occurs on vegetative stage and plant hopper on the reproductive stage of rice plant. Leafhopper eggs are arranged in bullet-like fashion on the stem and the plant hopper eggs in a batch of 2-4 on the sheaths. The GLH adults are pale green and that of BPH is brown.

Both of them are sap suckers. GLH can trasmit 'tungo virus' and BPH causes hopperburnt and is responsible for heavy loss in localized area.

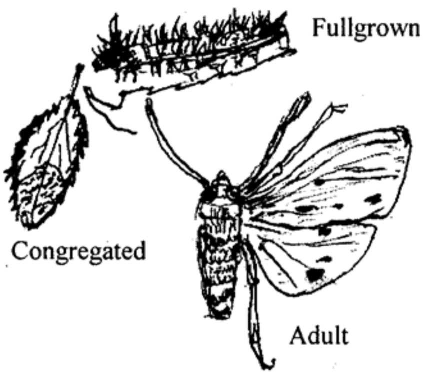
II. Pests of jute

A. Jute semilooper, *Anomis sabulifera* (Noctuidae : Lapideptera)

Life history and importance : The moth lays eggs singly on the undersurface of the young top leaves at night. The caterpillars feed gregariously on the top leaves and apical buds of the jute plant, resulting in the growth of side leaves. The full grown caterpillar is greenish, with distinct tubercles on the back and yellowish stripes on lateral sides. Pupation takes place in a rough cocoon made of silk thread under dried leaves and soil. The moths are medium-sized and earthybrown with dark spots and many lines on the forewing. It is a specific pest of jute.

B. Bihar hairy caterpillar, *Spodoptera obliqua* (Arctiidae : Lepidoptera)

Life history and importance : The eggs are laid in clusters on the lower surface of leaves. The young caterpillars are yellow with long hairs and feed gregariously, skeletoniging the leaves. The grown up larvae are orange-coloured with front and hind portions black. The entire body is densely covered with dark hairs. At that stage they disperse all over the fields and devour leaves and top shoots. The caterpillars pupate under the dried leaves or in cracks and crevices of the soil, in cocoons made up of moulted skin and hairs. The moths are buff-coloured, medium sized with black spots on wings. The pest causes considerable damage to jute crop.



C. Jute apion, *Apion corchori* (Apionidae : Coleoptera)

Life history and importance : The female weevil deposits eggs singly in holes at the apex of the plants made in the stem by the snout. The grubs feed on tissues. The grub is cream- coloured with brownish head. It pupates inside the stem. The adult is a small, dark brown insect with curved snout. The damage is caused by grub through feeding, resulting in knots in the fibre, affecting the quality of the fibre. It is considered to be one of the major pests of jute crop.

III. Pests of vegetables

A. Brinjal

Bringal shoot and fruit borer, *Leucinodes orbonalis Guenee.*

Caterpiller

Adult

Other than brinjal this pest also infests potato, bitter gourd, green pods of peas and other solanaceous plants. This species is distributed in Thailand, Laos, Malyasia, India Myanmar, Sri Lanka, Congo, East and South Africa, Pakistan and Bangladesh.

Young caterpillars are creamy white, but full grown are light pinkish in colour and measure about 18-23 mm in length. The moth is medium sized with white wings having triangular brown and red markings on the fore wings. The moth measures about 20-22 mm across the spread of wings.

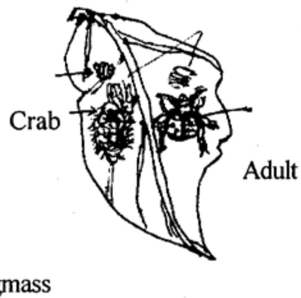
Damage : The larvae bore into the petiole and mid of large leaves and tender shoots and cause 'dead-heart'. In the later stage, they also bore in the flower buds and fruits, The flower buds shed in due to attack. The inside of the furit is damaged considerably and the entry hole can be plugged with excreta. Attacked fruit becomes unfit for consumption and marketing.

Life History : The hibernating larvae start pupating in early spring season. The emergence of moths takes place sometimes in March-April. A female lays about 80-120 creamy white eggs, singly or in batches of 2-4 eggs on the underside of leaves, on green stems, flower buds if calyx of fruits during its life span of 2-5 days. Its incubation period is 3-6 days. The young caterpillars bore into the tender hoots near they growing points, into flower buds or in the fruits. There are five larval instars and they are full grown in 9-28 days. A single caterpillar may destroy as many as 4-6 fruits. It pupates on the stem or fruit in grey tough cocoon. The pupal period is 6-17 days. The life cycle is normally completed in 20-43 days. There are five overlapping generations in a year.

Control : Remove and destroy all affected shoots and fruits with borer inside. Avoid continouns cropping of brinjal crop. Apply 800 ml Endosulphun 35 EC or Carbaryl 50WP or 200ml Cyoemethrin 10 EC in 250 liters of water per acre.

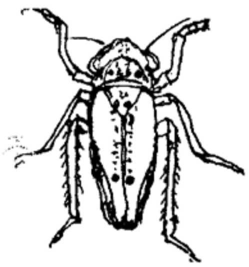
Leaf beefles, *Epilachna* sp. (Coccinellidae : Coleoptera)

Life history and importance : The eggs are laid on the undersurface of leaves in a batch. The eggs are light yellow and cigar-shaped. The grub is stout and yellow in



colour, and bears spines all over the body. Pupation occurs on leaves, having the learval skin attached below. The adult is yellowish brown, convex, oval-shaped with small, round black spots on elytra. The adult and grub nibble and scrape the upper surface of leaves. Leaves may dry up later.

Cotton jassid, *Empoasca devastants* (Cicadellidae : Homoptera)

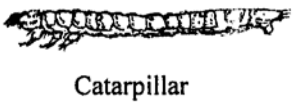


Life history and importance : Minute eggs are laid singly on the leaf-veins. The nymphs are light green and fast moving, usually on undersurface of leaves. The adult is small, slender and pale green. They suck the sap from the leaves which show yellow and reddish-brown colouration. Plants become weak due to drainage of sap.

B. Cucurbits

Red pumpkin beetle, *Raphidopalpa foveicollis* (Chrysomelidae : Coleoptera)

Life history and importance : The female has a pointed abdomen and lays eggs singly in the soil around the host plant. The eggs are oval, yellowish pink.The grubs are dirty white and grows on roots inside the soil. The pupa is formed in an earthen cell. It is whitish pale. The adult is reddish orange. The adults feed on leaves, cutting irregular holes. The affected plant starts withering. It is a major pest of cucurbitaceous crops.



C. Tomato

Fruit borer, *Helicoverpa armigera* (Nectuidae : Lepidoptera)

Life history and importance : The female moth lays eggs singly on the leaves after dusk. The eggs are round, greenish yellow, bright and sculptured. The caterpillars intially feeds on leaves. Later, they make irregular holes on the fruit and feed contents of fruit, keeping the body outside. The full grown caterpillars are green or dirty brown, having deep broken stripes on the sides of the body. They pupate in the soil. The adult is stout, brown, the forewing yellowish brown, having black spot on the anterior side.

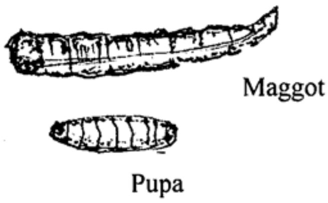
IV. Pest of fruit crops

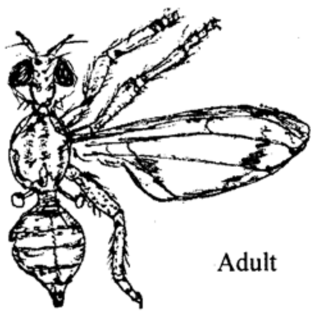
A. Mango hopper, *Idiocerus* spp. (Ciccadellidae : Homoptera)

Life history and importance : Eggs are laid on fresh leaves and inflorescence, inserting singly in the tissue. The nymphs are yellowish green and the adults are greenish brown, having the body broader towards the head and tapering posteriorly. The hoppers breed in large numbers and suck the juice from inflorescence, resulting in flower drop. They also excrete honey-dew, which imparts an oily appearance and helps the development of sooty-mould which affects the setting of fruits.

B. Mango fruit fly, *Dacus dorsalis* (Tephritidae : Diptera)

Life history and importance : The female fly lays eggs singly under the skin of the young green fruit. The eggs are shiny white, The maggots burrow deep into the pulp and





feed inside. The full grown maggot is long, apodus and cream-coloured. By the time the maggots nature, the attacked fruit drops and the maggots enter the soil for pupation. The pupae are light brown. The adult flies are moderate in size, marked with yellow, the wings have dark markings and females have projecting ovipositor. Considerable number of fruits are spoiled due to fruitfly infestation.

V. Pests of oilseeds

A. Mustard aphid, *Lipaphis erysimi* (Aphididae : Homoptera)

Life history and impotance : The immigrant alatae just after setting on flower buds during January, start laying apterous nymphs which are capable of producing fresh batch of nymphs, raising big colony within a short time. The full grown aphid is dirty green with short dark cornicle. Infested plants show curled up leaves, dried pinkish stem. The alate emigrants start producing when the plant is about to mature and dries up. Heavy loss in yield occurs due to aphid infestation.

B. Mustard sawfly, *Athalia proxima* (Tenthredinidae : Hymenoptera)

Life history and importance : Eggs are laid singly, inside and along the margins of leaves of young seedling by the saw-like ovipositor of the females. The young larvae

Larva

Adult

feed on the tender leaves. They are light green in colour when young and greenish-black when fully grown. Pupation takes place in soil inside an earthen cell. The larva is highly destructive in the nurseries of mustard. The adult is orange-coloured, with black head. Antennae and wings are smoky coloured.

VI. Pests of plantation crops

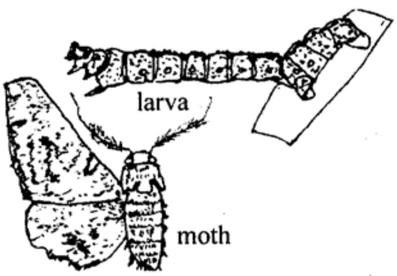
A. Tea

Tea mosquito, *Helopeltis theivora* (Miridae : Heteroptera)

Adult

Life history and importance : The eggs are laid in groups of two or more in green shoots of the bush when they are succulent. The young hairy nymphs are initially amber-coloured, later becoming smooth and orange-red. The adult is dark in colour and loves warm and humid climate for breeding. The adult bugs and nymphs suck sap from the young leaves and buds. The punctured sites on the leaves develop a small depressed areas which later turn brownish black and ooze out a kind of brown fluid from the centre. The leaves with several such dried-up black areas shrivel. The badly affected plants yield poor quality tea leaves.

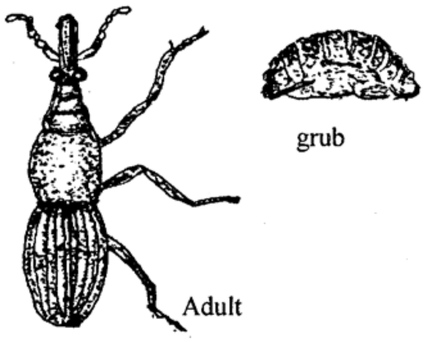
Tea looper, *Biston suppessaria* (Geometridae : Lepidoptera)



Life history and importance : The eggs are laid in irregular clusters, covered with buff-hairs on the trunk of shade trees in the vicinity of tea plantations or sometimes on tea bushes. Tiny caterpillars are dark brown with greenish lines on the body but gradually become brownish-grey or dark brown. The caterpillars produce silken thread to descend from the trees to the tea bushes. Pupation takes place in the soil under the bush. The moths are whitish-grey or dirty-grey with black margins and yellowish bands across the fore and hind wings. The caterpillar eat away the leaves leaving only the midrib and is considered to be an important pest of tea.

VII. Storage pests

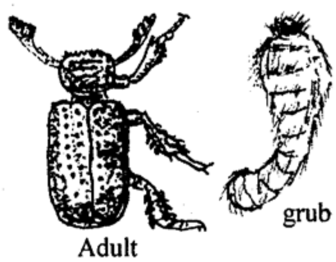
A. Rice weevil, *Sitophilus oryzae* (Curculionidae : Coleoptera)



Life history and importance : The female lays 200 to 300 eggs each in a small cavity inside a single grains. The eggs are whitish in colour, oval shaped and covered with a gelatinous substance. The grub is white with yellowish brown head and grows inside the grain feeding on the inner content. The full grown grub is short and stout. It pupates inside the grain. The adult weevil is a tiny, reddish-brown insect, with a long snout.

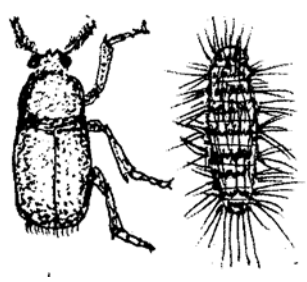
The pest is highly destructive in rice grains in storage.

B. Lesser grain borer, *Rhizopertha dominica* (Bostrichidae : Coleoptera)



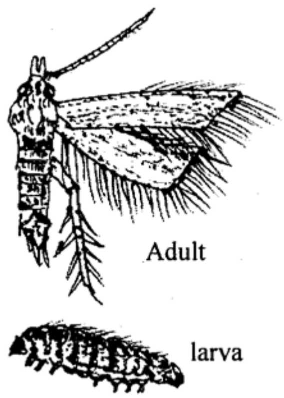
Life history and importance : The female lays eggs in masses or singly on the grains near the embryo. It may lay eggs on walls, bags and in cracks and crevices of the floor. The eggs are pear-shaped. The grub is dirty-white with light brown head and curved abdomen. It pupates inside the grain. Pupa is also dirty-white. The adult beetle is small, cylindrical, dark-brown, with a deflexed head, antennae terminating into tripartite club. The damaged grains become hollow and are rendered unfit for consumption.

C. Khapra beetle of wheat, *Trogoderma granarium* (Dermestidae : Coleoptera)



Life history and importance : The female lays eggs among the grains. Eggs are pinkish. The grubs are whitish and covered with fine reddish-brown hairs all over the body. The hairs at the posterior end are long. Only the larval stage is damaging. The larva starts feeding on the soft germ-point of the grain and continues feeding deeper into the kernel as it grows. Pupation takes place in the flour dusts, in cracks and crevices of the floor and other dark places in walls and gunny bags. The adult beetle is slightly brown, very small, stoutly built and oval shaped. It is a serious damaging pest of wheat in stored condition.

D. Angoumois grain moth, *Sitotroga cerealella* (Gelechiidae : Lepidoptera)



Life history and importance : The female moth lays whitish, minute eggs on the grain or in cracks and cravices of the floor. The eggs are oval and become bright red before hatching. The young caterpillar enters the grain through a hole and feeds on the kernel inside. The full grown caterpillar is pinkish and pupates in a silken cocoon inside the grain. The moth is tiny, shining, straw-coloured with fringed wings. The affected grains are rendered hollow and are full of larval excrements and webbings. The infestation is restricted to the surface layer of husked grains.

2.8 Insecticides Act and Rules : registration of insecticides, packing and labelling, enforcement machinery

Registration of insecticides

The registration of insecticides will be made by a Registration committee constituted by the Central Government. The intending person or farm will apply in a prescribed format for registration. On receipt of any such application, the Committee will enquire on the claims made by the applicant as regards the efficacy of the insecticide and its safety to man and animal, register the insecticide on payment of prescribed fee, allot a registration number and issue a certificate of registration within a period of 12 months from the date of receipt of the application. The Committee may refuse to register if found otherwise. There is a provision for appeal against non-registration or cancellation. The Central Government may, at any time, call for the record relating to any case. As per Insecticides Rules, the Registration committee will specify the precautions to be taken against the poisoning through the use or handling of insecticides.

Packing and labelling

Sale, distribution or exhibit of insecticides are prohibited without proper packing and labelling, approved by the Registration committee. The packing shall contain a leaflet with the information statement on :

(a) for which purpose the insecticides will be used and how,

(b) warning and cautionery measures including the symptoms of poisoning in case of toxic chemicals, suitable and adequate safety and emergency first-aid treatment.

(c) cautions regarding storage and application of insecticides,

(d) instructions on safe disposal of used containers,

(e) antidote for the poison,

(f) irritability to the skin, nose, etc.

Manner of labelling : (1) The following particulars shall be given in indelible ink on the label of the innermost container.

(i) Name of the manufacturer

(ii) Name of the insecticide (Brand name or Trade mark)

(iii) Registration number

(iv) Kind and name of active ingredients including their percentage

(v) Net content of volume

(vi) Batch number

(vii) Expiry date

(viii) Antidote statement

(2) The label shall contain a diamond shaped symbol which shall be divided into equal triangles, the upper portion shall contain the symbol and signal word and the lower portion shall show the specific colour for the particular category of insecticides as is given in the following table.

Category	**Oral LD 50**	**Dermal LD50**	**Signal word**	**Colour**
I (Extremely toxic)	1–50	1-200	POIS ON (with Skull Cross-bones)	Bright red
II (Highly toxic)	51–500	201–2,000	POISON	Bright yellow
III (Moderately toxic)	501–5,000	2,001 – 20,000	DANGER	Bright blue
IV (Slightly toxic)	> 5,000	> 20,000	CAUTION	Bright green

Besides, the following warning statements shall appear on the label.

Category I : (a) KEEP OUT OF THE REACH OF CHILDERN

(b) IF SWALLOWED OR IF SYMPTOMS OF POISONING OCCUR, CALL PHYSICIAN IMMEDIATELY

Category II : KEEP OUT OF THE REACH OF CHILDREN

Category III : KEEP OUT OF THE REACH OF CHILDREN

Enforcement machinery

Insecticide Inspectors play key role in the enforcement of Insecticides Act, 1968 and Insecticides Rules, 1971. A Government Officer may be declared as Insecticide Inspector if quatification permits and shall have power—

(a) to enter and search any premises

(b) to inspect, examine and make copies of records, etc, kept by the dealer,

(c) to make an examination and enquiry, stop any vehicle,

(d) to stop the distribution, sale or use of an insecticide,

(e) to take samples of any insecticide for quality analysis,

(f) any other powers as may be necessary to comply the Act and Rules.

The work of Insectide Inspector is complemented by the Licensing officer and Insecticide Analyst who are appointed by the Government and notified in the Official Gazette. The Licensing officer is required to be satisfied that the premises is equipped with proper storage accommodation for avoiding any hazards and for keeping the quality of the insecticide. The Insecticide Analyst shall analyse or test such sample of insecticides as may be sent to him by the Insecticide Inspector. The analysis is made in the Central Insecticide Laboratory, established by the Central Government. The analysis may also be done as regards quality in standard Government laboratory after proper notification by the Government. The duties of the Inspecticide Insector are :

(1) to inspect not less than three times in a year all establishments selling insecticides within the area of his jurisdiction,

(2) to satisfy himself that the conditions of licence are being complied with,

(3) to procure and send for test and analysis sample of insecticides which he has reason to suspect,

(4) to investigate any complaint,

(5) to institute prosecutions in respect of breaches of the Act and the rules,

(6) to maintain a record of all inspections made and action taken,

(7) to make such inquiries and inspections as may be felt necessary as per Act and Rules.

Unit 3 □ Non-insect pests of agricultural products

Structure

3.1 Nematodes

Introduction

Nematodes are worm-like animals popularly called Eelworms and belong to the phylum Nematoda. Most of the several thousand species of namatodes live in soil or water (fresh water, salt water) from bottom of the rivers, lakes, ponds, oceans from below freezing point to hot spring. The population in soil may be as high as several crores. They are free living, microbiovores, predators on nematodes or parasite on mosses, ferns, vascular plants, animals including livestock, poultry birds and man, causing various diseases. The number of estimated species lies between 30,000 to 5,00,000. Because of their manifold economic importance, the plant and animal parasitic nematodes have received worldwide attention and therefore have been extensively studied.

About 5000 species of nematodes are associated with plants, mostly are herbivores causing various levels of injury. Some are serious parasitic forms and some are pathogenic. These nematodes cause 35% potential loss of food crop production and the world crop taken together, the loss is about 20%. Horticultural crops are more attacked than field crops.

Morphology

The size of nematode is small 300-1000 microns long, some of them may be 4 mm long and 15-35 microns wide. They are often not visible in naked eye and therefore one needs a microscope to detect it. They are eel shaped, round in cross section, with smooth unsegmented body without any legs or appendages. Sometimes females of a few species become swollen at maturity having pear shaped spheroid bodies.

Anatomy

1. Body transparent, covered with a colourless cuticle, marked by striation. The cuticle moults during successive larval stages. The nematodes move by contraction and relaxation of longitudinal muscles. In addition, specialized muscles also present in

mouth, digestive tract and reproductive structures. Body cavity contains a fluid through which circulation and reproduction take place.

2. Digestive system is a hollow tube extending from mouth and leads to oesophagus → intestine → rectum → anus. Six lips surround mouth. All plant parasitic nematodes have hollow stylets or spears which are used for piercing plant cells.

3. Reproductive system is well developed. Female nematode has one or two ovaries, followed by an oviduct → uterus → vulva. Male reproductive system has a testis → seminal vesicle → terminates in a common opening with the intestine. A pair of protrusible copulatory spicules also present in male. Reproduction may be sexual, hermaphroditic or parthenogenetic. Male is unknown in some species.

Life cycle

The life cycle of most plant parasitic nematodes in general is quite similar. Eggs hatch → larvae which are structurally similar to adults. The larvae grow in size and each larval stage after moulting reaches to the next stage. Normally, there are 4 larval stages. After moulting finally, the 4th stage larva reaches to adult female/male. The female can produce fertile eggs either after mating with a male or in absence of male by parthenogenetically or can herself produce sperm (hermaphrodite). Life cycle from egg to egg may take 3-4 weeks under optimum environmental condition (specially temperature). However, during cooler period it may take longer period. The second larval stage (J-2) is the infective stage to plant. The infective stage needs a susceptible host for its feeding, otherwise it will die due to starvation. Rarely, larval stages may dry up and undergo quiescent stage or eggs may go under dormant condition during this period (when proper host is unavailable).

Ecology and seasonal occurrence

All parasitic nematodes live a part of their lives in soil. Many of these move freely in soil and feed on underground stems / roots. In specialized sedentary forms, the eggs, parasitic larval stages and males are found in soil for all their lives. The survival and movement of nematodes depend upon soil temperature. The maximum number of nematodes are found in soil layer between 0-15 cm depth and they prefer to concentrate their population around the roots.

The migration of nematodes is very slow and the distance which they normally cover in a season is about a meter. They move faster when soil pores are lined with thin film of water than those being waterlogged. The dispersals in nematodes are effected through flashing of water, through overhead watering, through infected plant parts with healthy plant parts or through carriers like farm produce, nursery plants etc.

Habitat

Habitat wise, some nematodes are either ectoparasites i.e. those which do not enter into root tissues and feed only on the cells near root surface. The endoparasites are those which enter the host tissues and feed therein. Both these types can be migratory ie they freely live in soil and feed on plants without becoming attached or sedentary.

How nematode feeding affect plants

The direct mechanical injury inflicted by nematodes while feeding causes only slight damage to plants. Most of the damage is caused by injection of saliva while feeding. Some nematodes are rapid feeders. They puncture the cell walls, inject saliva into cells, suck cell contents and then move on to the next one within a few seconds. Some feed slowly and may remain stationary at the feeding site for feeding from few hours to several days. The saliva is injected intermittently during feeding.

The feeding process affects the plant cells making those devitalized and dead. This also causes formation of tissue breakdown, lesions, swelling, gall fomation of various kinds, crinkling or distorted stems, foliage etc., Some of these are caused due to dissolution of infected tissues by nematode enzymes which cause tissue disintegration and death of cells. In some cases they cause abnormal cell enlargement (hypertrophy) by suppression of cell division or stimulate cell division resulting in formation of giant cell, galls, a large number of lateral roots at the points of infestation.

Plant disease symptoms caused by nematodes are complex. The root feeding species reduce the water nutrition intake capacity of plant from soil causing nutrition deficiencies, wilting etc. In some cases, the plant - nematode biochemical interactions impair the overall physiology of plants and make the plants exposed to other pathogens. resulting in causation of several other plant injuries. If the nematode population is very high, the mechanical damage caused to plants may turn out to be very serious.

Crop loss due to nematodes in India

Sl. No.	Species	Crop	Percentage of damage	Reference
1.	*Heterodera avenae*	wheat	60 million rupees (US $ 5 million/year)	Seshadri, 1973 Gill, 1994
2.	*H. zeae*	maize	11-29% (in North west India)	Gill, 1994
3.	*M. incognita*	okra	91%	Bhatti Jain, 1977
4.	*M. javanica*	sugarcane	23%	,,
		tomato	40%	Reddy & Singh, 1981
		bninjal	34%	Reddy & Singh, 1988
		tobacco	15-59%	Hussini, 1983

Sl. No.	Species	Crop	Percentage of damage	Reference
5.	*M. hapla*	carrott	50-59%	Sivkumar Vadivelu 1994
6.	*Globodera similis*	banana	30-60%	Nair, 1966
7.	*Tylenchulus semipenetrans*	citrus	15%	Anon., 1961
8.	*Hirschmanniella* spp.	rice	0.5-20%	Gill, 1994

Cropwise nematode problems

Crop	Nematode Pest	Symptoms
Rice	1. *Aphelenchoides besseyi* Christie	White tip, infected seeds are late to emerge, leaf becomes white and pale.
	2. *Ditylenchus angustus* (Butler)	Chlorosis with white patches.
	3. *Hirschmanniella oryzae* (van Breda de Haan)	Growth reduced, plants become stunted, shorter tillers.
Wheat	1. *Anguina tritici* (Steinbuch)	Yield reduation by 33%
Maize	2. *Punctodera chalcoensis* Stone.	Cyst nematode causes patches of stunted as Chlorotic plants.
Legumes	1. *Ditylenchus dipsaci* (Kuhn)	Lesions form on stem which are reddish brown and later turn black.
Potato	1. *Ditylenchus destructor* Thorne	Chalky greyish or light coloured spots appear below tuber surface.
Sugarcane	*Helicotylenchus* spp.	Distortion of roots, malformed lateral roots.
	Meloidogyne spp.	Produce aggravated disease complex.
Onion, garlic	*Ditylenchus dipsaci*	Infested parts become swollen at base with distorted leaves.
Sweet Potato	*Rotylenchulus reniformis*	Produces root knot symptoms

Crop	Nematode pest	Symptoms
Citrus	*Tylenchulus semipenetrans* *Radopholus citrophilus* *Meloidogyne javanica*	Cause various types of damages
Banana	*Radopholus similis*	damages banana roots
Coconut	*Rhadinaphelenchus cocophilus*	Causes red ring of coconut.
Cotton	*Rotylenchulus reniformis* *Hoplolaimus indicus*	Browning of invaded epidermal cells.
Tea	*Meloidogyne incognita, M. hapla*	Produce specific symptoms.
Black pepper	*M. incognita*	Produce characteristic
Betelvine	*M. incognita* *R. reniformis*	symptoms do
Flowers & Ornamental plants	*M. incognita*	do

Some specific nematode problems in crops

(i) **Root knot Nematode** (*Meloidogyne* Spp)

This group is the most important pathogenic nematode causing important problems in crops in tropical and subtropical countries. They are responsible for 5% of global yield loss due to root knot. The other % of losses are : beans — 11-24%, pumpkin - 22%, potato - 24%, okra - 42%, chilli - 22%, tomato - 60-70%. The important species of this genus are :

1. *Meloidogyne incognita* (Kof & White) - occur on 700 hosts, most important
2. *M. javanica* (Treub) — Occur on 700 hosts
3. *M. arenarea* (Neal) — pests of groundnut, coffee, vegetables.
4. *M. hapla* Chitwood — tea, potato
5. *M graminicola* Golden & Birchfield — Rice

Life Cycle :

Preparasitic stage : Eggs are laid in hundreds in a gelatenous masses protruded out from the body. During embryogenesis starting with a single cell egg, the contents of eggs pass through cleavage to blastula → turns to triploblastic grastula → J_1 larva → moults to J_2. Preinfective J_2 – 0.3 – 0.5 mm, slender, with hyaline tail moves freely in soil to locate its host. They can survive without food for several months.

The infective J_2 attack host root tips and mechanically enter into roots just above the caps. A few of them enter through weak spots on epidermis by repeated thrust. They orient themselves parallel to stelle and head pointed opposite to the tip and towards the developing steller region at the zone of cell elongation, with their bodies lying mostly in the cortex. Juvenile starts feeding on pericycle cells. The cell contents are extracorporally digested with pharyngeal hydrolytic enzymes. As a result of hydrolytic enzymes, the tryptophan is converted into IAA and that in turn leads to hypertrophy to form multinucleate giant cell around nematode's head. Cortical parenchyma cells around the giant cell and by undergoing multiplication (hyperplasia) form tiny primary giant cells. Those coalesce forming large secondary galls.

The post infective J_2 feeds for 2-3 weeks, gradually swell and becomes unable to move. It undergoes three successive moults. J_4 males remain coiled within 3rd cuticle. Majority turn to females and a few to males.

Reproduction may be parthenogenetic or sometimes bisexual. A female lays 400-500 eggs. Egg laying takes place about a week but this period may be for 2-3 months. Total life cycle takes 3-4 weeks at 26-27°C but this period may be lengthened when suitable host or temperature are not available. Number of generations per year depend upon nematode species, host, weather, condition etc.

Symptoms :

1. These nematodes are obligate parasites on underground parts and rarely form galls on stem (beans/cucurbits)

2. The development and vigour may be affected when seedlengs are attacked.

3. The disease appears in patchy form in the crop field.

4. The above ground symptoms include dwarfing, chlorosis, yellowing of leaves, leaf spots, loss of vigour, fewer fruit formation, wilting and death. Pollen viability is reduced and nutritional deficiency occurs.

5. Both primary and secondary galls are formed. Galling is due to production of growth regulators of J_2 from its subventral gland.

6. *M. hapla* — produces small spherical galls and profuse root branching. *M. incognita* and *M. javanica* produce large galls depending upon host. Galls on paddy, grasses are of discrete type.

7. Chemical analysis of galls indicate accumulation of NPK and other minerals taken up from soil but are not translocated to further up. In addition, growth regulators, protein etc. also accumulate in the galls. Hence, galls act as metabolic sink.

8. If the infection is severe, then the root system is severly reduced and disorganised galls are produced.

9. Forking of tap root or curly root tip on tubercles may also be formed.

Hosts : The common hosts are pulses, fibres, fruit trees, tobacco, betelvine, tea, ornamental plants, sugarcane, wheat, sorghum, banana, paddy, etc.

Management :

1. Adapting crop rotation
2. IPM - includes rotation with non-host crop and using resistant varieties. Judicious use of nematicides both organic and inorganic.
3. Proper selection of resistant varieties.
4. Irrigation of rice field reduces infestation.
5. Destruction of post harvested roots, soil drying, soil sterilisation, green manuring will reduce infestation.

Physical control :

Flooding : Flooding to a depth of 10 cm will reduce root knot nematode *Soil* solarization. This can be done in places where sufficient solar energy in available.

Hot water treatment of roots, burning of crop wastes (sorghum stalks), removal of knotted roots etc. are also effective.

Cultural control :

Drying of soil, crop rotation with non-hosts, clean cultivation, organic manuring, altering the sowing date, improving plant nutrition, using resistant varieties or genetic improvement of varieties etc. are some of the cultural control methods which may be adopted.

Biological control :

Applying chopped plant parts of neem, melea, marigold in soil. A fungus *Paecilomyces lilacinus* is also very effective.

Ectonycorhiza sp. form network of hyphae provide physiological and mechanical barrier to root knot.

Chemical control :

Fumigants DD and EDB, Durofume (@ 18ml/m^2 under polythene for 24 hrs will control. *M. incognita*), Aldicarbs, fensulphothion, ethoprop are of the systemic nematicides for control of nematodes.

(ii) **Cyst Nematodes (*Heterodera* spp.)**

These nematodes are mostly found in temperate climate but also occurs in tropical countries. Some of the globally important species are *Heterodera avenae, H. cajani, H. oryzicola, H. zeae* etc. These are obligate parasites and affect underground stems such as potato.

Life cycle :

Eggs and juveniles are characteristically retained by mature female whose cuticle after its death, gets hardened protecting eggs and juveniles from environmental stress Emergence of juveniles occur in two phases. The first phase coincides with the growth period of the host. The second is short with limited emergence. Some fungicides like 'Nabam' may stimulate hatching.

Root exudates : It may or may not stimulate hatching.

Process of hatching : The Juveniles of *Globodera rostrochinensis* start moving within egg shell and make slits on egg shell for emergence.

Heterodera schachtii

Symptoms : Patches of stunted plants appear and in case of heavy infestation the plants may die or become stunted. Lateral roots show lemon shaped small cysts

Life cycle : The Juveniles of this species undergo 4 moults. J_2 may remain dormant for several years within egg shell of brown cyst. The first moult takes place within egg itself. J_2 can remain in egg shell of a brown cyst in dormant condition in soil for several years. The optimum temp is 20-25°C.

Histopathology :

(a) Forward progress of J_2 inside a cortical cell, (b) perforation of cell wall by stylet thrust, (c) bending of stylet tip when the stylet meets a resistance, (d) head movement and stylet movement enter through cut in the cell wall by stylet thrust, (e) feeding from a nurse cell in the zone of modified cytoplasm, protoplast of nurse cell fuses with that of the neighbouring cells.

Due to enlargement of nematode, the cortex splits and posterior portion of nematode gets exposed. Adult male remains coiled with sausage shaped J_3 cuticle. Finally it escapes in soil and mates with several females.

Control : Aldicarb, carbofuran may be used but with caution.

Nurse cell system :

Nurse cells are host cells modified by nematodes and that act as metabolic sink so that the nematodes can comfortably feed on them. A genetical and histological compatibility occurs between host cells and nematodes. Nurse cells have dense cytoplasm, increased number of ribosomes, polyribosomes and other organells and presence of small secondary vacuoles in lieu of large primary vacuoles. Nurse cells act as metabolic sink drawing nutrients for the parasites for development during production of eggs. The inner walls of nurse cells often contain protuberances. Such nurse cells are called Transfer cells.

Uninucleate nurse cell

Single uninucleate giant cell is initiated in pericycle and then lead into the vessel which is greatly distorted. Exs. *Rotylenchulus macrodoralus* induce transfer cell.

Syncytium

Rotylenchulus reniformis, members of *Globodera* represent this type of nurse cell system. *R. reniformis* penetrates and swells into a kidney shape. A single row uninucleate giant cells forming a crescent which acts as the nurse cell system. It is initiated in pericycle and it expands with maturity and finally gets into vascular cylinder which is greatly distorted.

Nacobbus sp., invade the stele and stimulate both cell division and fusion of cell protoplasm after partial dissolution of cell walls. A spindle shape mass of cells with partially dissolved walls develop as syncyticem. These cells are rich with starch and nematodes feed at one end of this group of interconnected cells.

Infective Juveniles of cyst nematode penetrate roots intercellularly in a short time. Cell death is caused by direct penetration. It traverses the cortex and starts feeding there.

Giant cells

This type of nurse cell cosnists of a variable number of discrete multinucleate giant cells encountered only in *Meloidogyne* No dissolution of cell wall takes place. The individual cells expand within the differential vascular cylinder accompanied by synchronous mitosis without cytokinesis. *Meloidogyne* juveniles usually move intercellularly through the meristematic zone, crowd around root tips, penetrate it in about 6 rounds and continue movement for 24 hrs. Nematode secretion increases the host cell permeability and degree of permeability represents the stages of syncitium and giant cell formation by *Heterodera* and *Meloidogyne*, respectively.

Formation of giant cell

J_2 by repeated stylet thrust penetrates the root cells mechanically. The cell contents are sucked by nematodes through pharyngeal pumping action. Juveniles then enter cortical cells, takes position, allign themselves with their anterior ends directed towards the region developing into vascular cylinder, rather than root tip. Juveniles start feeding on the neighbouring vascular parenchyma cells, which begin to undergo marked changes and that lead to formation of giant cells. The giant cells continue to elongate for 3-4 days of initiating, get vacuolated and expand with increase of cytoplasmic contents. The surrounding cells exhibit hypertrophy making rooms for expansion of giant cells. Further elongation of giant cells can be caused by their intrusive growth into the xylem wound. The cell wall ingrowths develop excessive branching labyrinths — that giant cell is called Transfer cell.

There may be, another kind of giant cell formation. In the absence of cytokinesis, the protoplasts of the neighbouring cells coalesce as in *Vicia faba* by *M. javanica* cell walls break down cells fuse and all the nuclei of original cells undergo synchronous mitosis without cytokinesis. Overall, cell wall dissolution associated with giant cells is much less conspicuous than in syncitia induced by cyst nematodes. Giant cells contain ten times more protein than normal. Besides, high level of peroxidases, hydrogeneases, reductases and hydrolases, auxins, anticoagulants, etc. have been noted.

The plant growth is retarted due to giant cell formation and galls may be formed on the leaves and stems. Water and nutrition deficiency may be caused due to poor uptake or upward movement.

3.2 Mites

Introduction

Among the non-insect pests of agricultural crops which are gaining increasing importance globally, the plant mites probably are the most injurious ones and have caused great concern to both farmers and agricultural scientists. The plant mites may be our foes as those are important pests of agricultural-horticultural crops causing severe damage inflicting considerable economic loss to the growers. Some of those may be our friends also by becoming efficient biocontrolling agents There are some plant mites which act as vectors of plant viral diseases which further increase their importance.

What are mites and how do they differ from related forms

Mites are microscopic creatures (0.2 – 0.5 mm in size), belong to Prylum Arthropoda and are characterized by having non-segmented body (body segments have been fused to form a compact mass called Idiosoma which is set off from anterior part of body bearing mouthparts i.e. chelicera and pedipalp, called Gnathosoma) and have 4 pairs of legs in all post-larval stages (except in Eriophyoidea where only 2 pairs of legs present in all stages of development). From Insects, the mites differ in lacking wings, antennae and mandibles and by possessing normally 4 pairs of legs against 3 pairs in insects. From spiders (Araneae), the mites differ in having no cephalothorax and abdomen with a waist in between these two regions as is present in spiders.

Major groups of agriculturally important mites

(A) Phytophagous : There are 4 major groups of phytophagous mites like Tetranychidae, Tenuipalpidae, Eriophyidae and Tarsonemidae.

(i) Tetranychidae : These mites are commonly called spider mites as like spiders these mites can spin webs and cover their colonies to protect from natural enemies, as well as pesticides. They are soft bodied, variously coloured, colony forming, mostly live on undersurface of leaves but some may occur on upper surface as well. Larvae have 3 pairs of legs and postlarval stages have 4 pairs of legs. Size 0.5 - 0.6 mm.

(ii) Tenuipalpidae : These are commonly called falls spider mites as they look like spider mites but can not spin webs. They are flat, pear–shaped, brightly coloured, colony forming, live mostly on undersurface of leaves near midrib. Sometimes may also be found within galls (*Larvacarus transitans*), on fruit surface (*Brevipalpus phoenicis),* on twigs etc. The adults possess 4 pairs of legs (excepting *L. transitans* which has 3 pairs of legs. Size 0.3-0.35 mm.

(iii) Eriophyidae : These are called bud mites or gall mites or malformation mites, small (0.2-0.25 mm), whitish or creamish or light brownish, have only 2 pairs of legs in all stages of development, live as vagrants on undersurface of leaves or may be in axillary buds or in various types of galls (bead galls, finger galls, pouch galls, etc.) or may cause leaf erineum.

(iv) Tarsonemidae : These are called broad mites or yellow mites, size varies from 0.25 – 0.30 mm, convex, glossy, fast moving, adults with 4 pairs of legs and occur mostly on young leaves. Males are often seen carrying female deutonymphs, for mating with those as soon as they emerge as adults.

(B) Predatory : Apart from phytophagous mites there are many predatory mites on agricultural—horticultural crops and those help us by feeding upon the phytophagous mites and thereby help in biological control. Those mites belong to families Phytoseiidae, Ascidae, Bdellidae, Cunaxidae, Anystidae, Stigmaeidae, Tydeidae, Cheyletidae, etc.

Extent of crop loss

Although the extent of crop loss has not been properly estimated in respect of most of the pest mites in India but yet whatever data is already available is indeed alarming. Some such reports are : 50 – 80% loss in mango due to *Aceria mangiferae,* 30% in litchi due to *Aceria litchili,* 20-25% in paddy due to *Oligonychus oryzae,* 20-30% in sugarcane due to *O. indicus,* 15-30% on red gram due to *Aceria cajani,* 20-30% in cotton due to *Tetranychus urticae,* 15-50% in coconut due to coconut perianth mite, 5-11% in tea due to *O. coffeae,* 36% in pointed gourd, 13-31% in brinjal, 23-27% in bhendi—all due to *T. urticae,* 27-39% in chilli due to *Polyphagotarsonemus latus*— Sometimes there may be no yield at all as may happen in red gram due to attack of PPSM or the entire plant may die as may happen in brinjal due to attack of *T. urticae* / *T. neocaledonicus.*

General type of damage symptoms

Due to mite feeding as mentioned above, two types of damage symptoms are produced, viz. direct and indirect. The former may be of two types, viz. visible and non-visible. The visible symptoms, are : discolouration of leaves, russeting of leaves / fruits, erineum and gall formation, curling / crinkling of leaves, deformation, malformations, premature fruit drop, etc. The non-visible symptoms are reduction of leaf size, reduction in number of leaves / fruits per plant, shortening of shoots, damage in storage quality of fruits, etc. The indirect damage symptom are those where the mites during feeding transmit viral diseases. Some of the plant viral diseases known in India are, Pigeonpea sterility msaic disease (PPSMD) by *Aceria cajani,* Wheat streak / Spot Mosaic disease (WSMD) by *Acerea tulipae,* Fig mosaic virus (FMV) by *Aceria ficus,* Dolichos Enation Mosaic Virus (DEMV) by *Tetranychus ludeni,* Sugarcane Streak Mosaic Virus (SSMV) by *Aceria sacchari,* etc.

Due to all these damage symptoms, the plants suffer from stunting of growth and reduction in yield and finally the farmers suffer from economic loss. Various types of damage symptoms produced by pest mites are given in Table - 1.

General mode of biology

The general mode of biology is more or less same in all the phytophagous mites barring a few exceptions. The reproduction is through arrhenotoky (i.e. production of males from unfertilized females while fertilizid females produce offspring of both sexes). But in some cases, like *Petrobia,* reproduction is through thelytoky i.e. parthenogenetic reproduction is characterized by production of females and males are normally unknown, or if present, do not mate.

The different developmental stages are : Eggs → larva → protonymph → deutonymph → adult. In males, the deutonymph stage is missing in many cases. In between these stages, There is a resting stage, called quiescent stage, the duration of which may be for a few hours only. In most of the tetranychid and tenuipalpid mites, the above pattern is followed and the life cycle is completed in 7-10 days in Tetranychidae while in Tenuipalpidae, it may be still longer (15-20 days). In Tarsonemidae, only 2 life stages are seen, viz. larva and adult. In Eriophyoidea, there are two active stages, first stage nymph and second stage nymph. But in some eriophyoids, the life cycle is rather complicated showing alternation of generation as two types of females are produced, called deutogyne adopted for hibernation which start reproduction in next season while the other type is protogyne.

Seasonal occurrence & dispersal

Most of the phytophagous mites remain in the field throughout the year on one or the other host but population remains at low level during rainy season when most of the mites inhabiting foliar region are washed away and also during severe winter months when reproduction rate drops down below development threshold level. The population is high during summer months. i.e. May-Jnue. Temperature, day light and pH are important factors controlling population dynamics of phytophagous mites. The population reaches at devastating level during summer months (May-Jnue). and in many cases, they reappear during postmonsoon period (September - October). In temperate climate, some mites enter into overwintering stage either in egg stage (*Panonychus ulmi)* or in adult (many *Tetranychus* spp.). The period of occurence of different pest mites in India.

The dispersal of phytophagous mites is by (1) crawling from one plant to another, the rate of which is very slow, (2) Through other insects, lizards, birds, etc., (3) Through wind current and that is most effective. In many tetranychids, when population in a particular host exceeds above its carrying capacity, the mites congregate at the tip of the leaves specially during early morning, wherefrom those are blown away to other hosts. During this process those which succeed to reach the suitable hosts, survive, failing to which they perish and (4) by balooning. In some tetranychid species, the adults hang themselves through a fine silken thread and those are subsequently carried away to a distant place by wind current, where the silken thread acts as a parachute. This phenomena is called balooning.

Effect of mite feeding on minerals, inorganic and organic components of plants

The mite feeding causes depletion of different biochemical components of plants like minerals (iron, chromium, zinc, potassium, phosphorus, magnesium, manganese). inorganic compounds (nitrate, nitrites) and organic compounds (phenolics, carbohydrate, protein, chlorophyll) and all these severely affect the normal physiological activities of plants.

Kairomones and pheromones

The pest mites produce chemical cues (kairomones) which help the predatory mites in searching and acceptance of prey while pheromones given out by individuals of one species and are received by individuals of the same species for lures, masking, confusants, disruption of sex pheromones, etc. No work in these aspects has been done in India though such works are already on in advanced countries.

Management

Chemical control : The pesticides which have been found to give mortality of 70-90% are dicofol (0.05%). endosulfan (0.05%), ethion (0.03%), monocrotophos (0.05%), wettable sulphur (0.5%), botanicals like neem seed karnal extract (5%). oils of eucalyptus, *Vitex negundo.* Clerodendron, cotton oil, etc. Synthetic pyrethroids (cypermethrin, fenvalerate - 0.005%) though have good knock down effect but are harmful to predatory mites. Some new chemicals like fenazaquin, avemectin, bromoprophylate, acrinathrin are also effective.

Biological control : Predatory mites (Phytoseiidae, Ascidae, Cunaxidae, Bdellidae, Cheyletidae, Stigmaeidae etc.), predatory insects (Coccinellidae, Thripidae, Chrysopidae, Anthocoridae), Spiders, pathogens (Fungi like *Neozygites, Hirsutella, Calosporium, Entomophthora,* etc., *Bacillus thuringiensis,* viruses like spherical non-inclusion virus) are the potential biocontrolling agents for phytophagous mites.

Cultural control : Avoiding monoculture, growing carrier crop/intercrop. avoid dust accumulation, growing resistant varities and using optimum doses of fertilizers are some of the cultural practices found successful against mite pests.

Mechanical control : Destroying malformed plant parts, regular pruning, removal of ratoon crops are some of the mechanical control methods found successful against mite pests.

Integrated mite control : Using all available options mentioned above for keeping pest mite population below economic injury level is the essence of this control. It is economically sound and environmentally sustainable. In addition, the following other methods which are relatively new may also be combined.

Gene manipulation : In this method, the gene of an undesirable character is removed and another gene of the desired character is introduced. This method has been adapted for getting organo phosphoric resistant strain or temperature tolerant strain of Phytoseiid predator.

Sterile male technique : In this method, males are exposed to different grades of X-Rays for getting sterile males and those are released in field for minimising pest mite population. It has been adapted in case of spider mite pests.

Hormonal control : Juvenile hormones when applied to eggs of spider mite pest, the eggs did not hatch, or if hatched, those did not develop further. This method has not been practised properly in India. Hence, this will be an effective tool in mite control.

Conclusion

Though in India the study of plant mites have been made in diverse fields during the past one century but yet there are many areas like intensive exploration of plant mite diversity, studying the bioecological aspects of the economically important species. role of various biochemical and phytochemicals in causing some varieties more resistant / susceptible, depletion of various minerals and biochemical components due to mite feeding and working out successful IPM strategy for some of the most injurious mite pests, etc. along with some of the recent method of control discussed earlier, are the further scope of work and those are needed to be undertaken in furture.

Table 1 : List of mite pests occurring on different crops in India

Major Crops	Name of Plants	Mite pests
Vegetables	brinjal bhendi chilli cowpea tomato, potato cucurbits gourds, etc.	*T. urticae, T. neocaledonicus, A. lycopersici* *T. urticae* *P. latus* *T. ludeni* *A. lycopersici* *T. macfarlanei* *T. urticae*
Fruit trees	citrus, guava, grape vines pomegranate papaya pineapple date Palm litchi citrus ber pear, Plum mango fig	*B. phoenicis, O. mangiferus, B. californicus* *O. punicae* *E. orientalis* *D. floridanus* *R. indica* *A. litchii* *P. citri, E. orientalis, S. hindustanicus, P. oleivora* *L. transitans, E. cernuus* *B. praetiosa, P. ulmi* *O. mangiferus, A. mangiferae* *A. ficus, E. hirsti*
Pulses	red gram black gram, green gram, fenger millets	*A. cajani, S. cajani* *P. latus, T.urticae, T. neocaledonicus*
Plantation crops	arecanut tea coffee	*O. indicus, R. indica* *O. coffeae, A. theae. C. carinatus, B. phoenicis, B. obovatus, T. urticae, P. latus* *O. coffeae*
Ornamental plants	rose marigold zinia jasmine bougainvillea	*T. urticae, E. orientalis, B. phoenicis, B. californicus* *T. urticae, P. latus* *T. neocaledonicus* *A. jasmini* *B. cafifornicus*
Cereals	paddy wheat	*O. oryzae, O. indicus, S. andropogoni, S. spinki* *P. latens*
Commcrial crops	sugarcane	*O. indicus, S. andropogoni, A. sacchari, S. bancrofti*
Oil seeds	casor, soyabean coconut	*T. urticae* *A. guerreronis, R. indica*
Fibre Crops	cotton jute	*T. urticae, T. macfarlanei* *T. urticae, P. latus*
Shade Trees	saal neem	*O. biharensis* *E. orientalis*
Spices	cardamom chilli coriander	*D. floridanus* *P. latus* *P. latens*
Fodder	grass sorghum	*S. andropogoni* *O. indicus*

***Biology of Oligonychus coffeae* (Nietner)-The Red Spider Mite**

The species of red spider mite is the most widely distributed causing a great loss to many crops in India. This is considered as the second important pest of tea after tea mosquito bugs, *Helopeltis theivora.*

Host range : Tea, Coffeae, Jute, Castor, Mulberry, Orange, Indigo, *Triumfeltta neglecta, Hibisous ficulaeus, H. abelmoschus, Tephrosia candida, Derris robustam Eugenia sp. Litsea lancifolia* and many other plants.

Nature of damage : The red spider normally attacks the upper surface of mature leaves but in severe attacks young leaves are also equally attacked and the mite then spread to under surface. The damage is caused by the larvae, the nymphs and the adult mites, which feed on the sap of the leaves. The damage is characterized by reddish-brown spots which develp at the point of feeding. The affected leaves may dry up and fall. The mite spin a silken web and they live under this web.

Life history : Both males and females ae sexually mature on emergence. The males emerge first and search for the quiescent deutonymph female. Copulation starts immediately after the emergence of the female.

The eggs are laid singly on the leaf surface, mostly along the mid-rib and veins and in depressions. A female usually lays 4-6 eggs per day and about 137 eggs are laid in her life time. The egg is spherical and red in colour and changing to orange before hatching. The larval stage lasts for 1.5 to 2 days. After the first and second moults the larva becomes protonymph and deutonymphs respectively. The deutonymph is followed by a quiescent stage when transformation takes place. The total larval and nymphal stage lasts for 6-8 days during April to August.

The adult female is somewhat eiliptical, the posterior end of the abdomen being broadly rounded, and dark purplish-brown in colour. The male is smaller than the female. Generally there are several overlapping generations occur. Female lives up to 29 days.

Control : Sulphur dusts, wettable and colloidal sulphurs and lime sulphur preparation are extensively used against this pest. The acaricide, Chlorobenzene and Kelthane as spray containing 0.05% and 0.037% respectively have given adequate control of this mite.

Unit 4 ❐ Aquatic resources

Structure

4.1 Inland fisheries resources at a glance

India has a vast inland fisheries resources in the form of rivers, lakes and reservoirs, beels, ponds and tanks (Table 1). Each of this resource has its own ecological and faunal characteristics.

Table 1. Inland fisheries resources of India

1. **Rivers and Canals**	**0.16 million km**
2. **Lakes and Reservoirs**	**1.892 million ha**
3. **Brackishwater Area**	**1.383 million ha**
4. **Beels**	**1.6 million ha**
5. **Ponds and Tanks**	**1.996 million ha**

4.2 Riverine resources : river system

India is endowed with a network of rivers comprising I4 major rivers (catchment > 20,000 km^2), 44 medium rivers (catchment 2000 to 20,000 km^2) and 55 minor or desert rivers (catchment less than 2000 km^2). These rivers are the principal resources of freshwater fisheries in India. In terms of fisheries the rivers in India are divided into five major river systems :

l. Ganga river system **2. Indus river system** **3. Bramhaputra river system**	**Himalayan river system**
4. Eastcoast river system **5. West coast river system**	**Peninsular river system**

The first three are together grouped as Himalayan river system while the last two are grouped as peninsular river system. Each of the river system has a characteristic fish fauna.

1. Ganga river system :

It is one of the largest river system of the world , having a combined length of 12,500 km. Principal river is the Ganga with a total length of 3129 km while the network includes ten other rivers important among which are Gomti, Yamuna, Kosi Gandak etc. The river Ganga harbours 265 species of fish of which 34 species are commercial.

• Important commercial finfish species : *Labeo rohita, Labeo calbasu, Cirrhinus mrigala, Catla catla, Mystus aor, Mystus seenghala, Wallago attu, Tenualosa ilisha, Notopterus chitala, Pangasius pangasius, Gudusia chapra, Silondia silondia, Eutropicthys vacha, Setipinna phasa, Rita rita, Ailia coila, Bagarias bagarias*.

• Important commercial shell-fish species : *Macrobrachium malcomsoni, Palaeomon lamarrie.*

2. Indus river system :

The main part of this river system lies with Pakistan. A small part lies in India which is formed by the rivers: Jhelum, Chenub, Ravi, Beas and Sutlej.

Common finfish fisheries include the exotic species *Salmo trutta fario, Onchrhychus mykiss, Salmo gairdneri gairdneri* along with the Indigenous species *Tor tor, T. putitiora, Schizothorax progastrus, Labeo dero, Garra gotyla, Nemacheilus* sp. These are all adapted to hill stream.

3. Bramhaputra river system : This is the third important river system of the Himalaya. Combined length of all the rivers and their tributaries and distributaries is 4023 km. Principal river is the Bramhaputra which traverses the states of Assam, Sikkim and parts of North West Bengal.

Commercial fisheries : Altogether 126 species are available from Bramhaputra river system. The upper sector harbours the cold water fisheries, which include *Tor tor, T. putitora*, *T. mosal, T. progenius* and the catfish *Bagarias bagarias.* Important species of finfish in the middle segment comprise *Puntius sarana, P. ticto*, and several species of *Channa*.

4. East Coast river system :

Four rivers constituting a total length of 6437 km form the east coast river system. These rivers are :

i) Mahanadi,

ii) Godavari,

iii) Krishna and

iv) Cauveri.

The network is distributed over the entire peninsular India, east of Western Ghats in the west and southern part of central India including Chotonagpur hill ranges.

Important commercial finfish include *Labeo fimbriatus*, *Labeo kontius, Puntius pulchelus, Barbodes carnaticus*. The cauvery river is also known for *Tor khudree and Tor mussullah*.

5. West Coast river system :

Two rivers mainly comprise the west coast river system. These two rivers are:

i) Narmada

ii) Tapti

Important finfish species : *Labeo fimbriatus, L calbasu, , Tort tor, Rita rita, Mystus seenghala, Wallago attu, Mystus cavasius, Mastacembelus* sp. *Notopterus notopterus.*

4.3 River Ganges

The Ganges originates in the Himalayas after the confluence of six rivers - Alaknanda meets Dhauliganga at Vishnuprayag, Nandakini at Nandprayag, Pindar at Karnaprayag, Mandakini at Rudraprayag and finally Bhagirathi at Devaprayag (from here onwards, it is known as Ganga) in the Indian state of Uttarakhand. Out of the five, the Bhagirathi is held to be the source stream originating at the Gangotri Glacier at an elevation of 7,756 m (25,446 ft). The streams are fed by melting snow and ice from glaciers including glaciers from peaks such as Nanda Devi and Kamet.

After travelling 200 km through the Himalayas, the Ganges emerges at the pilgrimage town of Haridwar in the Shiwalik Hills. At Haridwar, a dam diverts some of its waters into the Ganges Canal, which links the Ganges with its main tributary, the Yamuna. The Ganges which till this point flows in a south-western direction now begins to flow in a south-eastern direction through the plains of northern India.

From Haridwar the river follows an 800 km (500 mi) winding course passing through the city of Kanpur, before being joined by the Yamuna from the southwest at Allahabad. This point, known as the Sangam is a sacred place in Hinduism. According to ancient Hindu texts, at one time a third river, the Sarasvati river, met the two rivers at this point.

Joined by numerous rivers such as the Kosi, Son, Gandak and Ghaghra, the Ganges forms a formidable current in the stretch between Allahabad and Malda in West Bengal. On its way it passes the towns of Mirzapur, Varanasi, Patna and Bhagalpur. At Bhagalpur, the river meanders past the Rajmahal Hills, and begins to change course southwards. At Pakaur, the river begins its first attrition with the branching away of its first distributary, the river Bhagirathi, which goes on to form the river Hooghly. Close to the border with Bangladesh, the Farakka Barrage, built in 1974 controls the flow of the Ganges, diverting some of the water into a feeder canal linking the Hooghly to keep it relatively silt free.

After entering Bangladesh, the main branch of the Ganges is known as Padma river until it is joined by the Jamuna river, the largest distributary of the Brahmaputra. Further downstream, the Ganges is fed by the Meghna river, the second largest distributary of the Brahmaputra and takes on its name entering the Meghna Estuary. Fanning out into the 350 km (220 mi) wide Ganges Delta, it empties out into the Bay of Bengal. Only two rivers, the Amazon and Congo have a higher discharge than the combined flow of the Ganges, the Brahmaputra and the Surma-Meghna river system.

4.4 Ecology of rivers

Ecology of a river is strongly influenced by the flow of water, source of water and topography of the land through which the river flows. The physicochemical parameters and assemblage of fish are determined by these factors. A river has three distinct region :

(i) Upland region where the velocity of water is high because of sharp gradient, depth of the water is low, bottom is made up of gravels and stones and temperature of water is low. The fish fauna constitute the species, which can tolerate low temperature and high velocity of water.

ii) Middle section of the river where velocity is moderate, depth and temperature of the water increases, and the river undergoes several bends depending upon the topography of the soil. The bends are often cut off from the main course forming floodplain or oxbow lakes along the course of the rivers. The low lying areas along the river and the oxbow lakes are regularly flooded during monsoon and act as the spawning ground for many riverine species. The oxbow lakes itself form an important fisheries in the state of Bihar, West Bengal and Assam along the river Ganga and Bramhaputra.

iii) At the mouth of the river, which meets with the ocean, the velocity is greatly reduced and the flow becomes divided into several branches creating deltas. The water is characterized by high salinity due to tidal water from the sea. Only euryhaline species, capable of tolerating wide fluctuation of salinity inhabit this section of the rivers.

The main fisheries develop in the middle section of the rivers and is influenced by its hydrobiological characteristics. The middle section of the river Ganga is characterized by a surface temperature of 16.5 to 31.5° C, turbidity 1100 to 2170 ppm, pH 7.4 to 8.3 and dissolved oxygen 5.0 to 10.5 mg/L. The water is highly productive and contains several phyto and zooplankton. However, fisheries is hampered by several anthropogenic activities such as pollution of water from industrial effluents and city sewage, erection of dams on rivers, abstraction of water for irrigation purpose etc.

4.5 Fisheries of lakes and ponds

Fisheries of lakes are called lacustrine fisheries. India has a vast resources of lakes, which are exploited for the development of fisheries and tourism. Ponds are also very important freshwater resources and constitute about 1.96 million ha area of the country. In West Bengal there are about 12 lakh ponds constituting about 2.76 lakh ha 50 % of the total supply of freshwater fish in the state come from pond resources.

4.5.1 Definition of lake

Lakes are defined as naturally formed hollow depressions on the surface of the earth, which get filled with water. Ponds, in contrast are man made water bodies.

However, lake has been variously defined by different authors.

1. **Forel (1892) :** A body of standing water occupying a basin and lacking continuity with sea.
2. **Muttouskii (1918) :** All large bodies of considerable expanse and deep enough to stratify thermally.
3. **Welch (1952) :** All large bodies of standing water in contrast to ponds which are small shallow bodies of quiet standing water.

4.5.2 Classification of lake

Lakes ae classified in several ways—

(a) Forel (1901) classified lakes based on thermal charateristic into three categories, viz. Polar (ice covered), temperate cold) and tropical (warm water).

(b) Hutchinson (1957) classified lakes based on circulation as amictic (no circulation), dimictic (two seasonal circulation), oligomictic (rare period of mixing at irregular intervals), Polymictic (continuous circulation).

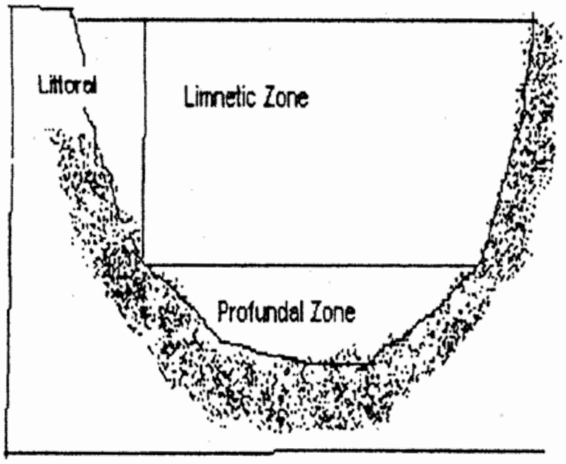
(c) Based on water quality lakes are broadly classified into three main categories : Fresh water lake, Salt water lake and Brackish water lake.

4.5.3 Ecology of lakes and ponds

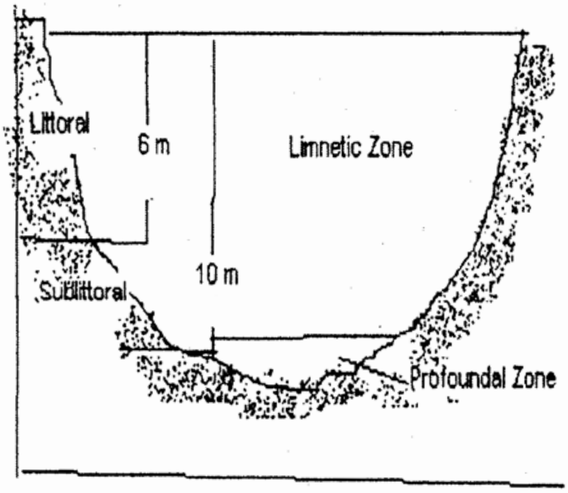
The freahwater lakes and pond habitats are vertically stratified into five distinet zones depending upon the intensity of light, temperature and absorption of light :

1. **Littoral Zone :** The shallow water zone with rooted vegetation near the shore that contains the oxygen rich circulating layer of warm water. In a deep water lake it is extended up to 6m depth.
2. **Sub-littoral Zone :** It extends from the littoral zone to non-circulating poor oxygenated cold water zone. It is extended up to 10 m depth.
3. **Limnetic zone :** The open deep water zone up to the depth of 50m. Light penetrates to entire depth and active photosynthesis occurs all along the depth.
4. **Profundal zone :** The zone situated beneath the limnetic zone with no penetration of light.

5. **Abyssal zone :** In very deep lake the sub-littoral zone is extended to dark bottom of the lake and is called as abyssal zone.



Pond



Lake

Biotic Communities :

Biotic communities of the ponds and lakes determine the productivity of these water bodies. Biotic communities are constituted by :

i) **Plankton :** Small animals and plants that have limited power of locomotion and remain at the mercy of the waves and currents of water. Plankton of plant origins are called phytoplankton and those of animal origin are called zooplankton.

ii) **Nekton :** The swimming animals are called neckton and are represented mostly by the fish in ponds and lakes.

iii) **Neuston :** The animals clinging on the surface of water are called neuston. Some aquatic insects and protozoans constitute these group of animals.

iv) **Benthos :** Organisms living at the bottom of the ponds and the lakes are called benthos. The worms, molluscs, nematods etc. form important benthic community in a pond or lake.

4.5.4 Problems in lake

Most of the lakes in India are degraded, depleted, and contaminated mainly by human activities. The main causes are inflow of domestic sewage, agricultural run-off, discharge of industrial effluents, over-fishing, introduction of exotic species and habitat degradation from population growth, expansion of cities. As more water is withdrawn for human use and more of it is returned to lakes and rivers as badly polluted, there is less water available to maintain vital freshwater ecosystems.

4.5.5 Restorative measures

i) Aforestation in lake basin and catchment areas.

ii) Shoreline stabilization and demarcation by fencing, shoreline roads and boundary roads.

iii) Maintenance of water level.

iv) Measures to prevent eutrophication : control point sources of pollution through reduction or diversion of domestic sewage entry; reduction of nonpoint source, mechanical and biological control of weed , sediment removal and increase of oxygen level of water through pumping or aeration.

v) Regular monitoring of water quality.

vi) Development of fisheries.

4.5.6 Some important Indian lakes

Freshwater Lakes :

1. **Kolleru :** Located in Andhra Pradesh. Total area covered is 90,000 ha. The lake is faced with the problem of inflow of effluents, siltation and infestation of water hyacinth.
2. **Kabar :** Located in Begusarai in Bihar covering an area of 6737 ha, Shrinkage due to sedimentation is a problem of this lake.
3. **Wular Lake :** This is the source of drinking water for Srinagar, and also acts as an absorption basin for floodwater. It has 18,900 ha water area. The lake is subject to heavy siltation due to loss of vegetal cover in the surrounding area.
4. **The Hussain Sagar Lake :** This is one of the largest man-made lakes in Asia, located in the heart of Hyderabad, contributing to its immense beauty. It is a sprawling artificial lake that holds water perennially. It was built during the reign of Ibrahim Qutub Shah in 1562, on a tributary of the river Musi.
5. **Logtak Lake :** It is located in Bishenpur in Manipur with an area of 26,600 ha. It is also faced with the problem of siltation, nutrient enrichment and encroachment.
6. **Ujni Lkae :** It is located in Sholapur in Maharasthra. Total area of the lake is

about 36,700 ha. Silation and mineral encroachment is the main problem of this lake.

7. Harike Lake : It is located in Amritsar in Punjab with an area of 4100 ha area. One of the major problems faced by this lake is the prolific growth of water hyacinth.

Other important freshwater lakes in India : Dal lake in Kashmir, Naital Lake in Uttaranchal, Kodaikanal Lake in Tamilnadu.

Saline water lakes :

1. **Sambhar Lake :** Located in the arid zone of Rajasthan, the Sambhar Lake is one of the largest inland saline lakes in India. Salt exrtraction is one of the major activities in the wetland.

2. **The Tso Morari Lake :** This is one of the largest in the Ladakh region and is almost like an inland sea. Situated at an elevation of about 4,900m, it is about 22km long, with a width varying from 5 to 7km and a depth of more than 30 m at the deepest point. The lake is probably a leftover from the Ice Age, formed by the melt waters of the icemasses left behind by the retreating glaciers. The waters from the surrounding areas drained into the lake. The huge amounts of water present in the beginning evaporated very fast in the desert-like atmosphere and what was fresh water became brackish and finally salty, unfit for human consumption.

3. **Pangon Tso :** One of the most spectacular lakes in Ladakh is the Pangong Tso, which lies across the Changla Pass from Leh. At an altitude of almost 4,500 metres, the Pangong Tso is only 8 km wide at its broadest point, but is an amazing 134km long. The Pangong is considered to be the longest lake in Ladakh. It is a saltwater lake formed in much the same way as the Tso Morari lake during the Ice Age.

Brackishwater lakes

There are two major brackishwater lakes in India: Chilka and Pulicut. Both the lakes receive freshwater from the rivers flowing into it and are connected to sea, thereby showing a characteristic of mixture of freshwater and salt water.

4.5.7 Chilka Lake

Chilka lake is situated in the Ganjam district of Orissa with a water spread area of 906 Sq. km. The water area increases during monsoon to about 1165 Sq. km. The lake is connected to the Bay of Bengal by a long outer channel through a single mouth while on the other side it receives several branches of Mahanadi river system. It is a shallow lake, the maximum depth being 3 meters in the south westem region, 2.5m in the central region and 1.5 m in the north west.

Hydrobiological characteristics of Chilka lake :

Chilka lake shows extreme annual cyclic changes in salinity, which ranges between 0.13 to 36.02 ppt. The northen and the central sector go nearly fresh during flood season and the salinity starts rising from Nov-Dec and reaches highest value in April - June. Average salinity of the southern sector is 9.5 ppt. Temperature of Chilka lake ranges from 17.5 to 32 °C, while dissolved oxygen and pH range from 2.6 to 15.6 mg/L and 6.8 to 9.7 respectively.

Two peaks of net plankton production occur, one in April-August and the second in October-December. The copepods are the chief zooplankton recorded from the lake. The benthic organisms include foraminifera, nematods, polychaets, ostracods , isopods, gastropods and lamellibranches.

Fisheries of Chilka lake :

About 158 species of finfish and shelfish are available from Chilka lake. The important group of finfish include the mullets (*Mugil cephalus* and *M. macrolepis*), the threadfins *Polynemus tetradactylus*, Hilsha (*Tenualosa ilisha*) the sea bass *Lates calcarifer* and other species like *Mystus gulio*, *Nematolosa nanus*, *Gerres setifer* and *Pseudosciana coihor*. The important shell-fish include the shrimp *Penaeus monodon* and *P. indicus*.

4.5.8 Pulicat lake

This lake is distributed over two states. The major part is located in the Nellore district of Andhra Pradesh while the rest part is located in the Chingleput district of Tamilnadu, where it is connected to the Bay of Bengal near the Pulicat viilage. Two seasonal rivulets Rayrla Vagu and Kalangi drain into the Pulicat lake. The tidal influence from the Bay of Bengal is restricted upto 16 km from the mouth of the lake with the Bay of Bengal.

Ecology of Pulicat Lake

The surface water temperature of the lake ranges from 24 to 31.8° C, depth 0.4 to 2.5 m, pH 8.1 to 8.5 and salinity varies from 5.8 to 38.8 ppt.

Fisheries : About 65 species of finfish have been recorded from Pulicat lake. These species include the mullets, scianids, threadfins, perches, clupeids and the catfishes. *Penaeus indicus, P. monodon, P. semisulcatus, M. dobsoni* are the abundant shel-fish species in the Pulicat lake.

4.6 Reservoir fisheries

4.6.1 What is a reservoir ?

All man-made impoundments created by obstructing the surface flow, by creating a dam of any description, on a river, stream or any water course, have been reckoned as reservoirs. However, there is ambiguity in nomenclature adopted by some states. The word tank is often loosely defined and used in common parlance to describe some of the small irrigation reservoirs.

David et al. (1974) defined the peninsular tanks as water bodies created by dams built of rubble, earth, stone and masonry work across seasonal streams, as against reservoirs, formed by dams built with precise engineering skill across perennial or long seasonal rivers or streams, using concrete masonry or stone, for power supply, large-scale irrigation or flood control purposes.

Irrespective of the purpose for which the lake is created and the level of engineering skill involved in dam construction, both the categories fall under the broad purview of reservoirs, i.e., man-made lakes created by artificial impoundment of surface flow. From limnological and fisheries points of view, the distinction between small reservoirs and tanks seems to be irrelevant.

After removing the anomalies in nomenclature, especially with regard to the small reservoirs, by bringing the large (above 10 ha) irrigation tanks under the fold of reservoirs, India has 19 134 small reservoirs with a total water surface area of 1 485 557 ha (Table 1.1). Similarly, 180 medium and 56 large reservoirs of the country have an area of 527 541 and 1 140 268 ha respectively. Thus, the country has 19 370 reservoirs covering 3 153 366 ha (Table 1.2).

4.6.2 Classification of reservoirs

Reservoirs are classified generally as small (<1 000 ha), medium (1 000 to 5 000 ha) and large (> 5 000 ha), especially in the records of the Govemment of India (Sarma, 1990, Srivastava *et al.*, 1985), which has been followed in this study. All man-made impoundments created by obstructing the surface flow, by creating a dam of any description, on a river, stream or any water course, have been reckoned as reservoirs. However, water bodies less than 10 ha in area, being too small to be considered as lakes, are excluded.

Some important reservoirs in India

1. Stanley Reservoir (Mettur Reservoir) in Tamilnadu on River Cauvery : 15343 ha area.
2. Govindsagar in Himachal Pradesh on River Sutlez : 16838 ha area.
3. Hirakud Reservoir in Orissa on River Mahanadi : 74592 ha area.
4. Nagrajunasagar in Andhra Pradesh on river Krishna river : 30,303 ha area.
5. Krishnarajsagar in Karnataka on river Cauvery : 12,924 ha area.
6. Maithan in Bihar on river Barakar : 11,491 ha area.
7. Panchet in Bihar on River Damodar in 7511 ha area.
8. Gandhisagar in Madhya Pradesh on river Chambal, 64750 ha area.
9. Raihand in UP on a tributary of river Son : 46620 ha area.
10. Farakka reservoir in West Bengal on river Bhagirathi.

4.6.3 Ecology of Reservoirs

Reservoir is a man-made ecosystem without a parallel in nature. The riverine and lacustrine characters coexist in reservoirs. During the months of heavy inflow and outflow, the whole reservoir mimics a lotic (river) environment whereas in summer, when the inflow into and outflow from the reservoir dwindle, a more or less lentic (lake) condition prevails in most parts of it. However, a reservoir has certain characteristics of its own.

Factors determining the water and soil quality in reservoirs are different from those of natural lakes. In the latter, the basin soil plays a predominant role in determining the chemical water quality through soil water interphase. In the reservoirs, on the other hand, the nutrient input from the allochthonous source often determines the water quality, nutrient regime and the basic production potential. This is because of the fact that the catchment of parent rivers is very often situated far away from the reservoir, under totally different geoclimatic conditions.

The ecology of reservoirs is radically different from that of the parent rivers. Dams alter river hydrology both up- and downstream of the river. The obstruction of river flow and the consequent inundation trigger off sudden transformation of lotic environment into a lentic one.

A new reservoir passes through three trophic stages :

i) **Initial fertility :** Inundation of the vast top soil bearing a cover of the terrestrial vegetation ends to decomposition of the vegetation. It causes initial fertilization and results in production of benthic micro and macro flora and fauna, plankton etc. Mineral enrichment occurs as the water level rises. Nutrients released stimulate great photosynthetic activity. The initial stage lasts for two to three years.

ii) **Trophic depression :** Gradually rate of nutrient release from the decomposing vegetation diminishes due to blanking effect of the reservoir bed by continuous sedimentation, increase in the volume of water and using up of available nutrients by aquatic vegetation. Once accumulated in deeper waters the nutrients get lost from the reservoir. Trophic depression is characterized by low food reserve and last for as long as 25-30 years.

iii) **Final fertility :** After trophic depression fertility level is reached in the reservoir at a much lower level than those at initial fertility. Regaining of fertility depends upon the accumulation of organic substrates.

Factors regulating ecology and productivity of reservoirs:

i) Size and shape ; (ii) Silt carried out by inflowing water and subsequent turbidity ; (iii) Thermocline ; (iv) Dissolved oxygen level ; (v) pH of water ; (vi) plankton abundance and primary productivity.

Nutrient budget

Most of the Indian reservoirs are characterised by low levels of phosphate and nitrate. Phosphate very seldom exceeds 0.1 mg l^{-1} in reservoirs free from pollution. However, the reservoirs of Rajasthan have particularly high levels of phosphate, ranging from traces to 0.929 mg l^{-1}. They receive phosphate from the rain washings derived from soils types like brown hills, grey brown hills, red and yellow and desert soils. In the highly eutrophic reservoir of Mans sarovar in Madhya Pradesh, phosphate levels of 4 to 13 mg/*l* were recorded.

Nitrate nitrogen in water in Indian reservoirs is mostly in traces and seldom exceeds 0.5 mg/*l*. Lack of nutrients in water, especially the nitrate nitrogen and phosphate, does not seem to be indicative of low productivity. In many cases, despite their virtual absence, the production processes are not hampered. In Amaravathy, Bhavanisagar, Gandhisagar, Ravishankarsagar and many other reservoirs, moderate to very high primary productivity is reported, although the phosphate in water is either absent or present in a very low concentration. In the tropical reservoirs, phosphate level in water has limited scope as an indicator of productive traits. This phenomenon is attributed to rapid turnover of nutrients (Ehrligh, 1960; Abbot, 1967) and their quick recycling, as seen from the high metabolic rates. Hayes and Phillips (1958) showed that 95% of the phosphorus could be taken up by the phytoplankton within 20 minutes, while some algae could convert inorganic phosphate into organic state in less than one minute.

Unlike the nutrients like phosphate and nitrate, the measure of total dissolved solids in the form of total alkalinity and the specific conductivity reflects the production propensities of reservoir satisfactorily, with the exception of Amaravathy which, despite very low levels of specific conductivity (38 to 63 μmhos), total alkalinity (7 to 84 mg l^{-1}) and total hardness (18 to 50 mg l^{-1}), supports a very rich plankton community and a good stock of fish.

Biotic communities

The highly seasonal rainfall and heavy discharge of water during the monsoons result in high flushing rate in most of the reservoirs which does not favour colonisation by macrophytic communities. Similarly, inadequate availability of suitable substrata retards the growth of periphyton. Plankton, by virtue of drifting habit and short turnover period, constitutes the major link in the trophic structure and events in the reservoir ecosystem. A rich plankton community with well-marked seral succession is the hallmark of Indian reservoirs.

Most of the reservoirs have three plankton pulses conciding with the post-monsoon (September to November), winter (December to February) and summer (March to May) seasons. The monsoon (June-August) flushing disturbs and often dislodges the standing crop of plankton. However, no sooner the destabilising effects wean away (as the dam outlets are closed), the allochthonous nutrient input favours an accelerated plankton growth. As the post-monsoon merges into winter, the turbulence decreases and water becomes clean, the plankton community progresses through a series of seral successions to culminate in a peak. The summer maxima coincide with the drastic drawdown, bringing the deep, nutrient-rich areas into the fold of tropholytic zone. The temperature, bright sunlight and rapid tropholytic activities also accelerate the multiplication of plankton during summer. In some cases, only two pulses(i.e., the post-monsoon and summer) are seen. However, the shallow, nutrient-rich reservoirs in the southern tip of the peninsula, by virtue of the fast turnover of nutrients and availability of sunshine and warmth, sustain a permanent bloom of plankton.

Benthos

Benthic invertebrates fauna show an erratic distribution in Indian reservoirs. The main factors that retard this community are the predominantly rocky bottom, frequent water level fluctuation and the rapid deposition of silt and other suspended particles. In spite of this, a number of reservoirs harbour rich communities of benthic invertebrates. The sequence of dominance of benthic communities closely follows the soil fertility pattern, the pre-impoundment debris often providing suitable habitats. The benthic community succession especially that of chironomids is sometimes used to characterize habitat changes. High shoreline development, variable slopes and vegetation act as favourable factors for the development of a rich assemblage of benthic organisms.

Ichthyofauna

Despite the cataclysmic faunistic changes associated with the impoundment, Indian reservoirs preserve a rich variety of fish species. The ichthyofauna of a reservoir basically represents the faunal diversity of the parent river system. On the basis of studies conducted so far, large reservoirs, on an average, harbour 60 species of fishes, of which at least 40 contribute to the commercial fisheries. The fast growing Indo-Gangetic carps, popularly known as Indian major carps, occupy a prominent place among the commercially important fishes. More recently, number of exotic species have contributed substantially to commercial fisheries. Broad categorization of the species is as follows:

The Indian major carps : *Labeo rohita, L. calbasu, L. fimbriatus, Cirrhinus mrigala, Catla catla.*

The mahseers : *Tor tor, T. putitora, T. khudree, Acrossocheilus hexagonolepis.*

The minor carps including snow trout and peninsular carps : *Cirrhinus cirrhosa, C. reba, Labeo kontius, L. bata, Puntius sarana, P. dubius, P. carnaticus, P. kolus, P. dobsoni, P. chagunio, Schizothorax plagiostomus, Thynnichthyes sandkhol, Osteobrama vigorsii.*

Large catfishes : *Aorichthys aor, A. seenghala, wallago attu, Pangasius pangasius, Silonia silondia, S. childrenii.*

Featherbacks : *Notopterus notopterus, N. chitala.*

Airbreathing catfishes : *Heteropneustes fossilis, Clarias batrachus,*

Murrels : *Channa marulius, C. striatus, C. punctatus, C. gachua.*

Weed fishes : *Ambassis nama, Esomus danrica, Aspidoparia morar,* *Amblypharyngodon mala, Puntius sophore, P. ticto, Oxygaster bacaua, Laubuca laubuca, Barilius barila, B. bola, Osteobrama cotio, Gadusia chapra.*

Exotic fishes : *Oreochromis mossambicus, Hypophthalmichthys molitrix, Cyprinus carpio specularis, C. carpio communis, Gambusia affinis, Ctenopharyngodon idella.*

4.6.4 Negative and Positive impact of Reservoirs

Negative Impact

Formation of reservoirs have affected especially the following Indigenous fish stocks:

1. The mahseers, snow trouts and *Labeo dero* and *L dyocheilus* of the Himalayan streams.
2. The anadromous hilsa, the catadromous eels,and freshwater prawns of all major river systems.
3. *P. sarana, T. tor,Tor mahanadtcus, T. mosal, L. fimbrtatus, L calbasu, and Rhinomugil corsula* of the Mahanadi river,
4. *P. dobsoni, P. dubius, P. carnaticus, C. drrhosa and Labeo kontius* of the Cauvery basin.
5. *P. kolus, P. dubius, P. sarana, P. porcellus, L. fimbrtatus, L. calbasu, L. pangusia and Tor kudree* of the Krishna river system, and
6. The mahseers, eels and *Osteobrama belangiri* of the northeast (Fig. 4.1).

The pristine streams of the river Sutlej harboured at least 51 species of fishes including the (exotic) trout, *Salmo truta fario*, the snow trouts, *Schizothorax spp.* and several species of hillstream fishes (Anon ; 1989b). Most of them were unique due to the sub-temperate climate and the zoogeographic afhliations to the Himalayan region. The upper reaches of the Sutlej and its tributaries were particularly rich in *T. putltora, L. dero, L dyocheilus* and *Schizothorax spp.* A decline in the number of species and their populations has been reported on account of changed ecological conditions especially the silt deposition at the bottom and the stratification of water body. Apart from minnows, many native species, such as, *Schizothorax plagiostomus, T. putitora, L. dero, L. dyocheilus* are on the decline. Proliferation of the exotic carps, *H. molitrix* and *C. carpio* in recent year has further to the local species.

Before the creation of Hirakud reservoir, the parent river Mahanadi had a rich fish fauna of 103 species, comprising both plain and sub-montane forms with sizeable representation of carps and catfishes. The common species of the river were *P. sarana, T. tor, T. mahanadicus, T. mosal, L. fimbriatus* and the Indo-Gangetic major carps. The endangered *T. mosal* and *T. mahanadicus* were protected in the temple tanks that were submerged during reservoir formation. Presently, the number of species has declined to

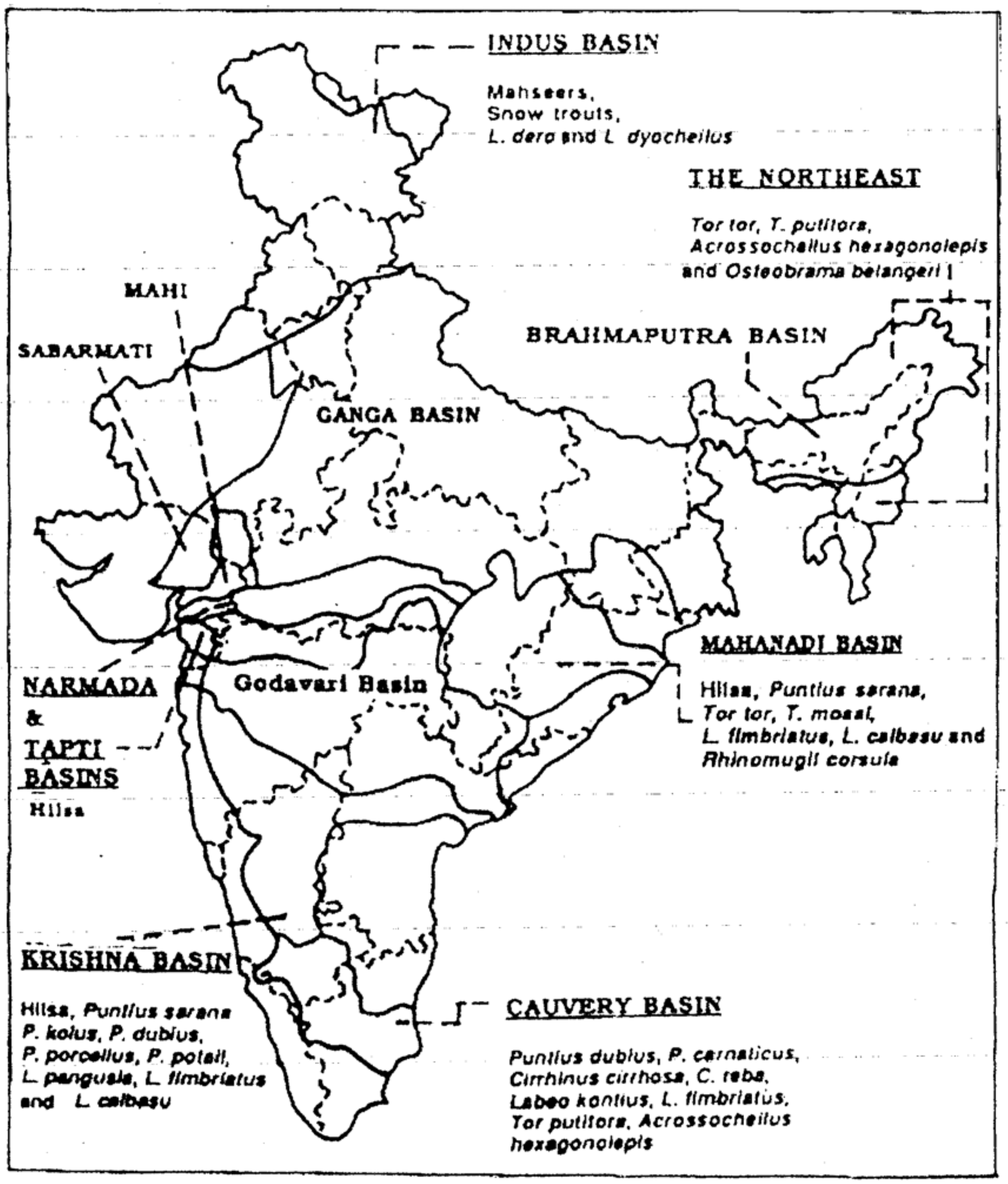


Figure 4.1 : Indigenous fish species affected by reservoir formation in India

40, of which many may disappear. The worst affected are *Tor mosal, Rhinomugil corsula* and the freshwater prawn *Macrobrachium malcolmsonii.*

Fishes affected in the two reservoirs in the **Krishna river system** viz, Tungabhadra and Nagarjunasagar are *P. sarana,* and *Labeo* spp. Soon after the impoundment, the Tungabhadra reservoir harboured a good population of indigenous *P. kolus* that contributed up to a third of the total fish landings. *P. dubius, P. sarana, P. porcellus, P. potail* and *Labeo pangusia* were also present in large numbers. Most of these native species have either disappeared or declined drastically due to the absence of fluviatile environment and the changed trophic structure. The vacant niche has been filled by minnow-predator combination, due to the management lapse of not inducting the fastgrowing species into the system.

Nagarjunasagar reservoir on the mainstream Krishna harboured rich populations of *Labeo fimbriatus, Labeo calbasu* and *T. khudree* in the earlier years of impoundment. On account of recurring breeding failure and habitat loss, these species have declined over the years, giving way to minnows which have shared the common niche with them. In the absence of any commercial fish to utilize the rich planktonic resources of the reservoir, they are mainly channelled through the detritus-molluscs chain to favour *Pangasius pangasius* and through grazing-predator chain to help the *Silonia childreni* populations. Thus, finally, these two catfishes have established a firm hold on the fish fauna.

Cauvery river system is the original abode of a number of fish species including P. dubius, *P. carnaticus, C. cirrosa, C. reba, L. kontius, L. fimbriatus, Tor putitora and Acrossocherilus hexagonolepis* which have been affected in various degrees by the impoundments, chiefly, Krishnarajasagar, Mettur, Bhavanisagar and Amaravathy reservoirs. During the last 25 years, the indigenous economic carps in Krishnarajasagar viz., *Labeo spp., P. dubius* and *P. carrtaticus* have suffered setback due to the changed ecological conditions, especially the components of fish food biotic communities. These species, contributing more than 60% of the total catch during the 1950s, have given way to the transplanted exotic common carp, *C. carpio*, which found a favourable environment in the reservoir *vis-a-vis* feeding and breeding. At present, most of the energy transfer is channelled through the detritus/benthos chain, giving considerable edge to the common carp which is a prolific breeder and competitor to *Cirrhinus* spp. for food.

One of the earliest casualties of hydraulic structures is the Indian shad *Tenualosa ilisha* (the hilsa) which was affected as early as mid 19th century when the Upper and Lower Anicuts were constructed on Cauvery. These barrages had severly restricted the migration of hilsa by obstructing their pathways and construction of Mettur dam (Stanley reservoir) in 1935 completely stopped the hilsa run in Cauvery. Several fishes were affected by the Mettur dam. *Puntius* spp. which used to form 28% of the landings in 1943-44 faded out in the mid 1970s. Although the indigenous *Cirnhinus cirrhosa* took some initial advantage, it also could not survive. Low water levels during July for three consecutive years have most probably caused its decline. Similarly, *Labeo kontius* which was next only to *C. cirrhosa* in Cauvery also disappeared from the reservoir. The Gangetic carps transplanted into the reservoir also did not find roots there. *C. mrigala* was stocked in 1950-51 and appeared in catch during 1957-58, contributing up to 13.9% in 1966-67, only to fade into insignificance later. The same fate met *Labeo rohita*. Recruitment failure, water level changes, and predator pressure are the main reasons for the failure of Indian major carps in Stanley reservoir. In 1993, the total catch of 115 t in the reservoir comprised *L. rohita* (19%), Wallago attu (15%), other catfishes (14%), *Puntius* spp. (14%) and *C. catla* (10%).

Bhavanisagar is the only reservoir in the Cauvery basin, where the indigenous species like *Puntius* spp., *Tor putitora, T. tor, A. hexagonolepis, P. dubius, P. carnaticus, L. kontius* and *C. cirrhosa* still hold together well. Their survival is mainly due to the uniterrupted breeding activities at Moolathurai and Nellithurai, especially when water is released from the upstream Pilloor reservoir. *P. dubius* ascends the river Moyar during the northeast monsoon and lays eggs in batches of 1 000 to 2 000 on the gravel beds. Similar breeding success has been confirmed in case of *Cirrhinus reba, Labeo fimbriatus*, *Labeo calbasu, L. kontius* and *Puntius carnaticus.*

Amaravathy and Sathanur with their prime fishes of tilapia and catla respectively are the examples of introduced fishes finding a favourable environment and propagating themselves into a dominant position.

Positive impact of reservoirs on fish fauna

Many species of fish not only manage to adapt to the reservoir ecosystem but also find it congenial and flourish there, which is the main reason for the rise in the biomass of reservoir in the early stage of impoundment. However, most of the fishes that manage to multiply in the reservoir system are not very high in priority from the commercial and ecological point of view. Stocks of the small clupeid, *Salmostoma phulo phulo* and *O. vigorsii*, which support a flourishing dry fish trade in Nagarjunasagar and Tungabhadra reservoirs, multiply in a much higher scale than they do in the riverine ecosystem. The catfish, *P. pangasius* which was believed to be a catadromous migrant, has not only adapted itself to become a resident population in Nagarjunasagar, it has also become a very important component of the population. Ramakrishniah (1994) described many instances where reservoirs acted as sanctuaries by citing examples of *Barilius bola* in Tilaiya (Damodar), *Mystus krishnensis*, *Osteobrama vigorsii*, and *Pseudeutropius taackree* in Nagarjunasagar (Krishna), *T. sandkhol* in Nizamsagar (Godavari), *Tor* *khudree* and *T. mussullah* in Shivajisagar (Krishna), *A. seenghala* and *T. putitora* in Pong (Beas) and Vallabhsagar (Tapti).

4.7 Probable questions

1. What is a reservoir?
2. Differentiate between lake and reservoir.
3. Name two important reservoirs in India.
4. Give salient features of changes in ecology for a new reservoir.
5. State factors involved in the transition of riverine to lacustrine ecology in a reservoir.
6. Define lake.
7. Name two bracishwater lakes in India and give their important fisheries.
8. Identify problems of lakes. State the restorative measures
9. Name the principal riverine systems in India.
10. Name the main rivers in the Ganga river system.
11. Which rivers fall under Himalayan river system? Name the principal fisheries.

4.8 Further reading

1. Fish and Fisheries of India - V.GJhingran, Hindhustan Publishing House
2. Freshwater Fish Culture - Vol-I - S.K.Sarkar, Daya Publishing House

Unit 5 ❐ Culture of aquatic organisms

Structure

5.1 Method of culture

There is wide variation in the method of culture of finfish and shellfish. The variation lies in the degree of control over the environment in which the organisms lie. An aquaculturist always tries to maximize production. The natural habitats generally have low standing crops. However, natural habitats can be manipulated through additional inputs to maximize production.

The intensity of aquaculture means the density of organisms per unit volume or per unit area. However, density at a particular intensity may vary widely between different groups. For instance culture of tilapia at 100 kg / m^3 of water in a recirculatory system is considered to be intensive culture, while culture of shrimps at 50 individuals /m^2 (1-2 kg / m^3) in ponds is considered to be intensive.

Intensity depends upon input. Greater the interisity, more is the requirement of inputs into the system. Based on the inputs the system of aquaculture is divided into following categories:

A. For Culture of Fish
- i) Extensive
- ii) Intensive
- iii) Semi-Intensive

B. For Prawn / Shrimp Culture
- i) Extensive
- ii) Semi-Intensive
- iii) Intensive
- iv) Super-Intensive

5.1.1 Culture of fish

Extensive culture of fish :

Extensive aquaculture is based on natural ecosystem and has thus limited inputs to maintain animals growth and survival. Seeds form the principal input and natural food form the sole source of nutrition for growth of fish. Natural productivity of such system is augmented through low cost inputs like organic fertilizers such as cow dung, compost, bio-gas slurry etc. but lacks aeration or other mechanical inputs into the system. It is characterized by low stocking density (< 500kg / ha or 3000 fingerlings of carp/ha) and depend largely on the natural productivity within the system to support growth of the fish. Carps, tilapia etc. are cultured in this way. Production of carps is achieved at 2-3 ton /ha/year.

Intensive culture of fish :

The main difference in the intensive culture of fish from the extensive culture is that the nutrition of the fish comes from the artificial feeds and there is no scope of utilization of natural diets. Though fertilizers are used in this system their contribution to production is low. Stocking density depends on the type of habitat such as ponds, raceways , cages etc. and its capacity to maintain the water quality conditions required for the cultured organisms. Generally stocking density is lowest in ponds followed by cages and maximum in raceways.

The main characteristics of intensive system are :

1. Simple food chain : Feed - Cultured organisms
2. Low energy losses from feed input with high food conversion ratios from specialized artificial feeds
3. No recycling of energy.
4. The requirement of high inputs of energy (e.g. feed, nutrients, aeration, filtration, pumping)
5. High yield per unit area.

Water quality is maintained by high water exchange rate in some cases by mechanical means. Aeration and water exchange helps in reducing metabolites load from ponds. In intensive culture in indoor tanks, particulate waste removal, gas exchange and oxygen production are all undertaken by mechanical means.

In outdoor intensive system with a soil substrate and phytoplankton there is settlement of particulate wastes, decomposing by bacteria and gas exchange enhanced by mechanical aeration. Stocking density in intensive system varies greatly with the type of system and cultured organisms.

Production level may touch over 15 ton ha/ year.

Table 1. Comparison between extensive and intensive aquaculture system

	Extensive	Intensive
1. Establishment Cost	Low	High
2. Culture system used	Natural water bodies	Fabriated culture system including tanks, pond system raceways, sea cages
3. Technology level	Low	High
4. Degree of control over environment, predator, competition, disease etc.	Very low	High
5. Operation, stocking rate & production level	Low	High
6. Dependence on local climate and water quality	High	Low to very low
7. Monitoring of water quality	Nil	Undertaken regularly
8. Food resources	natural food organisms, often some input of animal and plant wastes	Pelletised fabricated feed
9. Production kg/ha/yr	Low (20-500)	High (50000–1,00,000+)
10. Production cost	Low to very low	High to very high

Semi-intensive culture of fish

Semi-intensive is a system of culture intermediate in between extensive and intensive culture. However, there is no abrupt cut off point to mark the semi-intensive culture. This system, to some extent, relies on natural productivity, but there is more supplementation in the form of :

a) Addition of aeration to maintain dissolved oxygen.

b) Addition of inorganic or organic fertilizer to improve natural productivity

c) Addition of supplementary feeding (Prepared feed)

Semi intensive culture is almost exclusive to ponds and allows for an increase in the stocking density within the pond.

A comparative account of limnological characteristics of three culture systems is given in Table 2 and characteristics of three culture system adopted for tilapia culture is given in Table 3.

Table 2. Comparative account of limnological characteristics of different system of culture

Nutrient	Extensive	Semi-Intersive	Intensive
Organic carbon (%)	0.5–1.5	1.5	>2.5
Available Nitrogen (mg/100g soil)	25-50	50-75	>75
Available Phosphorus mg/100g soil)	<3.0	3-6	>6.0
Recommended dose of fertilizers /ha/year			
Raw cattle dung (tones)	20	15	10
Urea (46% N Kg)	150kg N=322 kg Urea	100 kg N=218 kg Urea	50 kg N = 104 kg urea
Single supper phosphate	75 kg P=470 kg SSP	50 kg P=310 kg SSP	25 kg P=155 kg SSP

Table 3. Characteristic of tilapia culture system

	Extensive	Semi-intensive	Intensive
1. Place of culture	Ditches, rice fields, backyard, ponds, community ponds	Ponds built specially for fish farming	Small ponds, tanks, cages, raceways
2. Stocking density - Number / m^2 or m^3	<1	2-3	>5
3. Source of seed for stocking (fingerlings)	Wild source	Commercial hatcheries	Own hatchery
4. Reproductive control	None	All male stock may be used	All male stock
5. Fertilization	None except incidental, runoff fertilization	Manure and inorganic fertilizers applied	None
6. Feeds	None except occasional farm by products and house hold wastes	Farm by products such as rice bran, oil seed cakes or supplementary compound feeds	Complete compound feeds
7. Aeration / water exchange	None	Limited, occasional water exchange	Aeration and water exchange to manage water quality
8. Culture densities	Seasonal	6-9 months	4-6 months
9. Yield (mt/ha/yr)	<1	1-5	>5

5.1.2 Culture of prawn / shrimp

As mentioned above the prawn shrimp culture may be divided into four categories. The main characteristics of these categories are discussed below:

Extensive culture of prawn/ shrimp (low stocking density farm)

Shrimp farm with low stocking densities are typically located in tropical water impoundments ranging from ~ 2 ha to > 100 ha and located adjacent to estuaries, bays and coastal lagoons and rivers relying recruitment of seeds from natural resources. They frequently involve polyculture with herbivorous fishes such as mullet, milk fish and others. At some low stocking farms liming is done if soils are acidic and sometimes animal manures or other organic materials to stimulate production of natural food for shrimp.

Ponds are stocked with post larva (PL) by opening sluice gates to incoming tides. Alternately juvenile prawn/ shrimp be netted from shallow coastol waters and stocked into pond. In all cases these shrimp feed natural phytoplankton and zooplankton, small plants and animal living in or on the pond substrate and particulate organic matter suspended in the water or lying on the bottom. This natural production may be prompted with application of organic or chemical fertilizer.

Semi-intensive culture of prawn/ shrimp (low stocking density farm)

Semi-intensive farming is done at medium stocking densities. Pond preparation is elaborate with dry out once or twice a year, tilling and liming and fertilization with N, P and Si compounds to promote natural production. Organic fertilizers are sometimes used. Although water exchange capacity rates used are 5-15 % of pond volume per day some farmers adopt exchange rate of 2-5 % to reduce cost of pumping and minimize fertilization need and possibility of pathogen introduction. Formulated feed with 20-40% crude protein are usually applied 1-3 times per day. Natural productivity is important for the juvenile shrimp growth during the early weeks at all intensities of shrimp culture. Subsequently, there is variation in the degree of dependence on formulated feeds, which is not as great at this moderate densities as it is at higher culture densities.

Intensive culture of prawn / shrimp (high stocking density)

Shrimp farms adopting intensive culture, use ponds of 0.1 to 2 ha typically Various types of raceways and above ground tanks are also used for this purpose. Pond preparation is more elaborate and feed is apptied 6-8 times a day. Mechanical aeration is needed to support large shrimp biomass. Various chemicals in the form of calcium peroxide, burnt lime, zeolite, chlorine, iodine, formalin and bactericides are applied to pond to improve water quality and prevent water quality deterioration and diseases. Various probiotics, such as bacterial inocula and enzyme preparations are added as in serni-intensive system.

Super intensive culture of prawns / shrimp (very high stocking density)

This system with very high stocking densities include the highest level of environmental control to the point of some being located indoor in green houses and other structures. Annual productions even reach 20-100 mt / ha and higher.

Pond management is based on 2000 water exchange capacity heavy aeration (up to 50 or more hp / ha) and the production of a bacteria dominated and stable ecosystem. The feeding regime used promotes the growth of heterotrophic bacteria and essentially makes the pond into a large outdoor bioreactor, akin to a sewage oxidation pond. In these high density, Zero- water exchange systems the pond ecology shifts (at weeks 9 to 10 after stocking) during the production cycle from an autotrophic phytoplankton based community to a heterotrophic bacteria based community. This shift improves water quality through fast digestion (oxidation) of organic wastes and without production of toxic metabolites.

Feeding rate often exceeds 350 kg/ha/day without resulting in deterioration of water quality once this heterotrophic bacterial community has been developed and established in ponds. This shift also recycles wastes into nutritious bacterial flocks, the basis for natural production in this system.

Table 4 : Variation in main parameters of different culture system for prawn and shrimp.

Parameter	**Extensive (Low density)**	**Semi Intensive (Medium density)**	**Intensive (High density)**	**Intensive (Very high density)**
1. Stocking density (PL/m^2)	1-5	5-25	25-120	120-300
2. Pond / Tank area (ha)	5-100	1-25	0.1-5.0	0.1-1.0
3. Seed source	Wild	Wild and Laboratory	Wild and Laboratory	Wild and Laboratory
4. Water exchange (% daily)	Tidal (<5%)	Pumping (5-12 %)	Pumping (up to 25%)	Pumping (25% +)
5. Feed	Natural productivity	Natural productivity and formulated feed	Natural productivity and formulated feed	Natural productivity and formalated feed
6. Mechanical aeration	None. Minimum water exchange	Water exchange and some mechanical aeration	Mechanical aeration	Mechanical aeration
7. Productivity cycle (days)	100-140	100-140	–	–
8. Annual production (kg/ha)	50-500	500-5000	5000-20,000	20,000-1,00,000 estimated

5.2 Culturable Sources

5.2.1 Criteria for selecting culturable species of finfish and shellfish

It is most important to select right species of finfish / shellfish for culture to maximize production and achieve profit out of it. The following points are considered most important for selecting a species for culture.

1. Water quality parameters : Each species has specific requirements of water quality parameters for optimum growth, survival and production. The most important water quality parameters that affect growth and production of a finfish or shellfish are dissolved oxygen, pH, temperature, salinity and nitrogen (ammonia, nitrate, nitrite) concentration of water. The selected species has to adapt to the existing level of these parameters.
2. Growth rate : Aqua culturist always consider that the species under culture reaches to the market quickly. Therefore, species with high growth rate is always preferred. However, there is always a risk of disease or culture system failure with high growth. Farmers often choose a lower risk species with moderate growth rate to avoid unpredictable loss in aquaculture.
3. Feeding habit : Feeding habit of a species and its adaptability accept artificial feed is of prime importance in an aquaculture farm. Animal feeding higher in the food chain generally require more expensive diets. Since live feed culture is expensive the species, which accept artificial feed are preferred for culture. Food habit also includes food and the column of the water in which the species feeds. The bottom feeders are difficult to be cultured in cages.
4. Reproductive Biology : A reliable source of juvenile or seed is fundamental to all aquaculture. So seed must be available in the required quality and quantity.
5. Hardiness : To achieve a profitable production culturable species is exposed to condition that are different from the natural habitat of the cultured species, Crowding, fluctuation in water quality, netting etc. put stress on fish / shellfish. The species under culture should be able to withstand all these stresses and maintain a high rate of survival and growth. Ability of the fish to resist disease and avoid mass mortality is considered to be important factors.
6. Marketing : It is also important to evaluate market value of the species before it is introduced into culture.
7. Economics : Cost of production including stock, feed, electricity, interest on money borrowed, labour etc. and retum for the sale of the product must be estimated with a cost and return analysis for a particular species or combination of species for culture.

5.2.2 Culturalde species and their importance

A. Carp Culture

Polyculture of carps based on three Indian major carps, Rohu , Catla and Mrigal is an age old practice in India. Later some exotic carps have been added to utilize the resources of the pond and maximize production. Apart from these six species a few other carps, both indigenous and exotic, are also used in carp culture in India. A brief summary of these species is given below in Table 5.

Table 5 : A brief summary of carp species used for culture

Species	Feeding habit and seed resource	Importance
1. *Catla catla*	It is a surface feeder and planktophagus feeding both zoo and phytoplankton, but predominantly feeds on zooplankton. Accepts artificial feed well. Seed is avail from natural resources in Ganga or through hapophysation	The species has a high demand in the local market and is preferred by the caterer for serving community function.
2. *Labeo rohita*	It is a column feeder,planktophagus and herbivorous. It accepts artificial feed well. Seed procurement is same as *Catla catla.*	Prized fish for domestic consumption.
3. *Cirrhinus mrigala*	It is bottom feeder and on detritus of plants and animals. Seed resource is same as that of Catla.	Demand is relatively less as compared to Rohu and Catla. But it is a tasty fish and has a fsirly high demand in the market.
4. *Labeo calbasu*	Bottom feeder and competitor of Mrigal. Seed is obtained through hypophysation.	Relatively low demand in the market.
5. *Labeo bata*	Bottom feeder and competitor of Mrigal. Seed is obtained through hypophysation.	It has a high demand in the market and more costly than similar size IMC.
6. *Cirrhinus reba*	Bottom feeder and competitor of Mrigal. Seed is obtained through hypophysation.	It has a similar high demand as that of bata. However, production rate is low.

Exotic Species		
1. *Cyprinus carpio communis*	It is bottom feeder and feeds on animal matter avoiding competition with Mrigal. Hypophysation is not required to obtain its seed. Sexes are kept separated for a few months before introducing into the hapas with aquatic weeds to induce the fish fry spawning	Only large size fishes have moderate demands in the market.
2. *Hypophthalmicthys molitrix*	Surface feeder, planktophagus and feeds predominantly phytoplankton. It is a keen competetior of Catla and growth surpasses Catla when stocked together.	Low demend for domestic consumption.
3. *Ctenopharyngodon idella*	It moves all round the pond and helps in aeration.It feeds voraciously on aquatic weed and 50% of the weeds consumed are excreted out in semi-digested condition, which serves as food for the detritivore fishes and increases the productivity of the pond.	

Table 6 : Some other exotic species used for semiintensive culture of fish

Species	Feeding habit and seed resource	Importance
1. *Oreochromis mossambicus*	Commonly called as Mossambique tilapia.Versatile feeding habit. Accepts artificial diet and refuse of kitchen.	It has a high market demand.
2. *Orechromis niloticus*	Commonly called as Nile tilapia.Growth rate is higher than Mossambique tilapia. Versatile feeding habit and can be grown on artificial diet or any type of kitchen refuse.	The fiah has a high market demand.
3. *Puntius javanicus*	It is an omnivorous fish preferring submerged aquatic vegetation like *Hydrille, Ceratophylum, Najas* etc. It also feeds on the on animal matter specially the young stages of fresh water molluscs.	Seeds are obtained through induced breeding in Bangla bundh or through hypophysation.

B. Catfish culture : A few species of catfish are culture for commercial exploitation in india. A brief summary of thse species in given below in table 7.

Table 7 : Species of catfish culture in India

Species	Significance
1. *Clarias batrachus*	Obligatory air breather and can be cultured in low depth water or in cages with upper part lying above water surface. The fish accepts artificial diet and responds to hypophysation.
2. *Heteropneustes fossilis*	Air breathing fish and cultured with *Clarias* and Anabas. It breeds in monsoon and responds to hypophysation. Highly cannibalistic habit during fry stage results in heavy mortality in nursery tanks.
3. *Pangasius pangasius (cultured in Sewage fed ponds)*	Very hardy species and can withstand low dissolved oxygen. The fish is suitable for culture in sewage-fed ponds and low lying water bodies. The fish is also used for biological control of molluscs. The fish is with compatible for culture with carps. It accepts artificial diet.
4. *Wallago attu*	Highly carnivorous species and predatory and therefore difficult culture with carps. It breeds in monsoon and responds to hypothysation. The hatchlings are cannibalistic.
5. *Ompok bimaculatus/ pabda/malabaricus*	All three species are commonly called as Pabda. It responds to hypophysation and accepts artificial feed. The growth rate is high. Monoculture is preferred and culture for 12 weeks results in growth of 80-90g.

Culture of Prawn and shrimp : Prawn and shrimp culture has grown up as an industry because of export value of the product. A brief summary of the species used for culture is given below in table 8.

Table 8 : Species of prawn / shrimp used in semi-intensive and intensive culture.

Species	Importance
Freshwater Prawn 1. *Macrobrachium rosenbergii*	Also known as giant fresh water prawn (GFP). Although this is a freshwater prawn it migrates to mouth of the esturaries with moderate salinity for spawning and the post larvae are available in selected segments of the estuary. GFP seed is available in the Phuleswar-Uluberia in Rupnarayan and Chakdaha in Hooghly estuary.

2 *M. malcomsonii*	Second important species of freshwater prawn after GFP. The spawning and seed availability is same as GFP.
3. *M. idae*	Relatively small sized freswater prawn. Seed resource is same as that of GFP.
4. *M. rudae*	Same as *M. idae*
Brackishwater Shrimp	
1. *Penaeus mondodon*	This is also known as tiger prawn because of its characteristic band on abdominal shell. Seeds are obtained from the coasts or from the mough of the estuaries along with tidal water throughout the year with a peak season during March to July. Tiger prawn has a high export value.
2. *Penaeus indicus*	Requires higher salinity for culture. Seed availability is poor in West Bengal, but available almost through out the year in Orissa, Andhra, T.N., Kerala and Goa coasts.

In addition to intensive culture of shrimp, both GFP and the tiger shrimp are cultured in West Bengal in extensive culture system using tidal water in Sundarban areas. In this culture a few brackish water species of fish are also cultured along with the prawn / shrimp. The species that are frequently cultured include *Liza tade, L. parsia, Mugil cephalus, Lates calcerifer, Etroplus suratensis* etc.

5.3 Further readings

1. Aquaculture - farming aquatic animals and plants - Pohn S Lucas and Paul C Southgate (Editors) - Blackwell
2. Handbook of fisheries and aquaculture - ICAR, New Delhi
3. Biology of finfish and shellfish - S.L.Chonder. SCSC Publisher, Howrah

5.4 Possible questions

1. Differentiate between extensive and intensive culture of fish.
2. What is super-intensive culture of shrimp.
3. How a species is selected for aquaculture?
4. Name the species of brackish water fish that are cultured with shrimp/ prawn in extensive culture system.

Unit 6 ❑ Culture, hypophysation and farm management

Structure

6.1 Monoculture and Polyculture

6.1.1 Monoculture

Monoculture means culture of a single species of fish. Fish culturists often opt for culture of single species when:

a) the species under consideration is commercially most important and it is profitable to culture the species alone than culturing it with other species.

b) the species under consideration has a very fast growth rate.

c) one sex of the species grow better than the other and the fast growing sex has a high market value.

d) the species is highly predatory and can not be cultured along with other species.

Monoculture is adopted mostly for prawn and shrimp culture. Highly commercial species of prawn and shrimp is cultured alone because of its high demand in the market and high market price.

Techniques of Monoculture

Monoculture of fish or shell-fish species is done generally under intensive culture system. Traditional ponds are not used for such culture because entire pond can not be utilized for such culture. Monoculture of fish is done in raceways, cages and pens while monoculture of shrimps and ponds are done in shallow ponds with continuous replacement of water.

Raceways are basically elongated tanks in which water enters at one end and exits at the other. These are elongated narrow and shallow water tanks with continuous water flows. Cages are floating structures with a net suspended below. Cages are relatively cheap as compared with raceways. Pens are like hapas fitted in row in shallow water and not very much different from cages. Pens are usually large and the walls of enclosures may be closed spaced stakes, such as bamboo stems or wire or other mesh. Suitability of a culture system varies from species to species. Raceways are suitable for shell-fish culture, while cages are suitable for culture of catfish like Singhi, Magur, Koi etc. Pens are generally set in shore areas of ocean for culture of marine species.

Disadvantages

There are many disadvantages of a monoculture system.

i) Production cost is high

ii) If there is any failure of the crop the loss can not be compensated from other crops.

iii) Since monoculture is generally of intensive type, there is a probability of environmental hazards to set in.

6.1.2 Polyculture

Polyculture is defined as the culture of more than one species of fast growing compatible species of fish together. Compatible species means species that occupies complementary niches especially in regard to their food and feeding and do not compete with each other.

Objectives of polyculture :

The main objective of a polyculture system is to utilize the entire resources of a pond to maximize production of fish per unit area or volume of water of a pond.

A pond is characterized by its diversified spatio-trophic environment comprising of various natural food organisms such as phytoplankton, zooplankton, periphyton, macrophytes, benthos and detritus at different strata of pond water column as well as in the bottom. The success of polyculture, therefore, depends on judicious combination of species, preferably with diversified feeding habit including planktivorous surface/ column feeders, benthic/detritivorous bottom feeders, omnivorous and macrovegetation feeder.

Selection of fish species :

Planktophagus fish

Since plankton (both phytoplankton and zooplankton) grow enormously in fertilized pond it is important to include planktophagus fish in a polyculture system. Since the planktons are available in surface water the planktophagus fish also occupies the surface water of a pond. The Indian major carp *Catla catla* is an important plankton feeding species which predominantly feeds on zooplankton. This species is combined with an exotic carp, the silver carp *Hypophthalmichthys molitrix*, which feeds predominatly on phytoplankton. Algal blooming is common in most tropical manure fed ponds. By stocking phytoplanktophagus Silver carp in appropriate density certain algal blooming can be controlled. Another exotic carp, the bighead carp, *Aristichthys nobilis* is a predominatly zooplankton feeding species and can replace the Catla.

Herbivorous fish

Labeo rohita from fingerling stage onwards is predominantly a herbivorous fish consuming decaying vegetation, higher plants forming a more than half the bulk of diet. The species occupies column of the pond. The species is often combined with the exotic grass carp *Ctenopharyngodon idella* which is a macrovegetation feeder and used to control weeds of a pond. The grass carp inhabits all depth of a pond. Since grass carp consumes more food than it can actually digest, almost 50% of the consumed food is excreted out as semi digested materials, which serve as the food for many bottom dwelling fish and invertebrate organisms.

Bottom feeders

Fish belonging to this group feed primarily at the pond bottom. They consume a variety of decaying organic matter, aquatic organisms such as clams, insects, worms, snails, and bacteria living in or on the sediments. The Mrigal *Cirrhinus mrigala*, the common carp, *Cyprinus carpio, Labeo calbasu, Labeo bata, Labeo gonius* are noted for this behavior. Mrigal and the common carp are compatible because Mrigal feeds on detritus, mostly of plant origin while the common carp feeds on animal matters. *L. calbasu, L. bata, L. gonius*, can compete with Mrigal if stocked with the later.

Piscivorous fish

Piscivorous fish are frequently stocked in ponds to control unwanted reproduction of fish that enter the pond with the water supply and compete for food with the stocked fish. Piscivorous fish consumes small prey fish and prevents them to grow large enough to compete with the cultured species. However, to avoid direct prey on the cultured species the piscivorous species are stocked when the cultured species have grown sufficiently bigger than the piscivorous fish. Commonly used piscivorous fish include the sea bass, *Lates* spp.; catfish, *Clarius* spp. and *Silurus* spp.; snakeheads, *Channa* spp etc.

Factors affecting species selection

1) Water temperature : Growth of fish is intimately associated with temperature. The species selected for polyculture should adapt to the existing temperature regime of the pond.

2) Market value : The market price and demand should be considered before a fish species is chosen for culture. When two or more fish can fill the same feeding niche in a pond, the choice should be based on which will maximize economic returns to the farmer.

3) Pond fertilization practices : Manures and chemical fertilizers increase production of natural fish food organisms in ponds. Thus, more food is made available to fish. Fertilized ponds may be stocked at higher rates than unfertilized ponds.

4) Feeding habits : Supplemental feeds are given when ponds are stocked at higher rates. Stocking bottom feeding fish such as common carp prevents sinking foods from being wasted.

5) Tolerance to pond conditions : Polyculture ponds are usually heavily fertilized or manured. This practice may cause low oxygen levels and other conditions in the water that are stressful to fish.

Stocking management

Species selection

Judicious selection of compatible fast growing species is of vital importance in polyculture system. A combination of six species, viz. Catla (*Catla catla*), Silver carp (*Hypophthalmichthys molitrix*), Rui (*Labeo rohita*), Grass carp (*Ctenopharyngodon idella*), Mrigal (*Cirrhinus mrigala*), and Common carp (*Cyprinus carpio*) fulfills the species selection requirement and has proven to be ideal combination for freshwater carp culture. Of these, Catla and Silver carp are surface feeders, Rui is a column feeder, Grass carp is a macrovegetation feeder and Mrigal and Common carp are bottom feeders. The six species combinations have been found to yield maximum production and are generally preferable in the region. These species are the "back bone" of polyculture. A list of compatible species with their spatio-trophic habits is given in Table-1.

Table 1 : Compatible carp species for polyculture with their spatio-trophic habits.

Species	**Spatio-trophic habits**
Silver carp (*Hypophthalmichthys molitrix*)	Surface feeder - Phytoplanktophagous
Bighead carp (*Aristichthys nobilis*)	Surface feeder - Zooplankton feeder
Catla (*Catla catla*)	Surface feeder - Zooplankton form the major diet
Grass carp (*Ctenopharyngodon idella*)	Surface/column feeder - Macrophyte feeder
Rui (*Labeo rohita*)	Predominantly column feeder - plankton and organic debris form the major diet
Thai Sarputi (Puntius gonionotus)	Columnlbottom feeder - Plankton and soft aquatic weeds form the major diet
Mrigal (Cirrhinus mrigala)	Bottom feeder - Detritivore
Common/Mirror carp (Cyprinus spp.)	Bottom feeder - Omnivore

Stocking density

Rate of stocking generally depends on the biological productivity of a pond and the amount of supplementary feeding. In general, stocking rate is determined in relation to water surface area of a pond. A pond having an average water depth of 2.5 m may be stocked at the rate of 700-900 fingerlings/bigha.

Species ratio

Selection of species ratio generally depends on seed availability, market demand, nutrient status of a pond etc.

The following general guidelines are found to be very useful :

- Six species culture system :

Under six species combination the system surface feeders should form about 40-50% (catla 10-15%, silver carp 30-35%); column feeder (rui) 20-25% in moderately deep ponds (above 2 m average water depth), and 10% in shallow ponds (below 2 m average water depth); bottom feeders 30-40% (mrigal 15-20% and common carp 15-20%) and macrovegetation feeder (grass carp) 5-10% depending upon the availability of a dependable source of weed supply.

- Five species culture system :

In the absence of dependable source of feed for grass carp five species combination may be adopted wherein Silver carp, Catla, Rui, Mrigal, Common and Mirror carp may form 20-30%, 10-15%, 15-20%, 10-15% and 15-20% respectively.

- Four species culture system :

Although silver carp grows faster and contribute significantly to the total production, due to lower price and market demand in some areas it is not a preferred species. Under such condition four species combination may be followed consisting of Catla 30-40%, Rui 20-30% in deeper ponds and 10-15% in shallower ponds, Mrigal 15-20% and common carp 15-20%.

- Three species culture system :

Depending upon the market demand, price and availability of quality seed, even a three species combination system consisting of 3 indigenous carp species may be followed (Catla 40%, Rui 30%, and Mrigal or Common carp 30%).

Generally all the fish species should be stocked at a time. However, it has been observed that due to some degree of inter-specific competition for food between catla and silver carp the growth of catla is affected. As such, it is recommended that silver carp should be stocked one or two months later than catla, by the time catla generally picks up good growth rate. Silver carp with its faster growth rate is able to attain over 1 kg size in 9-10 months.It is advisable to stock the ponds with larger fingerlings of 10-15 cm size for better survival. Recent experiments have, however, indicated the possibility of high survival and production rates when stocked with early fingerlings (5-8 cm) in predator free ponds. The other advantage of using smaller size (5-8 cm) is the cheaper price.

6.2 Hypophysation technique for sustained fish production

Non availability of pure seed is major constraint in mass scale culture and sustained production of Indian and Chinese carps. The major carps normally breed in suitable riverine habitats during the monsoon months and the fertilized eggs, hatchlings, post larvae (together known as spawn) drift downwards and are collected with the help of specially designed nets.

But there are several disadvantages in the collection of seeds from natural sources in rivers. These are as follows:

1. Seeds are mixture of economic and uneconomic species.
2. Sorting out of economic species only from this mixture is a tideous job.
3. Transportation of seed is a problem.
4. There is uncertainty in the quantum of availability of seed.

These disadvantages have necessiated the development of an easy technique to procure pure seed of desirable species of carps. This was made possible through the technique of hypophysation during the fifties in the twentieth century.

What is hypophysation ?

Hypophysation is a technique in which pituitary gland of fish is processed to extract **gonadotropin**, which is then injected to gravid female and male fish to spawn. Fish may be induced to spawn with the help of synthetic hormones or other inducing agents. But the term hypophysation is applicable only when pituitary extract is used. The pituitary is known as hypophysis and using hypophysis for inducing fish to spawn is called hypophysation. However, the term INDUCED BREEDING is broadly used for any technique used to induce fish to spawn.

Objectives of hypophysation

The main objectives of hypophysation are :

1. To get pure seed of a desired species for culture.
2. To ensure availability of seed in adequate quantity.
3. Sustained production of seed over a long period (generally five to six months for carps extending from March to August)

History of hypophysation Technique

Houssay of Argentina is pioneer in introducing the concept in 1930 that fish pituitary can be used to induce fish to spawn. However, the concept was applied successfully in Brazil only in 1934 by von Ihering and his collaborators. The Russian scientists also successfully applied the technique of hypophysation on sturgeons in 1937.

In India, Hamid Khan (in Lahore, Punjab, now in Pakistan) made the first attempt to induce carp to spawn by mammalian pituitary, but did not succeed. Hiralal Chodhury - the legendary Fisheries Scientist was pioneer in the application of hypophysation technique for induced breeding of fish in India. Dr. Chaudhury and his collaborators first successfully induced the cap minow *Esomus dendricus* and the catfish *Pseudotropius atherinoides* by fish pituitary extract injection in the Cuttack Research sub-station of the Central Inland Fisheries Research Institute, ICAR. Success for the more difficult to spawn the Indian major carps and the Chinese carps came two years later in 1957. Gradually the breeding technique was improved and large scale induce breeding by hypophysation started in commercial scale. The technique has then spread from India to other countries.

Hormonal background of hypophysation

Gonadotrophic hormones (Gonadotropins) play a vital role in regulating the development of gonads and spawning. There are special cells called gonadotrophs in the anterior pituitary. These cells secrete gonadotropins (GtH). In higher vertebrates gonadotropins are of two types - FSH and LH. Fish gonadotropins are proportionately poorer in FSH than mammals, but contain normal amount of LH. This was probably the cause of ineffectiveness of mammalian pituitary extract on fish spawning. According to some authors there is only one GtH in fish which they termed as LH-like in physiological action. However, there are other authors who believe that fish have two GtHs. But these two GtHs can not be classified as FSH and LH; rather these are classified as GtH1 and GtH2.

Pituitary extracts contain GtH, which stimulates two hormones in the ovary, oestradiol 17β and 17α, 20 (β-dihydroxy-4-pregnen-2-one (17α, 20β-diOH prog), and three hormones in the testis - testosterone, 11-ketotestosterone and 17α, 20β-diOH prog. oestradiol 17β initiates vitellogenesis in ovary and rest of the maturation i.e chromosome condensation, extrusion of first polar body and germinal vesicle breakdown (GVBD) are initiated by 17α, 20β-diOH prog. The spermatogenesis process in the testis is completed by the testicular hormones.

Factors responsible for breeding of carps

1. ***Conditions prevailing during natural spawning in rivers :*** Flood and rain, current of water, increased dissolved oxygen, optimum water temperature, shallow inundated areas (spawning grounds) and spawning congregations are considered important ecological inducements for natural spawning in rivers.

2. ***Other conditions prevailing during natural spawning in bundh :*** High turbidity, low pH, low total alkalinity, water temperature range of 27° - 29°C, increased conductivity of water and abrupt rise of water level have been recorded as conducive for spawning in dry and wet bundhs.

There is an increase in the water content of the gonad of carps on hypophysation. This has been referred by Clements and Grant (1964) as 'hydration factor' and the hormones regulating this hydration process appeared to be gonadotropin with possible involvement of electrolytes and other endocrines.

3. ***Conditions conducive for spawning through hypophysation :*** In case of induced breeding of carps through hypophysation in ponds, cool, rainy weather, accumulation of fresh rain water in the ponds and a water temperature range of 26°-30°C are conducive to successful spawning. However, the optimum temperature range for spawning varies from region to region.

Techniques of induced breeding by hypophysation

1. ***Brood fish management :*** One of the most important pre-requisite of induced breeding by hypophysation is the availability of brood fish, which respond easily to the pituitary extract. The quality of ideal carp brood fish is as follows

i) Carps 2-4 years old and weighing 2-5 kg weight respond best to hypophysation

ii) The brood fish should be healthy and free of any infection.

iii) There should be minimum deposit of fat in the body.

iv) In brood male carp a gentle pressure near the abdomen results in milt to ooze out.

v) In brood female carp the abdomen becomes soft, buldging, slightly swollen with pinkish vent. However, this may be deceptive in case of grass cap because of excessive feeding and in Catla due to fat deposition.

Raising brood fish : An adequate stock of brood fish is a basic pre-requisite for successful and large scale induced breeding of carps by hypophysation. It is advisable to raise brood stock-in the farm itself. Standard size of a brood fish pond is 0.2 to 0.5 ha with an average depth of 1.2 to 1.5 m during summer. season. Ideal stocking density is 1500-2000 kg / ha. Supplementary feed (with 30 % crude protein) is to be provided at the rate of 1-2 % of the body weight at the beginning. Subsequently, the feeding rate may be increased depending upon the rate of growth. An excess amount of protein is required during the last 5-6 months of culture. However, care should be taken that fish do not take excess food so that there is deposition of fat in the body of fish, which may prevent spawning of the fish.

Regular monitoring of fish for control of disease, if any, is required. In the selection of brood fish, both the size and age of the fish are important considerations. Carps 2-4 years old and weighing 2-5 kg are the best for hypophysation.

2. ***Collection and preservation of pituitary :***

Pituitary glands are collected from the market from the severed heads of carp or other fishes. The glands are preserved in absolute alcohol. The pituitary hormones are dissolved in water, but not in alcohol. So only absolute alcohol is used for preservation. The alcohols are changed after 24h and kept in airtight vials and stored in cool place preferably in dessicator. It can be stored in this condition for 1 year with change of alcoholonce in 3 months so that the potency of the gland is not reduced due to absorption of moisture by the alcohol. This is the standard size followed in India. In Russia and USA the gland is largely preserved in acetone.

3. ***Determination of dose of pituitary extract :***

Determination of proper dose is most important for a successful spawning. It depends on several factors :

i) Species of fish

ii) Size and stage of sexual maturity of the fish

iii) Potency of the gland

iv) Ecological factors of breeding

Dose determination of Indian carps

Since hormonal content varies with the size of the pituitary gland it is reasonable to relate the dose of the pituitary hormones with the weight of the gland and weight of the recipient fish. Hence the dose of hormone is expressed as weight of the pituitary gland in mg/kg of body weight. However it is difficult to assess the stage of maturity of the female Indian and Chinese carps by external examination and appearence.

The dose as evolved by experimentation in the Cuttack Research substation (CIFRI, ICAR) for Indian and Chinese carps are as follows:

Indian Carps

Female : Two doses are given at an interval of six hours

1st dose : 2-3 mg/kg

2nd dose : 5-8 mg/kg

Male : Only one dose is given at the time of second dose of the female.

Dose : 2-3 mg/kg (If yield of milt is not quite free during testing a higher dose of 4-5 mg/kg is often given).

Chinese carps (silver carp and grass carp)

Female : Two doses like Indian carps

1st dose : 3-4 mg/kg

2nd dose : 7 - 10 mg/kg

Male : One dose at the time of second injection of female like carp.

Dose : 3-6 mg/kg

Sometimes the Chinese carps are given three doses in a gradually increasing order at an interval of three hours, the total dose being 10-14 mg/kg.

Knockout dose : During late in the season females are often injected with single knock out dose usually at 10-14 mg/kg body weight of ripe females of IMC and 15 - 20 mg/kg body weight of ripe females of grass carp and silver carp.

Dilution and pituitary extract preparation

A concentration of 2-4 mg in 0.1 ml of extract and a dilution of 0.2 ml/kg body weight of recipient fish have been found most effective for carps. However, the volume of extract is arbitrarily determined with an objective that only minimum quantity of an extraneous matter should be injected into the fish to avoid any physiological stress. Usually, 0.2 to 0.6 ml extract is considered adequate for brood fish ranging between 1 to 4 kg.

For making extract the pituitary glands are taken out of the alcohol and soaked in filter paper. The glands are then placed in a glass homogenizer and macerated well along with distilled water. Instead of distilled water physiological salt solution is also used in many countries. The volume of the water or salt solution should be adjusted to the amount of gland and volume of extract required for injection. After homogenization the gland extracts itself can be injected when intraperitonial injection is used. But when intr-mascular injection is used the extract is further centrifiged at 3000 rpm for 10 minutes so that the gland debries are sedimented and the supernatant is used for injection.

A 2 ml hypodermic syringe with 0.1 ml graduation is used for injection of the pituitary extracts. The intramascular injection is given at the base of the pelvic fin or through caudal peduncle. The later is most preferred location. When two injections are given (in case of female) the injections are pushed on either side of the caudal peduncle.

Spawning

After the second injection of female and the only injection of male, both females and males at the ratio of two males to one female are kept in breeding hapas erected in the marginal areas of the pond. The rectangular breeding hapas are made of fine mosquito nets and fixed with bamboo poles at depths so that bottom of the hapas do not touch the maddy bottom and at least 15 - 20 cm of the upper margin of the hapas remain above the surface of the water.

Within 6-8 hours the fish starts spawning. Both females and males synchronize in releasing the gamets. Fertilization results immediately. The grass carp and silver carp requires stripping to release eggs and milts. The stripped out eggs are taken in a tray and males are stripped to release milt over this tray. The tray is gently shaked to initiate fertilization. The fertilized eggs are transferred to breeding hapa.

Fertilized egg, incubation and transfer to hatchery

The eggs soon after fertilization start swelling up. This is called water hardening. Within 45 minutes the balstodisc is formed and rapid division starts. The unfertilized eggs also swell up, but gradually become opaque and whitish. The fertilized eggs remain transperent and development proceeds to develop embryo. Approximately 10 hours after fertilization an elongated embryo is formed and it starts twiching movement. The eggs hatch out after 14 - 18 hours of fertilization.

Eggs are not transferred from the hapa at the early stage of development. The eggs are generally transferred from the breeding hapa when the eggs are fully water hardened. Roughly within 4-8 hours (3-4 hours for silver and grass carp) the eggs become fully water hardened and are transferred to hatching hapa or to any modern hatchery system.

Hatching Technique

The technique of hatching of fertilized eggs of fish has undergone evolutionary changes in last two decades. The three types of hatching technique as evolved chronologically are discussed below:

Pond hapa hatchery :

This type of hatchery is the oldest type. This is made up of two hapas one set inside another. The outer hapa is made of thick meshed cloth (Markin or other durable and cheap cloth) and fitted with bamboo pole in the marginal areas of pond at a depth little over 1 m. The standard size is 1.8m X 0.9m X 0.9m. The 25-30 cm of the upper margin remain projected out of water.

The inner hapa is made of round meshed mosquito net (1.75m X 0.75m X 0.45m) and stitched within the outer hapa exactly to the shape of the outer hapa. The bottom corners of the inner hapa are tied to the inner loop of the outer hapa and top corners of the inner hapa are tied o the bamboo poles.

The eggs are spread inside the inner hapa at the rate 0.075 to 0.1 million eggs per hapa. The eggs hatch out and come in to the outer hapa from where these are collected.

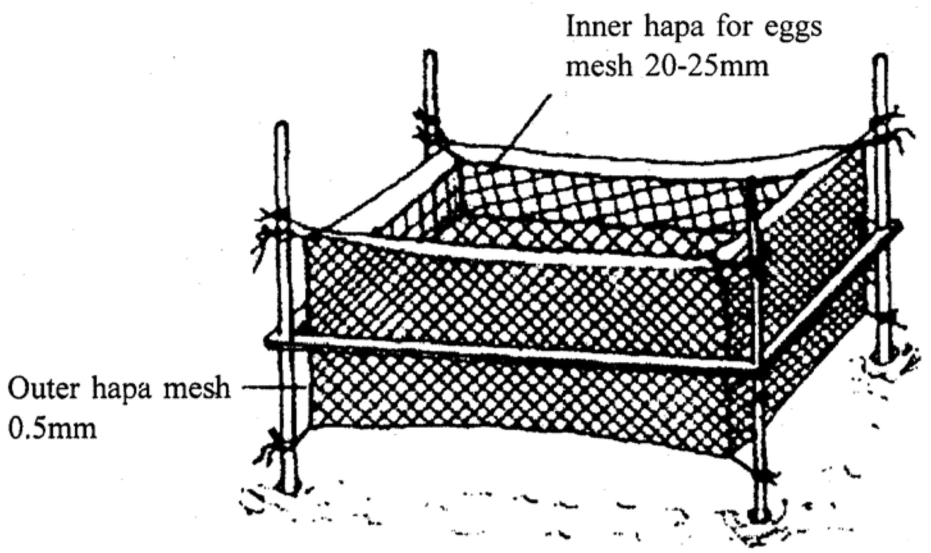


Fig : 6.1 Pond hapa with inner and outer chamber

Glass Jar hatchery :

The glass jar hatchery consists of cylindrical glass jars, which receive a regulated water supply through the bottom of the jars and the water flows out through an out let set at the top of the jars. Each jar contain about 6.3 liter of water and is capable of accommodating 50,000 fertilized eggs. The rate of water flow is maintained at 600-800 ml per minute for IMC and 800-1000 ml per minute for grass cap and silver carp. At a temperature range of 29-33 °C hatching is completed 3 hours earlier than the pond hapa. The hatchlings come out through the outlet of each jar and are collected through connecting trays fitted in one end to the outlet of the jars and another end to the hatching hapa (also called as spawnery) fitted in a cistern.

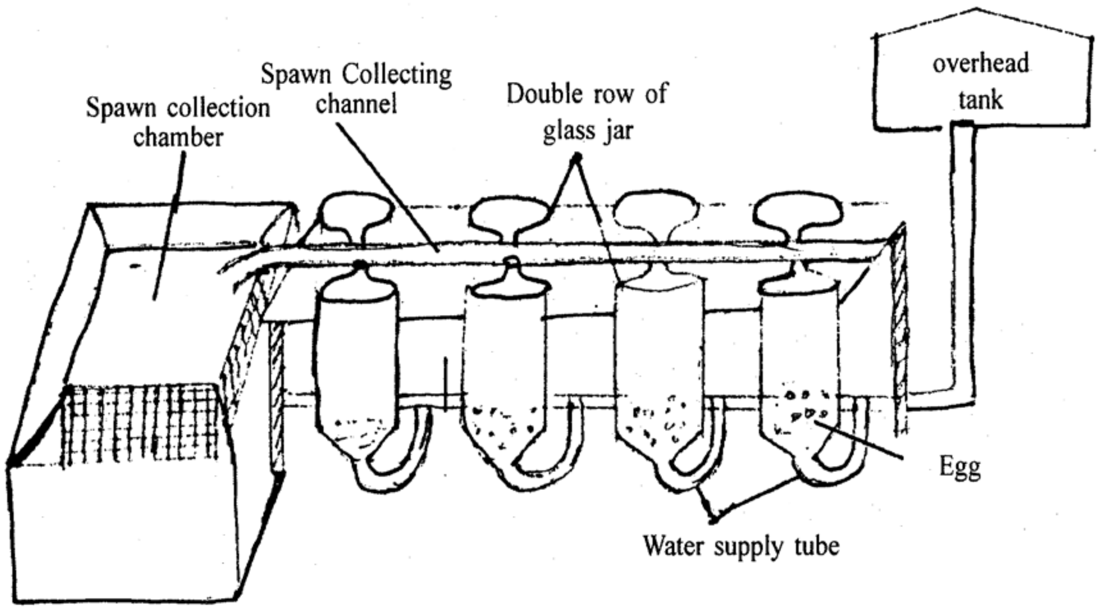


Fig : 6.2 : Glass Jar Hatchery

Chinese circular hatchery :

This is the most modern hatchery, which is most effective in fish seed production on commercial basis. Each hatchery unit has four parts :

a) An overhead tank to continuously supply water to hatchery.

b) A spawning or breeding pool for injected fish to spawn.

c) An incubation pool.

d) Hatchlings receiving pond.

Overhead tank: The overhead tank is placed at an elevated place and a deep tube well pump is attached to it to ensure continuos supply of water.

Spawning pool or breeding pool: The spawning pool or breeding pool is a circular cemented tank. Water enters into the tank through pipe set along the periphery of the bottom of the tank. The pipe has many unidirectional bent inlet so that water moves circularly within the tank. It provides a simulative riverine environment. Additionally artificial shower is sprinkled on the tank. Under such conditions, even the grass carp and silver carp do not require stripping for spawning when they are released after injection into such spawning pool. Water from the spawning pool go out through a centrally located outlet pipe. Volume of the water in the tank depends upon the height of the central outlet pipe. Generally the depth of water in the breeding pool is maintained up

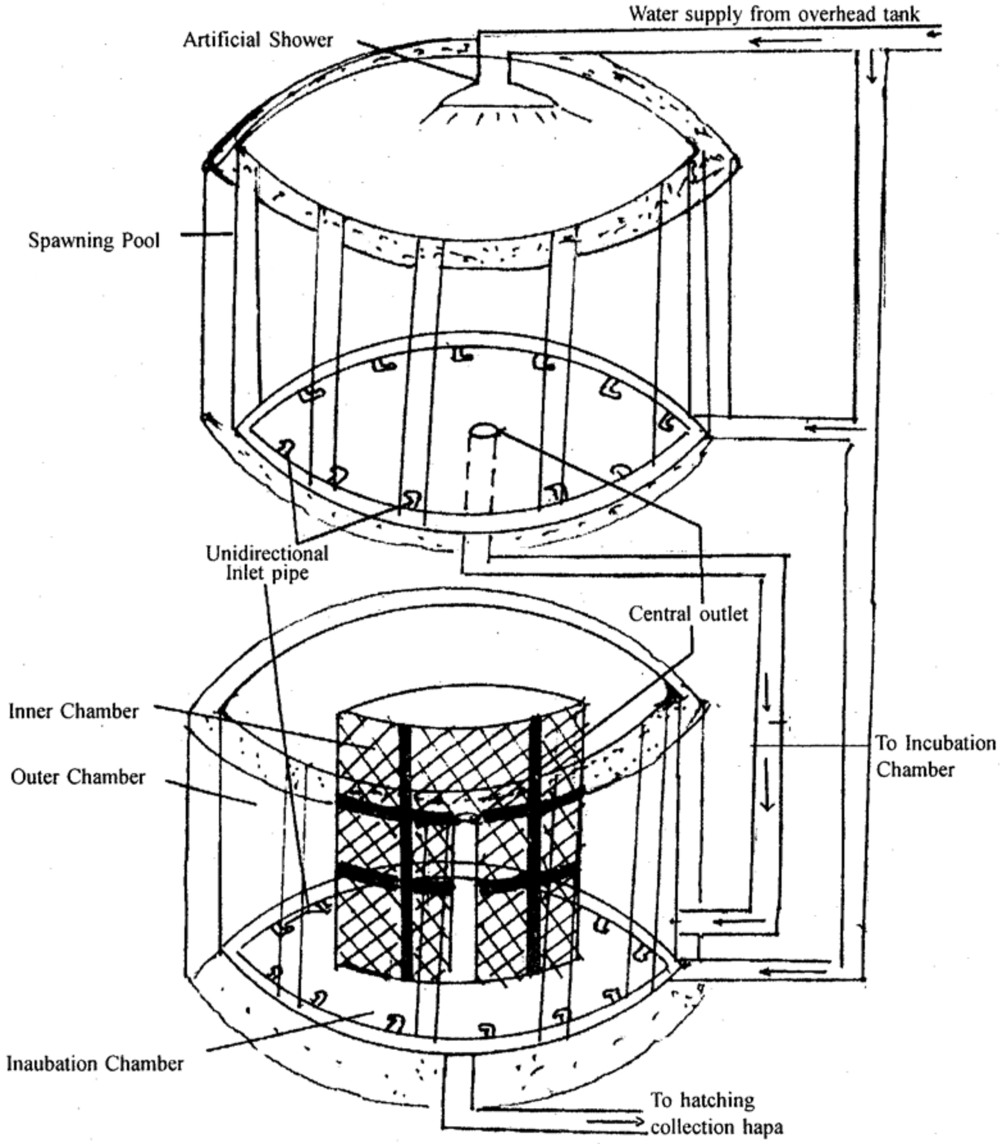


Fig 6.3 : Chinese Hatchery

to 1.5 m based on the brood density and 3-5 kg of brood and 0.7- 0.8 eggs per m^3 is considered to be optimum for incubation. The mouth of the out let pipe is covered with mosquito net so that the fertilized eggs do not go out. The outlet pipe is so fitted that it can be removed from the base when eggs are to be collected from the pool. The breeding pool should have a sloping bottom leading to the outlet at centre, so that it can be completely drained when required without leaving any eggs behind.

Incubation pool : Basic construction of incubation pool and water supply pattern is similar to spawning pool. But in incubation pool the tank is divided into an outer and an inner chamber by a wall of fine mesh cloth erected by iron frame or cemented wall. The water hardened fertilized eggs are released into the outer chamber, either directly from the spawning pool or through hand collection. The eggs move along with water and finally hatch out as hatchlings. After hatching the left out egg shells are crushed on the fine mesh net placed in between two chambers by the pressure of the circularly moving water. The crushed egg shells enter into inner chamber and are washed out through centrally located outlet.

Hatchling receiving pond : The entire unit is set on the bank of a pond. The outer incubation chamber may be directly connected to a hatchling receiving hapa in the pond or the hatchings are collected from the incubation chamber and are released into the hatchling hapa.

6.3 Fish farm management

Management is the process of getting activities completed efficiently and effectively with and through other people. Management is both art and science. It is the **art** of making people more effective than they would have been without a management. The **science** is how management do that. Essential components in management are : Planning, organization, resourcing, leading or directing and controlling. Each component is discussed in detail below.

Planning

Management starts with planning. Good management starts with good planning. Without a plan a farm will never succeed. Planning is a system of decisions. It involves decision regarding what is to be achieved and how to achieve in future. It is focused on desired future results. Planning not only helps farm managers to avoid errors and wastages, but also aids the management to become both efficient and effective.

The following steps need to be adapted for proper planning.

i) To identify the goal.

ii) Then to figure out the best way to achieve it.

iii) To measure the resources available.

iv) To compare strengths and weaknesses of individuals and other resources.

v) To consider all the probable scenarios and plan for them.

vi) To figure out the worst possible scenario and plan for that too.

vii) To evaluate different plans and to develop one which will work the best.

Budget as part of planning

Financial control of a farm is exercised through budget. A budget is both a plan and a control as the budget preparation is an integral part of the planning process and the budget itself is the end point of the planning process.

Budget is an estimate of expenses or income for a specific time period. The ultimate objective of fish culture is optimum production with sound cost benefit ratio for economic return.

Benefits of budget

1. Budget leads to better planning of fish culture.
2. Budget enables to forecast future activities.
3. Budget ensures a vivid statement and understanding of whole activities in a farm.

Organization and resourcing

When there is a plan one has to make it to happen. To make it happen the management has to check the following points:

a) Is everything ready ahead ?

b) Are the workers / farmers trained?

c) Are the workers/ farmers motivated?

d) Do they have the equipment they need?

e) Does everyone understand his role and the importance of his role to the overall success.

Direction and monitoring

When everything is set it is necessary that some one on the top of the organization put the switch on to start everything functioning. When everything is moving, the director/ manager has to keep an eye on things to make sure that everything is going according to the plan. When it isn't going according to plan, he/she needs to step in and control the plan.

Reassessment

Every decision taken and the action taken should be reassessed on the basis of advanced technology and if any mistake is done the problem is isolated, reassessed and correct measure is taken.

Scientific management of fish farm

Fish farm management entails the performance of supervisory tasks like site selection, designing and construction of ponds, pond preparation, selective stocking, water quality management, feeding, growth, monitoring and hazard analysis up to the stage of harvesting and marketing. Scientific management focuses on rational principles for handling equipments, inputs and money and to secure maximnm benefits for fishermen.

i) Utilization of scientific principles for all activities.

ii) Selection of fishermen with correct attitude and proper training.

iii) Interdependence between management and fishermen.

Planning and decision making

Planning, decision making and solution of problems in a fish farm are the key functions of adequate management. Farmers always face problems during cultivation. These problems should be solved with right decision. Right decision eliminates the root cause of the problems. Decision may be simple like selection and combination of species to be stocked, quality of feed to use etc. or complex like construction of a fish farm or a hatchery. When a farm is to be constructed there are several alternatives to carry out the work such as:

a) the farm is to be constructed on loan

b) the farm is constructed on part loan and part cash

c) the farm is constructed on 100 % cash.

Best management always calculate the cost, return and sustainability so that a risk free return is guaranteed. It depends on proper planning, budget and monitoring.

General planning for site selection in a fish farm

The importance of a good site :

The whole future success of a fish farm depends on the selection of a good site for a fish farm. The layout and the management of the farm depends on the kind of site selected, which strongly affects the cost of construction, the ease with which the ponds can be managed, the amount of fish produced and, in general, the economics of the entire farm.

Factors influencing selection of a site :

Following points must be considered before selecting a site of fish farm:

i) Level of production desired: subsistence or commercial

ii) If commercial, which culture system to adopt?

- Extensive or intensive;
- Monoculture or Polyculture
- Seasonal or year-round.

iii) The fish species to culture - mainly carps or catfish or both

iv) Whether fish seeds to be bought or produced in the farm itself

v) Water availability - Good quality water supply is required to run the farm.

vi) Soil quality of the farm site - Sites with rock and gravel beds, sandstone and limestone are avoided. Preference should be given to soils such as sandy clay, silty clay loam and clayey loam.

vii) Local topography: An ideal topography for a fish farm menas :

- Water drainage by gravity
- Minimum earthwork is required
- It is easy to balance the volume of earth to be excavated and that to be filled in.

Such ideal sites are found on gently sloping ground, where the slope is 0.5 to 3 percent. Slopes greater than 5 percent, however, should be avoided. If a horizontal land is used it will be more costly to build drainable ponds.

Other important characteristics of the site :

a) Vegetation cover : if there are big trees or a dense population of smaller trees, clearing the land will be difficult and costly Open woodland, grassland, old paddy fields or land covered with low shrubs permit easier and cheaper construction.

b) Accessibility : the use of artificial feeds on a commercial farm, pond management and marketing will require good access by road to the site.

c) Multiple uses of the ponds : it is sometimes advantageous to be able to use the ponds for purposes other than fish farming such as livestock watering, gardening or domestic use. Such integrated fish farming should be well planned.

d) Proximiry and size of market : once harvested, the fish should preferably be sold fresh, as soon as possible and with the least costs.

e) Availabiliry of inputs: Regular inputs such as feed ingredients and juvenile fish should be available locally.

Economics of Species Selection

The choice of aquaculture species is often a balance between biological knowledge and economics. Prior to selecting a species for culture it is important to understand the biology as well as the economics of the species. The environmental requirements (DO, temp., pH etc.), feeding habit, growth rate and reproductive biology of the species under consideration should be properly assessed before its selection. Then economics of the species is assessed. Apart from production of protein for human consumption there are many other objectives of aquaculture such as production of industrial or pharmaceutical products, production of ornamental species for aquarium industries etc. Depending upon the production objectives, the cost of production including stock, feed, electricity, interest on money borrowed, labour etc. and the returns from sale of the product, economic viability of a species is assessed.

Production Management

Maximum production requires application of up-to-date scientific principles and efficient marketing of the product. Production costs depends upon the technique of culture adopted: intensive, recirculatory type, semi-intensive etc. Intensive culture involves more investment on water quality management, feed and health management. Total production increases, but the cost of production also becomes high. Market price should always be higher than the production cost so that there is profit. If there is no profit, then the farmer has to seek for an alternative cheaper method of production (e.g. from intensive to semi-intensive) to reduce the production cost. However, it is not a matter of having positive balance of profit to costs. If the rate of return on the investment in an aquaculture venture is not greater than the prevailing standard rate of return from investments then the venture is effectively unprofitable.

Marketing management : Success of a fish farm heavily depends on how the products reach to the consumer. For this purpose there is need of an efficient marketing system. The demand of an aquaculture product in the market depends on several factors such as:

i) Price per unit

ii) Income level of buyers

iii) Price of substitutes and tastes

Normally the demand curve in a market is down-ward slopping- indicating that buyers purchase more of the product as its price is lowered. On the other hand the market supply of the product is usually upward-slopping, indicating that greater supplies become only available if producers are paid higher prices. The point at which these two curves meet represents the equilibrium of the market. The corresponding market price and the quantity traded are the equilibrium price and equilibrium supply from the farm / traders. For a sustainable farm management it is necessary to maintain this equilibrium.

The supply curve may shift downwards (increased supply for any given price) under following conditions:

i) The price of one or more input falls, e.g. fish food.

ii) New technologies are developed that lowers the production cost.

iii) Improved methods to control diseases in aquaculture.

iv) Genetic selection and breeding may raise the productivity of the cultured species of fish / shrimp.

Trends in demand and supply of aquaculture products in the market should be carefully analyzed in predicting future prices and markets for aquaculture products.

Extension

Extension is the process of conveying the technology of scientific fish culture to the fish farmers for better production and economy. The main objectives of extension are :

a) To educate farmers about the recent development in the techniques of culture and its input.

b) To convey the improved techniques in easily understandable form suited to the level of awareness and literacy.

c) To create a favourable attitude for introducing new things and change.

Methods of Extension: Following methods are adopted for extension:

a) Training and workshop

b) Film show

c) Lectures from experts

d) Demonstration of farm techniques

6.4 Further reading

1. Principles of Aquaculture - R.R.Stickney (Wiley)

2. Aquaculture - Farming aquatic animals and plants - John S Lucus and Paul C Southgate (Blackwell)

6.5 Probable questions

1. What is hypophysation ? How pituitary extracts are prepared? State dose of pituitary extract required to induce IMC. What is a knock out dose?

2. Draw and describe the functioning of a Chinese hatchery system for hatching of carps.

3. What are the advantages of polyculture? Discuss objectives behind species selection in polyculture. State combination of species in six species culture system.

4. What are the basic components of a farm management? State importance of planning in a fish farm management. Discuss factors influencing selection of a fish farm site.

Unit 7 ❐ Prawn culture

Structure

7.1 Farming method

Distribution and biology

The freshwater prawns are generally called Palaemonid prawns or non-penaeid prawns in contrast to penaeid prawns which are normally called as shrimps mostly represented by *Penaeus monodon, P. indicus*, etc. There are about 150 species of freshwater prawns distributed all over the world of which the most important genera is represented by *Macrobrachium.* The most common species of *Macrobrachium* are—*M. rosenbergii, M. malcolmsonii, M. idea, ·M. birmanicum, M. rude, M. choprai, M. villosimanum, M. lamarrei, M. scabriculum*, and *M. mirabile.* The freshwater giant prawns. *M. rosengergii* is well known due to its faster growth, higher tolerance to salinity and temperature and less cannibalism.

Freshwater prawns are found distributed from lower to upper reaches of river having tidal influence with salinity. It grows to a maximum size of 200 g. Matured males are distinguished from females by their larger size and possessing enlarged second pair of walking legs. The juveniles (2-9 cm) have 1-8 horizontal lines on the carapace, but no such lines are found in adult which carries an elongated and sharp, upturned rostrum. With increase in size, the freshwater prawns undergo the process of periodical moulting. The number of moults in a lifespan depends on the age and the type of food. In mature females moulting occur prior to mating.

Production pond

The potentials of freshwater prawns in organized culture in confined water first started in China. It is now practiced in many countries like India, Hawaii, Mauritius, Taiwan, Thailand, Indonesia, Philippines, Malaysia, Israel and others. Ponds, the same as for carp culture, are used for the culture of freshwater prawn, but the water supply invariably comes from irrigation canal or wells. The ideal size of production pond is 0.2-1.0 ha and the depth is 0.7-1.0 m. The inlet of the ponds is provided with screens of fine meshed nylon cloth so that predators can not enter into the ponds.

There are two types of culutre such as batch culture and continuous culture. In batch culture, the juveniles are grown only for 4-5 months and are harvested at one time, whereas in continuous culture, the juveniles are stocked once in every year and the marketable sized prawns are first harvested after rearing for 4-5 months. The smaller prawns are released back in the production ponds and culture operations are continued for another period of 3 months. Afterwards, the water is completely drained out for total harvest of prawns. Thus, the production ponds are used for two batch culture cycles in a year.

Selection of size at stocking

Selection of size at stocking is an important consideration since the growing period is rather short for 4-6 months. Generally, four weeks old juveniles greater than 35 mm to 45 mm is recommended for fast growth in *M. rosenbergii* and *M. malcolmsoni* and hence nursery rearing phase is eliminated. Before stocking, the juveniles are acclimated in the waters of culture ponds for some time.

Stocking rates

A stocking density of 25,000 – 30,000 seed prawn / ha of juvenile has been recommended in general. However, the density can be increased to 40,000 – 50,000/ha if there is a provision of water exchange in the production pond and advanced techniques are used. For obvious reasons, a relatively higher stocking density of 200,000 seed prawn may be used for better yield in continuous culture ponds.

Management of production pond

Management of production pond is most important protocol for the successful culture of freshwater prawns. Prawn culture ponds are pre-prepared on lines similar to those for carp culture.

Pond fertilization

The production ponds are fertilized with either organic-cow dung or poultry manure (200 kg/ha) and inorganic salt with single super phosphate (25 kg/ha) every month during the culture period.

Feeding

Adult prawns feed on aquatic insects, algae, mollusks, crustaceans, fish, etc. In the absence of natural food, these animals may turn cannibalistic, preying on their own fellow members. Supplementary feeds such as trash fish, mollusks, tapioca, pig dung are given in the form of balls at the rate of 5-10% body weight, once in 3 days. In some countries, chicken carcasses are staked in production ponds. The decayed carcass serves as an ideal food source to the scavenging prawns.

Water quality

Water quality specially temperature, pH, dissolved oxygen, total hardness, ammonia, should be monitored at periodical intervals and necessary corrections should be made when required. The pH of water in the culture pond should remain between 7.0–8.5. Changes of pH above or below the range is harmful to prawn growth. If the pond soil remains on the lower side, lime in the form of quick lime (calcium oxide) may be applied to correct the acidity of pond soil. Calcium oxide is applied at the rate of 500 – 1000 kg/ha depending upon the pH of pond soil. Since pH above 8.5 is harmful for prawn growth, pH of water should be corrected to bring down for about 2 – 4 weeks prior to stocking with seed prawn. Water hardness is known to play an important role for the successful culture of freshwater prawns as this species thrives well in freshwater with incrcasad amount of hardness.

Temperature - growth relationship

Growth of prawn is strongly influenced by temperature of water. Growth is maximum during the period of mid February to May when the ambient temperature of water shows a rise of 5°C from January to February.

Provision of hideouts

The prawns have a strong territorial instinct, the smaller ones are likely to be attacked by the larger and stronger ones. Hence, scrap nets or palm leaves may be installed as to form hideouts at various places in the production ponds. Moulted soft prawns generally become a prey to stronger individuals. These factors may cause a large variation in size structure of a confined population. Therefore, strong protection measures such as hideouts should be provided into the pond. The hideouts also harbour attached algae and other organisms which serves as good food source for the growing prawns. In some case, the weed *Ipomaea* may also be grown in small batches which may serve as shelters particularly for the freshly moulted prawns.

Carp-prawn mixed culture

Freshwater prawn may also cultured in polyculture with any combination of major or exotic carps such as catla, rohu, grass carp, silver carp, milkfish, mullet and tilapia. As prawns are bottom dwellers, the density of bottom grazing fish such as mrigal and common carp should be less. The faecal matter of grass carp may be a good source of food for freshwater prawns. Since carps are non-predatory, they do not cause any harm on prawns. On the other hand, juvenile or adult prawns do not prey upon or otherwise injure the fish. This combination of carp prawn polyculture is very profitable because, prawn yield may fetch a good market price thus making high profit of the culture system.

Prawn polyculture

In some places, mixed culture of freshwater prawns viz., *M. rosenbergii, M. rude, M. malcolmsonii and M. carcinus* has been carried out successfully.

Harvesting

After the grow out period for 4-5 months, the prawns are harvested by dewatering the water bodies. When environmental conditions are favourable, the juvenile prawn may grow up to 50 g in five months culture period. A production of 1.5 to 2.0 t/ha/5-6 months, with 90% survival of prawns has already been obtained.

7.2 Life cycle and larval rearing techniques

Breeding characteristics

Generally shrimps have a life span of 1-2 yrs; but the freshwater prawns may live upto 7-8 yrs. After living 3-4 months in river the female becomes mature. Its cephalothorax becoming yellowish purple, at the time when the ovary is mature. The species of *Macrobrachium* breeds during December-July, in the Hooghly estuary and August to December in the South-West coast depending on the onset of monsoon. Depending upon the age and size of prawn, the fecundity of *M. rosenbergii* ranged from 7000 to 5,03,000 in different regions of the country

Life cycle

An adult male with hardened carapace mates at night with a freshly moulted female when the male deposits the sperm as as a mass at the base of the walking legs of female. Following the process, the female releases eggs. which are fertilized by the viable sperm mass. The fertilized eggs are get attached to the abdominal appendages of the female. This female is now called berried females which are known to migrate to areas of suitable salinity in the estuarine regions for the purpose of hatching their young (Fig. 1)

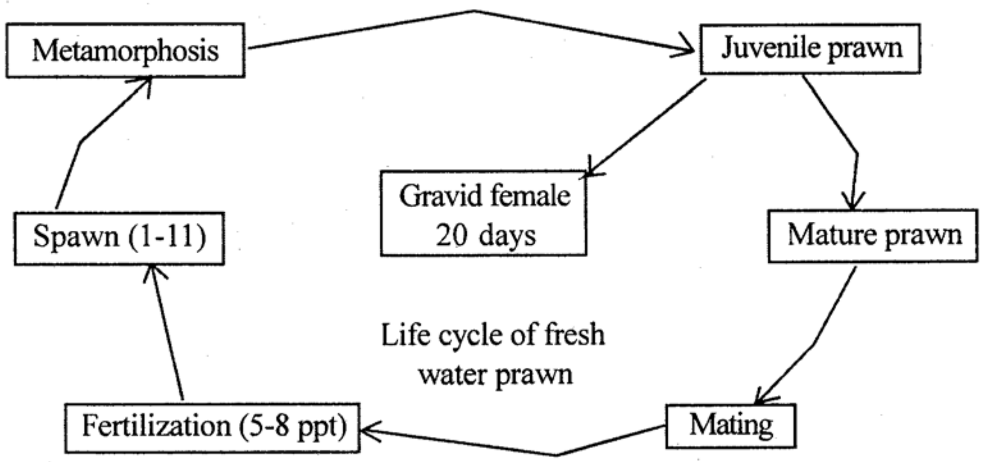


Fig. 1 Life Cycle of freshwater prawn.

The fertilized eggs are carried by the females for about 3 weeks. After tenth day, the originally bright orange eggs begin to turns into darken to slate-grey colour.

The eggs hatch into zoea stage, which then starts to feed. Better survival of the larvae is found in coastal waters with salinity range of 10-20 ppt. In a period of 50 days, the larvae pass through 12 stages and finally metamorphosed into juveniles and takes benthic mode of life. In young prawns, moulting is frequent and is invariably once in every 10 mm growth. Each moulting occurs in 4-5 days during the larval stage.

The freshwater prawn has to enter the esa, for part of its life cycle for the purpose of breeding. The scientific information about the early development of freshwater prawn is not really known. However, the information of the developmental stages of penaeid shrimps may be used to represent the life cycle trend of freshwater prawn. This may be represented as follows :

Mature male and female

↓

Fertilized eggs. (235-275μ) and Greenish in colour

↓

Absorb water and swell up in round shape (330-440 μ ; first and second polar bodies are present)

↓

Begin to cleavage (30 - 40 minutes)

↓

Embryonic formation (2-2.5 hours)

↓

Formation and completion of first and third appendages. (4-12 hours)

↓

Hatch into nauplius larva (13-14 hours)

↓

Metamorphosis into zoea stage larva (2-3 days)

↓

Metamorphosis into Mysis stage larva (3-4 days)

↓

Metamorphosis into post larva (PL) (6-12 days)

Juvenile prawn migration

The juveniles migrate upstream where they sexually mature in about nine months when the body colour changes from their original transparency to bluish or brownish. Mass migration of freshwater prawns is found in river Godavari. Migration commence during the flood season and continue during the post-flood period up to early summer.

Larval rearing techniques

Prawn seeds are procured from wild natural sources or may be obtained after captive breeing for artificial propagation. From naural riverine sources, seeds are collected from different sites of the rivers like Hooghly—Matla estuary, at the confluence of river Churni with Hooghly, Roopnarain, Godavari and Travancor region of Kerala with the help of the meshed cloth bag nets of 2 m long and 1 m diameter. Post larvae and smaller juveniles of *M. rosenbergii* may be procured from nature.

In artificial propagaticn method, 3 berried females treated with 15-20 ppm formalin solution for about 30 minutes, are introducted in each of the rectangular flat—bottom tank. The larval tank size of 5 × 2 × 1m is ideal. This is now filled with brackish water (1 ppt) and provided with cloth to avoid the escape of hatched young at the time of changing the water. Each tank has a gentle slope at the bottom for easy draining, which is facilitated by an outlet tube fixed at one side of the tank. The outer end of the drain tube is fixed with a fine meshed cloth to avoid the escape of the hatched young at the time of changing the water.

When these larval are 10 dyas old, they swim upside down and 25-28 days after hatching they become post-larval and swim normally.The post-larval are now carefully caught from the larval tank with the help of hand nets. In holding tanks, the post—larvae are reared for 1-4 week or till they reach a size weighing 1-2 g on foods such as, nauplii, tubifex, worms and fish meal before they are stocked in production ponds. It is stated that survival of larvae was better when the salinity ranges between 10-20 ppt.

In a period of 50 days the larvae pass through 12 stages and finally metamorphosed into juveniles and takes benthic mode of life. In young prawns, moulting is frequent and is invariably once in every 10 mm growth. Each moulting occurs in 4-5 days during the larval stage. The newly metamorphosed juveniles are gradually acclimated to low salinity and then to freshwater for further rearing in production ponds.

The stocking density may range from 67-249 larvae per litre and for the production of juveniles the density may range from 25-32 per litre in the running water system. At an average density of 7 larvae per litre, it took 43 days to complete the larval development.

7.3 Hatchery techniques and harvesting

Artificial propagation of freshwater prawn requires good quality of water, adequate high protein feeding and care in the rearing. The facilities required for larval rearing of freshwater prawn are essential and the same as that of penaeid prawn hatcheries. The larval development is much elaborate passing through several steps in nauplius, zoea and mysis stages before they attain the postlarval stage. Generally six nauplii, three zoea and three mysis stages are recognized.

Usually propagation is carried out in hatchery or it may be partly in the hatchery and partly outside. Obviously, the size of the hatchery depends on the intended production. The information about the hatchery room for freshwater giant prawns is not available at length, however, the hatchery information of the shrimps may be used for the freshwater giant prawn. For production of one million shrimp larvae every 1-2 months intervals, the hatchery is required.

It is about 10-20 half metric tons (0.5 m^3) plastic fibre/fibre glass tanks (Fig. 2) or with one or two 4 × 4 × 1.5 m concrete / wooden / plastic ponds.

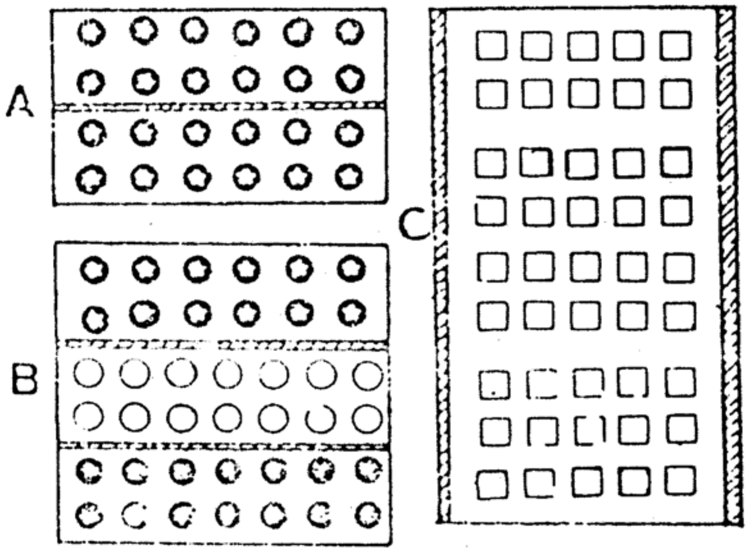


Figure 2 : Examples of arrangements of draining ditches (oblique lines), PVC tanks (round) and cement ponds (square) in a shrimp hatchery. A ditch situated at the centre ; B. Dual rows of ditches ; C. Two-sided ditches.

The hatching and rearing of early larvae of *M. rosenbergii* are conducted in 40% sea water. The breeding stock is reared in either freshwater or slightly brackishwater of the salinity between 2 to 8 ppt. The incubation period lasts about 19-20 days and is carried out in 6-12 ppt salinity. The zoea stage larvae emerges from eggs and the avarage larval reairing period is 40 days.

In *M. malcolmsonii*, the salinity in the hatchery tank is maintained at 10% sea water for 2-3 days before hatching. Further increase in salinity from 10-40% sea water is also required in the same day of hatching. As development progresses, the salinity is increased by 5% once a week to 70% sea water level. Zoea I passes through 15 moults.

Water quality

Good water quality is a basic need for the artificial propagation of prawn larvae. The maintenance of water quality, aeration and proper feeding are the important factors in hatchery management. It must be free from silt or clay and without pollution.

The favourable water quality is maintained by aeration, agitation, and filtering the water. The use of recirculated water through biological filter is highly favoured. Salinity at 12-16 ppt, pH about 7.5 to 8.0, temperature 26-30°C and water depth of 0.5 m have been considered satisfactory for prawn growth.

Collection of seed prawn

Concentration of larvae in the rearing tank and sufficient quanity of proper feed are important factors that affect the survival and growth of prawn larvae.

The eggs hatch out in about 4-5 days, particulrly during early hours. After 3-4 dyas of hatching at least 50% of the water should be carefully drained off from the larval rearing concrete tanks and oxygen rich freshwater with pH of 7.0-8.5 should be maintained. These larvae when 10 days old, swim upside down and after 25-28 days, they become post larvae and swim normally.

The post larvae are caught carefully from the larval tank with the help of hand nets and are stocked and reared in concerte holding tanks with freshwater at the rate of 5000 m^2. The population may be thinned out, so as to maintain the stocking denisty of $2000/m^2$ after a rearing period of one month. In holding tanks, the post larvae are reared for one to four weeks or till they reach a size weighing 1-2 g on foods like nauplii, tubifex, worms and fish meal before they are stocked in production ponds.

Unit 8 ❑ Integrated fish culture

Structure

8.1 Principles of integration

8.2 Integretion of paddy fish culture - methods

8.3 Integration of livestock -fish culture -methods

8.1 Principles of integration

Integrated fish farming may be defined as a sequential linkage between fish farming and live stock or agricultural crops. Capture and culture fisheries have become expensive due to fuel crisis and the rising cost of chemical fertilizers or the cost of feed in culture fisheries.This has created an awareness in developing an alternative strategy of development for food production which should rely on locally available sources of renewable energy and resource.

The underlying principle of the integrated farming are the utilization of the synergetic effects of interrelated farm activities and the conservation, including the full utilization of farm wastes.This is based on the concept that organic wastes of diverse origin should not destroyed but be returned to the earth for the welfare of mankind. In most countries, the waste disposal practice is based on the idea that 'solution to pollution is dilution'.

Rationale of integrated farming

With a view to enhancing the income of the farmers, the practice of fish farming integrated with crop and livestoke production has been originate It is an ancient practice adopted in China and have been introduced into several Southeast Asian countries including Bangladesh, Vietnam, Thailand, Malyasia, etc. The main objective was to develop an efficient means of utilizing farm resources to the maximum extent. Farm wastes can be reused as fertilizers or animal feed or accumulating pond silt can be recycled for fertilizing agricultural crops. The rationale behind raising fish on animal manures becomes apparent when it is found that 72 to 79% of nitrogen, 61 to 87% of phosphorous and 81 to 92% of potassium in the feed rations fed to animals are recovered in their excreta. The pond embankment can be used for the cultivation of different cash crops for animal raising. It is also possible to hire the hard labour at low price when there is less demand for other farm activities.

The low lying areas not suitable for agriculture are reclaimed at low cost for the culture of fish and the wide embankments of ponds are used for crop and animal farming. Integrated farming of fish and ducks has been devloped as a means of reclaiming sodic soils for agriculture in Hungary. It is, therefore, evolved as a unique and lucrative venture and provides a higher farm income, makes available a cheap source of protein for the rural population, increase productivity on small holdings and increases the supply of feeds for the farm livestock. India produced large quantities of plant and animal residues to the tune of over 322 and 1000 million metric tones, respectively per year. The quantum of residues may easily be traced from 307 million bovine population, 181 million sheep and goats, 16 million pigs, and over 150 million poultry and other livestock. Other farming activities such as mushroom cultivation, rabbit, sericulture, and apiculture also provide huge quantities of organic materials for aquaculture. The examples of duck cum fish culture, poultry cum fish culture, paddy cum fish culture, etc (Fig. 1) are self reliance. Basically, fish culture integratd with agricultural crop and livestock provides several advantages:

i) provides high income and is dependable source of cheap protein for the rural population
ii) increases productivity in small land holdings
iii) increases supply of feeds for the farm livestock
iv) maintains a clean evironment and enhances scenic beauty
v) respects the wastes as resource
vi) offers great efficiency in resource utilization
vii) reduces risk by diversifying crop
viii) provides additional food and income
ix) increases employment opportunities, nutrition and income of rural populations.

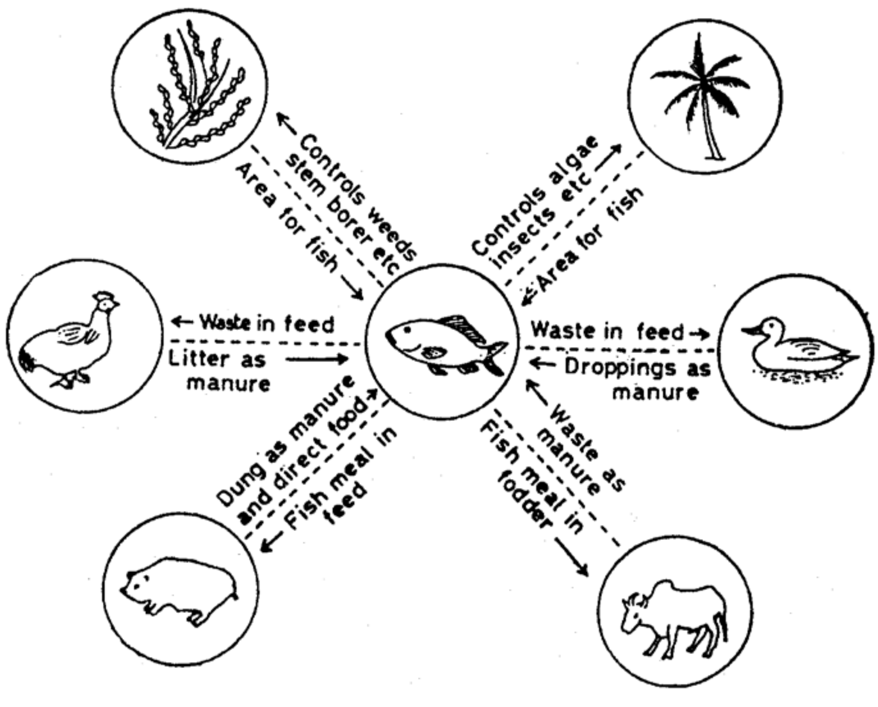


Figure 1 : Flow chart showing various aspects of integrated farming

The ecosystem of integrated fish farming

The ecosystem of pond used for integrated fish farming is not basically different from other pond ecosystem. It starts with the processes of trapping solar energy for the prodution of organic materials via the primary producers of phytoplankton and utilization by a series of consumers followed by decomposition of organic matters by fungi and bacteria and release of nutrients for primary production. Basically both grazing and detritus food chains are involved.

Food chain and food web

Animal manure when applied in fish ponds, there are three pathways by which the manures are converted into fish biomass.The first is the grazing food chain or autotrophic one which starts from phytoplanktom - zooplankton and then to fish. The next one is the detritus food chain or heterotrophic pathways which involves the use of accumlated detritus and benthic animal in the bottom of the pond. In the pond ecosystem loaded with organic manure, there is dominance of microbial populations. The third pathway is the direct feeding on organic matter. The bottom dwelling fishes like common carp, mrigal, etc. directly utilize bacteria coated organic particles in manure. Some fishes are known to eat directly to some extent the manure of cattle or other animals including night soil.

The mechanism involved is that organic wastes entering the pond ecosystem enhance the production of natural food for fish mediated through microbial degradation and mineralization. Temperature, pH and other environmental factors play important role in the degradation mechanism.The factors such as temperature, light, micro- and macroflora, inorganic nutrients, carbon, phosporus and nitrogen are the main requirements for phytoplankton growth. It is important that nutrients released from the added wastes should be in proper ratio so as to sustain the level of primary production as excess nutrients may have adverse impact on the growth of phytoplankton.

8.2 Integretion of paddy and fish culture - methods

Though rice is staple food for over 1.6 million people of the world, 90% of the rice is produced in Asian countries. In traditional paddy cultivation during monsoon with sufficient water level, many naturally occurring fishes used to breed in the paddy fields. Collection of fish from paddy fields has been an age old practice in India. In fact, practice of incorporation of fish in rice fields was introduced in southeast Asian countries from India more than 1500 years ago.

In India, only 0.03 per cent of total 6 million hectares of land under rice cultivation is used for rice- fish culture. the advantages are : economical utilization of land, minimum extra labour, savings on labour cost towards weeding and supplemental feeding and enhanced rice yield. Additional income and diversified harvest such as fish and rice from water, and vegetables such as bean, onion, sweet potatoes, papaya, etc, through cultivation on pond embankment. Some other agricultural crops such as maize, banana, coconut etc. are also integrated with fish culture. The fish yields of different countries adopting rice-fish culture is given in Table 1.

Table1. Fish yields of various countries adopting rice fish culture

Country	Area under rice-fish culture	Fish yield in rice culture
Vietnam	1550	25-380 kg/4.5m
Indonesia	67,000	30-50 kg/40-60 days
Malaya	45,500	135kg/year
Japan	12,000	145 kg/year (without supplementary food 2250 kg/year (with supplementary feed)
Java		30-50 kg/40-60 days

Selection of rice varieties

The kharif paddy varieties are selected, because these varieties not only possess strong root system but also capable of withstanding flooded conditions. Further, they have s life span of 150 days and, therefore, fish culture is possible for about 4 - 5 months after their trans-plantation. In the coastal paddy field of West Bengal. the rice varieties selected are: Mashuri, Sodamota, Kalomota, Talmugug, Damodar, Dasal, Vytilla, Bilikagga, CSR-4, CSR-6, Matla, Hamilton, Palman 579, BKN, Rp -6, FR -46B, Arya, etc.The varieties selected in coastal waters of Kerala are: ADT 6, ADT 7, Rajarajan, Pattambi 15, Pattambi 16, etc.

Selection of fish

The selection of species for culture depends on the likely duration of culture and the quality of water. The fishes are capable of tolerating shallow water (<15 cm), high temperatures (up to 35C), low dissolved oxygen and high turbidity. Species such Indian major carps (*Catla catla, Labeo rohita Cirrhinus mrigala), Cyprinus carpio, Chanos chanos, Oreochromis mossambicus, Anabas testudineus, Mugil* spp, *Clarias batrachus, C.macrocephalus, Lates calcarifer, Channa striatus, C.marulis* are extensively cultured in rice fields. Some progressive farmers also use freshwater prawn for culture in rice fields. Several species of shrimps are grown in the fields: *Penaeus indicus, P. monodon, Macrobrachium rude, Palaemon styliferus.*

Culture methods

In India, only 0.03% of total six million hectares are now used for rice-fish culrture. The paddy field retain water for 3 - 8 months in a year particularly in low lying areas. The most common system used at present is rearing fields, concurrently with the rice crop.

Fish culture in rice field may be carried out in two ways: simultaneous culture and rotational culture.

Simultaneous culture

In this practice, rice and fish are cultivated together. Rice fields (Fig.2) of 0.1 ha may be economical. Normally four rice plots of 250 m 2 (25×10 m) may be formed in such an area. In each plot, a ditch of 0.75 m width and 0.5 m depth is dug. The dikes enclosing the rice plots may be 0.3 m high and 0.3 m wide. The ditches have connections with the main supply or drain canal, on either side of which, the rice plots are located through the inlet outlet structures of the dike. The depth and width of the supply or drain canal may be slightly smaller then that of the ditches The ditches serve not only as a refuge when the fish are not foraging among rice plants, but also serve as capture channels in which the fish gather when water level goes down. Suitable bamboo pipes and screens are placed in the inlet and outlet structure to avoid the of predatory fish and the escape of fish under culture. The water depth of the rice plot may vary from 5 to 25cm depending on the type of rice and size and species of fish to be cultured.

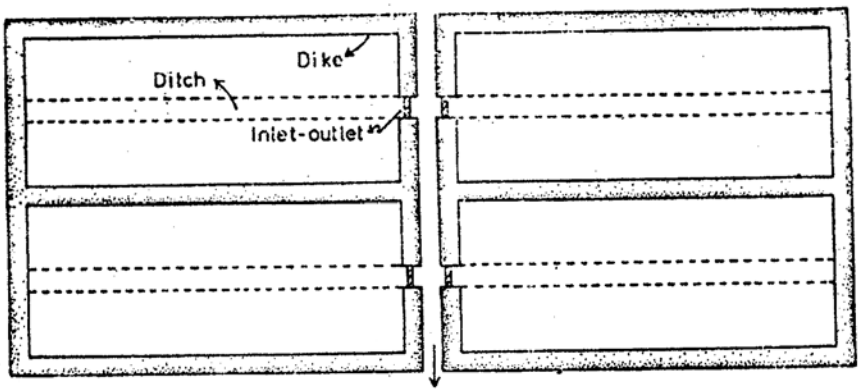


Figure 2 : Rice field ith trenches for rice-fish culture

Culture methods

Five days after transplantation of rice, fish fry (1 cm) are stocked at the rate of 5000/ha or fingerligs (8 - 10 cm) at the rate of 2000/ha. The stocking density can, however, be doubled if supplemental feed is given daily. The stocking of juvenile prawns (2-3cm) at the rate of 1000/ha may be done after the rice seedlings are well rooted. The plankton production in rice fields can be increased if some amount of fertilizers in excess of requirements for rice fields are added. No supplementary feeding is necessary.

For controlling the insects, the insecticide Furadon (Carbofuran) may be used at the rate of 1 kg/ha. It is recommended that the insecticide is mixed with basal fertilizers and applied once during the final harrowing.

After a period of 10 weeks in case of fry stocking or 6 weeks in case of fingerlings, the rice field are slowly drained off and fish are harvested. The harvesting of fish my be done about a week before the harvest of rice.

Growth and production

The growth rate of fish is also moderate in rice fields as the production of plankton is rich. Individual growth of 100 g and yield of about 2000 kg/ha is possible in simultaneous culture practice. The production of prawn is high and quite profitable.

Advantages of simultaneous culture

a) fish increases rice by 5 - 15 per cent, which is mainly due to indirect organic fertilization through fish excrement and also the control of unwanted filamentous algae which may otherwish compete for nutrients.

b) Tilapia and common carp control unwanted aquatic weeds which may otherwish reduce the rice yield up to 50 per cent.

c) Insect pests of rice like stem borers are controlled by fish feeding on them like murrels and catfish.

d) Fish feed on the aquatic intermediate hosts such as malaria causing mosquito larvae, thereby controlling water borne diseases of human beings.

e) Rice fields may also serve as the fish nurseries to grow fry into fingerlings. The fingerlings may either be sold or stocked on production ponds and thereby serving as source for stocking materials for composite culture.

Limitation of simultaneous culture

Despite potentials of simultaneous fish rice culture, it has some limitation as follows:

(a) use of agrochemicals is not feasible

(b) maintaining high water level is not possible comsidering the size and growth of fish

(c) fish like grass carp may feed on rice seedlings

(d) fish like tilapia and common carp may uproot the rice seedling

However, these problems can be overcome througs judicious management.

Rotational culture

In Kerala, Pokkali fields are utilized by traditional farmers for brackishwater aquaculture during summer fallow months on rotational basis. It is reported that fish yield could exceed the income from rice in the rotational culture.

The coastal paddy fields are under the influence of backwaters which are in turn controlled by tides. The rain fed coastal saline areas are mainly used for growing kharif rice during the monsoon period when soil salinity is low. Paddy cum brackishwater fish culture is a short term brackishwater aquaculture along with production of khariff paddy crops. Such practices are adopted in the upper and middle stretches of estuary in West Bengal where salinity is either low or lowered by frehwater discharge diluting the tidal water.

Plot selection

Most of the coastal area is low lying. The farm for rice cum fish culture is selected in such a site that desirable water level may be maintained during low and high tides and frequent draining of monsoon water during desalination process. The sluice in the embankment is essential for regulating the flow of tidal and drainage water. Availability of seeds for commercially important species of fish and prawns is another important criteria for this type of fish farming.

Plot design

Construction of an earthen dyke surrounduing the paddy plot is essential for retaining water and also holding the fishes and prawns during the culture period. A perimeter canal is necessary on the inner periphery of the plot. For one hectare paddy plot, the width and depth of canal may be about 2 m and 1 m, respectively. In addition to the perimeter canal, two cross trenches of about 1 m width should be constructed at both the directions which will join the perimeter canal in opposite directions (Fig 3). The bottom of the trenches should be above the perimeter canal so that the water can be drained into the canal during the course of desalination. Entry of tidal water is made through the feeder during high tides and some box type sluice gate

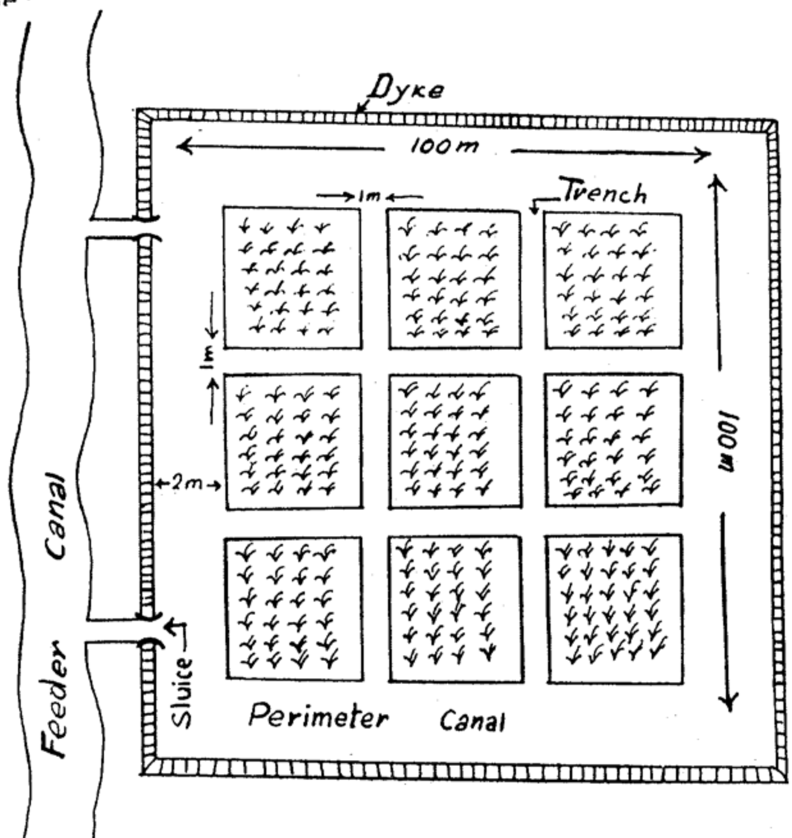


Figure 3 : Design of a paddy-cum-brackishwater fish culture plot (1 ha)

Selection of fish

The brackishwater fishes like *Liza parsia, Liza Tade, Rhinomugil corsula, Lates calcarifer, Mystus gulio, Macrobrachium rosenbergii, M. rude, Metapenaeus brevicornis, M. monoceros, Penaeus monodon* are cultivated.

Management of paddy fields for aquaculture

During summer months, short term brackishwater aquaculture may be undertaken as rotational crop. The water salinity should be between 10 to 40 mmhos/cm. Intake of brackishwater must be suspended before the onset of monsoon, the culture species harvested, and then the land should be exposed to monsoon precipitation for the purpose of desalination. The transplantation of khariff paddy seedings is done. After some days of transplantation, fingerlings of freshwater fish and prawns are released into the plot to obtain second crop of fish along with paddy. As benthic animal are more dominant, release of greater abundance of benthic fishes should be done.

Generally paddy is harvested by the end of November. Freshwater aquaculture may be extended further up to December depending upon availability of water. After this, the plot is dried completely and prepered for the next crop of brackish water aquaculture.

8.3 Integration of livestock -fish culture -methods

The fish culture integrated with husbandry of most domesticated animal such as duck, pig, cattle, chick, sheep, etc is most important as they are considered as living fertilizer factories and involve various forms of integration with fish farming. In this system, it is necessary to enclose the live stock quarter adjacent to the pond, considerable quanities of wastes from poultry, duckery, piggery, and sheep farming are available. Within the system of integrated farming the types of live-stocks to be raised with the fish depends on the compatibility of the species of the live-stocks and their biologcal habits with the fish stock in ponds. In this culture system, excreta of ducks, chicks, pig and cattle are either recycled for use by fish or serve direct food for fish and thereby reducing the cost of fish production.

(a) Duck and fish farming

The integrated management of fish-cum-duck, specially raising of duck on the surface of fish pond has been found to be economically efficient farming practice which have been adopted in many countries for several centuries. Of all kinds of animal integration, duck cum fish farming has not only the best economic profit, but also demonstrates the close integrated relationship. The compatibility of ducks and fish has long been recognized as it is a means of reducing the cost of feed for duck and convenient and inexpensive way of fertilizing pond for the production of fish food.There is a symbiotic relationship in duck cum fish cuture practice.

Ponds

The barrage type of ponds, made by damming shallow valleys, are most suitable for duck/fish farming, as the ducks can lie on natural slopes.

Good quality duckling is very improtant for successful farming. The ducklings produced from dependable source are ready for release into fish ponds in 14-20 days depending on weather conditions. The rapid growing strains of duck may reach marketable size when become 42-58 days old. During the period about 5 weeks when the ducks are on the ponds, 300 - 500 ducks per ha may contribute about 2.1 - 3.5 tons of droppings in the ponds.

Duck house

There are two basic ways of keeping ducks on fish ponds. One is to allow them free access to the whole pond area and the other is to confine them in enclosures. In the former, a good proportion of their droppings fall directly into the pond in a more or less uniform mannar. The ducks are able to forage around the whole pond for food organisms. However, considerable energy is used up by ducks for swimming around and this may affect the growth rate and feed conversion of the animal.

In the second case, some selected strains are confined in enclosures for maximum growth. Wire fences are built on adjacent part of the bank and suitable feeding and resting areas are provided. About one quarter of the enclosure will be on land and the rest in water. Some of the droppings fall directly into pond, and the rest have to be washed into it.

Density of ducks

About 300 - 500 ducks are raised per ha of ponds during the summer season in East European countries, but they are raised on fish ponds throughout the year in tropical countries. The breeders are selected after the first egg laying, which starts when the ducks are 6-7 months. The ducks are fed at the rate of 9-10% of body weight per day with protein rich diet. About 120-140 eggs are produced per female per year.

In some countries ducks (2000-4000/ha) are raised for over two years. The egg laying ducks start producing eggs in 4-5 months and continue to lay for two years, after which they are sold. Each duck lays about 250 eggs per year.

Selction of fish

In duck cum fish culture practice, the common species of fish used are herbivorous and omnivorous fish. As the nutrient rich duck manure enhances both phyto and zooplankton production, phytoplankton feeding silver carp and zooplankton feeding Catla and common carp as omnivore are suitable for farming.

Fish yield

In duck yield per ha of 500 - 600 kg silver carp, 150 - 200 kg bighead carp and 1000 - 1200 kg common carp of marketable size is very common. Under a stocking density of 20,000/ha and culture period of 90 days, a fish production of 2000 kg/ha has been achieved. Duck production is about 1000-1200 kg (each weighing 2 - 2.4 kg).

(b) Chick and fish farming

The integrated fish farming with chicken is also promising. Integrated farming of fish and chicken is popular in Indonesia and to some extent in Thailand. The droppings of chicks are rich in nitrogen and phosphorus and is therefore very efficient fertilizer for fish ponds. Chickens can be housed over the pond using the bamboo poles, the droppings can directly can fall directly on the ponds and act as fertilizer for increasing the fish food organisms.

Stocking density of chicks

The humber chicks that may be used for raising fish per ha vary from 250 to 300/ha depending upon the variety and location of the farm. In some case with high stocking density of fish, chick density may be up to 4000/ha.

Selection of fish and stocking density of fish

The same principle of composite culture is followed for species selection in chick and fish farming. The species are algae feeder, plankton feeder, benthic animal feeder, detritus feeder, etc. Indian major carps, such as catla, rohu, mrigal and exotic carps like silver carp and common carp are stocked for culture. Freshwater prawn can also be introduced as a candidate along with other species of carp species. In some cases, tilapia and murrels are also introduced for culture. The stocking density of fish fingerlings/ha is variable and it ranges from 5000-20,000/ha.

Fertilizer and supplementary feeding

As the principle of fish farming integrated with the use of excreta produced by other animals integrated with fish raising, no chemical fertilizer or manure or supplemental feeds have to be given at any stage in order to reduce the cost of production.

Fish yield

It is reported that by stocking 5000 giant freshwater prawn *Macrobachium rosenbergii* and 1500 silver carp in one hectare area, it is possible to harvest 600 kg of prawns and an equal amount of fish in a four month culture period with a density of chick 250/ha.

(c) Pig and fish farming

In fish farming integrated with pig, it is a common practice to have wider embankments in fish ponds to facilitate the construction of pig house and also planting of fruit trees, vegetables and other crops. The numbre of pigs reared may range from 45 to 100 pigs which are is enough for one hectare water area. The avarage production of manure per pig is around 7.8 - 8 tons per year. However, the output of manure depends on the size and age of the pig. Considering 45 - 90 pig/ha, the output manure amount to 351 - 600 tons / ha per year. In Taiwan, even higher rates of 150 - 300 pigs/ha are maintained taking proper care to prevent pollution of water and mortality of the stocked fish.

In practice, the wastes are conveyed to a specially built tank, where sedimentation and fermentation of manure takes place. At regular intervals, the supernatant liquid from the tank is allowed to flow into the ponds. The sludge than remains in the tank is removed periodically for fertilizing agriculture crops. Thus, the loading of decomposable organic matter in the ponds is reduced.

Feeding of pigs

In the pigs integrated farms are fed with feedstuffs produced on the farm. The aquatic plants such as water hyacinth, *Ipomoea, Pistia, Walffia, Lemna* and *Azolla* may be grown in the adjoining water bodies of the farm. The foliage of several terrestrial plants such as vegetables, corn, rice and leguminous plant are used as feedstuff. Sometimes, these plant materials are mixed with rice bran, banana coconut meal, soya bean wastes, fish meal, etc. for feeding the pigs.

Selection of fish

Fish like grass carp, silver carp and common carp (1: 2:1) are suitable for integration with pigs.

Feeding of fish

Pig dung contains 70 per cent digestible feed for fish. It is stated that feed while passing through the alimentary canal of pig, gets mixed with certain enzymes which continue to act even after defecation. The undigested solids present in the pig dung also serve direct food source to tilapias and common carp.

Duration

The duration of culture of fish and pigs varies, but generally it is about one year.

Fish yield

The fish yield may vary from 2 - 18 tons/ha per annum. The pigs are generally sold when about 90 - 100 kg in weight.

Economics

The overall economics of pig cum fish culture depend on local conditions. It is stated that adoption of such integrated farming increases the productivity per area and input and also increases the farmers income by factor of 2 or more.

(d) Chick-pig-Fish farming

For a better utilization of droppings from chicks as a feed of pigs in an integrated manner, a modification of integration has taken place in a two tier system. The upper panel is occupied by chicks and the lower panel by pigs (Fig. 4). In this system, chick droppings are directly used as feed of pigs, and pig manure finally fertilize fish ponds. The urine and pig dung are conveyed to a oxidation tank for production of methane for household use. The liquid slurry is then discharged into pond through small ditches runing through pond bunds. Alternatively, the pig manure may be heaped in some location of the pond or may be applied in fish ponds by dissolving in water.

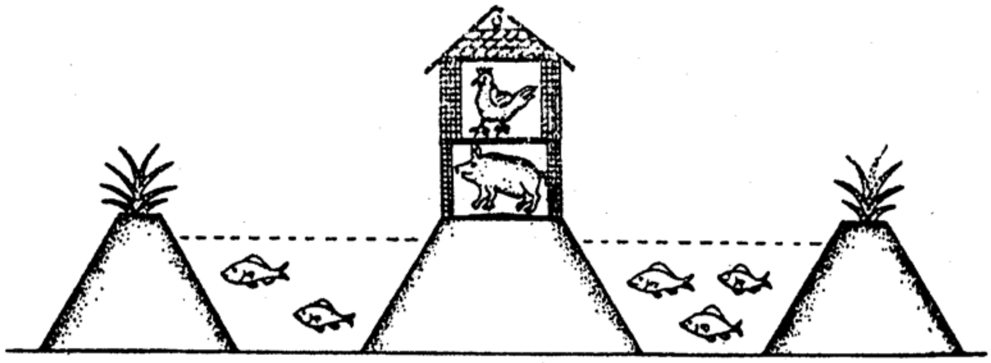


Figure 4 : Model showing poultry-pig-fish culture

A density of 60 - 100 pig has been found to be good enough for pond of one hectare area. The optimum dose of pig manure per hactare fish pond has been estimated as 5 tons/year.

Fish yield

Fish yield of 3000 kg/ha can be obtained under a stocking density of 5000 fingerlings/ha in a culture period of six months.

(e) cattle and fish farming

The same principle which is applicable to integration with pigs, chicks or ducks, may also be adopted for cattle fish farming integration.

It is necessary to construt cow sheds in the vicinty of fish ponds and the slurry from the biogas plants may be discharged into the fish ponds. This has become very popular in some countries like Hong Kong, Taiwan, Philippines, etc. In China, the cattle sheds are situated very near to the fish ponds and wastes and washings from the sheds are conveyed through pipes directly into fish ponds.

In many farms in China, mulberry plants are grown on fish farm dikes for silkworm production. The mulberry wasted and silkworm pupae waste are used to feed the fish directly, and also serve partly as fertilizers for the ponds.

When coconut and banana are cultivated in rows in wetlands, the ditches erected between such rows act as supply or drainage canals. These canals serve as fish culture system. Larvivorous fish species such as *Channa striatus C. marulius* and *Oreochromis mossambicus* are suitable for culture.

A unit of 5-6 cows can provide adequate manure for one hectare pond. In addition to 9000 kg of milk, about 3000 - 4000 kg fish/ha/year can be harvested with such integration.

Farming of other animals in association with fish

Integration of fish farming is also possible using other domestic animals like goat, rabbit, etc. In Indonesia and in some places in India on experimental basis, goats are also used for integration with fish culture. Goat excreta is a good organic fertilizer with 60% organic carbon, 2.7% nitrogen, 1.78% phosphorus, and 2.88% potassium.

An adult goat weighing 20 kg may contribute 300-400 g excreta per day and about 50-60 goats are needed for a fish pond of one hactare area. It is also reported that rohu and mrigal grow well when pond is manured with goat excreta. This integration can produce 3.5-4 tons/ha/year of fish with supplementary feed or input of fertilizers in addition to goat meat.

Though not popular, rabbits are also integrated with fish culture. Rabbits are reared in cage, hutch and floor systems. It is stated that rabbit excreta, low in moisture and high in nitrogen content, is quality manure for sustained plankton production and therefore useful in fish culture.

However, these practices are still under experimental trails and would require time for commercial application.

Unit 9 ❐ Innovative Culture Methods

Structure

9.1 Culture in Recirculatory systems

9.2 Cage and pen culture

9.3 Wastewater recycling through aquaculture

9.1 Culture in Recirculatory systems

Culture methods adopted for fish culture may have a wide range of variations basically depending upon the stocking density and species cultured. Culture in recirculating system has been evolved to intensify stocking density per unit area, mimimize space and water requirements, providing maximum protection against fish disease and maxmimizing fish yield per unit area. This approach is most important towards conservation of water which is one of the most burning issues of the present day.

Basics of recirculation system

Basically it is a closed system with facilties of water being reused and, therefore saving water for aquaculture. Because of more stringent environmental laws and regulatory mechanisms, the farmers are inclined to utilize environment-friendly technologies like recirculating systems in aquaculture.

Recirculating aquaculture systems provide a rearing medium that is constant and adjustable, with only slight and slow variations. Desirable water quality such as : temperature, oxygen, nitrogen, pathogen-free water can be achieved through the recirculating system in such a way that more intensive and reliable production may be obtained. At the same time, it leads to significant savings in energy needs. The reciruclatory system has been gaining considerable importance in recent years.

There are several kinds of recirculating units depending upon the purpose. They may be installed in the indoor as semiclosed system or in the outdoor water recirculatory system. Naturally there are some modifications required to meet the demand of the unit. The indoor culture units are basically used to examine the physiological performance of fish, whereas the outdoor system is mainly for commercial production of fish.

Principle

The principle of this method is based upon using a limited quantity of water for fish culture by means of recirculation and oxygenation and at the same time removing the metabolic wastes of fish such as ammonia, carbon dioxide, etc.

The recirculatory system is of two types (i) indoor system and (ii) outdoor system. While the former is used either as fish nursery or experimental system for physiological or growth studies of fish under laboratory conditions, the latter is used as commercial fish nursery for culturing fish under very high stocking densities for obtaining maximum yield per unit water area.

Unit components

The recircularory system unit consists of the following components. Certain modifications and advancement of the system are, however, possible with inclusion of some additional components that may be necessary for its efficient functioning. The basic components are :

(a) Reservoirs

(b) Biological filter (biofilter)

(c) Culture tank

(d) Settling chambers

Reservoris

Basically there are two reservoirs in the recirculating unit. Further modifications are done depeneding on the degree of treatment required for the culture of value added fish. For example, some more reservoirs may be added in between the reservoirs with a view to enhance the efficiency of effluent treatment which is essential for the culture of certain valuable and sensitive species.

In principle, water from culture unit is allowed to enter into a primary settling chamber for settlement of solid materials (Fig. 1). The water is then passed into the biofilter (Fig. 1) where ammonia is nitrified into nitrite and nitrate through nitrifying bacteria. The nitrification is highly oxygen dependent. It also removes other toxic substances that may be present in culture water. The biofilter is typically followed by a secondary settling chamber where all dead organisms and organic matters are accumulated. From secondary settling chamber the treated water is returned to the culture chamber. When further reclamation of aquaculture effluents are necessary, a tertiary treatment chamber is provided for further reduction in the level of nitrate, trace elements, etc. A UV sterilization chamber is also required for treatment of water discharged from tertiary chamber. In more advanced recirculating units, ozone is injected into the inflowing water that enter into the fish culture unit (Fig. 1).

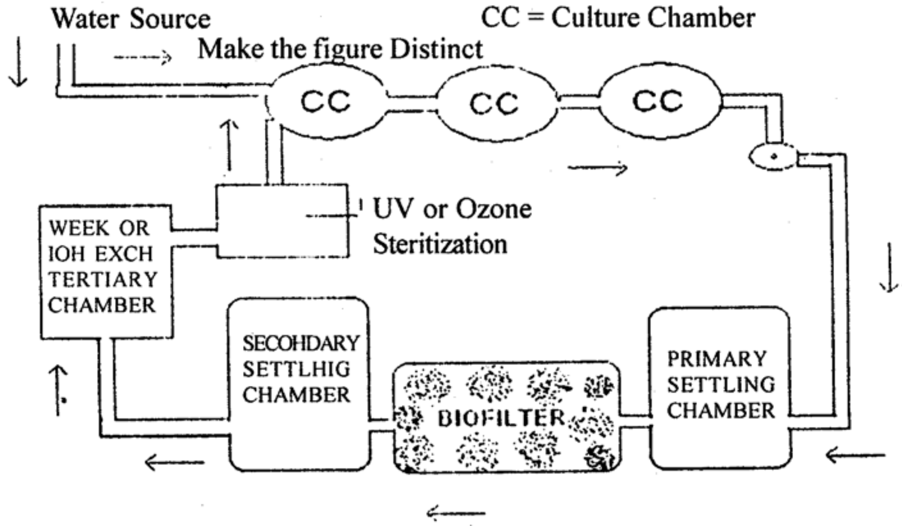


Figure 1 : Components of recirculatory system

Culture tank

Fish culture units may be closed, semi-closed or open type. Typical culture tanks are either circular tanks or linear raceways. These units are either concrete, fibre glass, plastic and metal sheets (aluminum or stainless steel). The water volume of the culture tank may vary depending upon the specific purpose. In most cases, culture tanks are less than 10 m in diameter and seldom exceeded 1 m water depth. Circular tanks have an advantage over rectangular tanks due to uniform water flow and better maintenance of water quality.

In linear receways, water enters at one end and is discharged through the outlet. A ventury drain system can be used to avoid dead space, but solids will tend to settle throughout much of the long axis unless flow rate is quite high.

In advanced model, each recirculatory system may have several culture tanks connected with each other and also with the main component of the system. It is economically profitable to have more culture tanks in each unit as cost of operation will be reduced in such cases.

Settling chamber

Water containing particulate from culture tanks is passed into the settling chamber for sedimentation before entering into the biofilter. The rate of water exchange is kept as low as possible to affect sedimentation. Settled solids are generally uneaten feed, faeces and bacterial load. Solids settled in the bottom are taken out through a valve set at bottom for the purpose.

Biofilter

The water from the settling chamber is passed into a biofilter chamber set with a bed of gravel or sand. The purpose of this chamber is to promote oxygen dependent nitrification via nitrifying bacteria which are present and colonize on the wall of gravel and sand particles. These aerobic bacteria perform nitrification in presence of oxygen.

Various modifications of biofilter are now available. These are basically to increase the efficacy of biofilter for improvement of water quality.

Secondary settling chamber

Water leaving a biofilter contains a lot of organic matter in the form of dead bacterial flock that occurred in the biofilter medium. Removal of this dead bacterial flock is done in the secondary settling chamber that helps to keep the water clan in the culture tank.

Tertiary treatment

Water leaving the secondary settling chamber still may contain high concentrations of certain nutrients like phosphate, nitrate, and micronutirents. Water hyacinth *Eichornia crassipes* is used to remove excess nutrient from the water coming from secondary settling chamber.

UV or Ozone sterilization

It is also necessary to kill all the pathogens that are present in the water and also to increase the level of oxygen required for fish growth in the culture tank. For this reason, water is sterilized using UV sterilization system and ozone treatment. This is done at the dosage of 0.56 to 1.0 mg/1 ozone for 1-5 minutes. Aeration assists greatly with the conversion of ozone to molecular oxygen.

Indoor water recirculating system

The unit (Fig. 2) consists of two reservoirs — upper and lower, each of about 1000l capacity placed one above the other. Water from the upper reservoir flows into a small and shallow container which is exposed to ultraviolet rays for killing the pathogenic microbes of the inflowing water. The water is then transferred by gravitation to experiments troughs through the main pipeline drawn from the UV lighter chamber. Each trough is provided with a wire-mesh cover at the top and an outlet at its back about 5 cm from the top. Water flows at a desired rate of 2-3 liter/min from the tap into each of the troughs. It is oxygenated by difusion through atmospheric contact, while the water splashes into the troughs. The overflowing water from fish containing troughs into the lower reservoir through another pipeline. The lower reservior is provided with a biological filter where ammonia is transformed into nitrate via nitrite. The filtered and ammonia free water is then collected into the bottom part of the lower reservoir from where it is pumped into the upper reservoir using 1/20 HP motor.

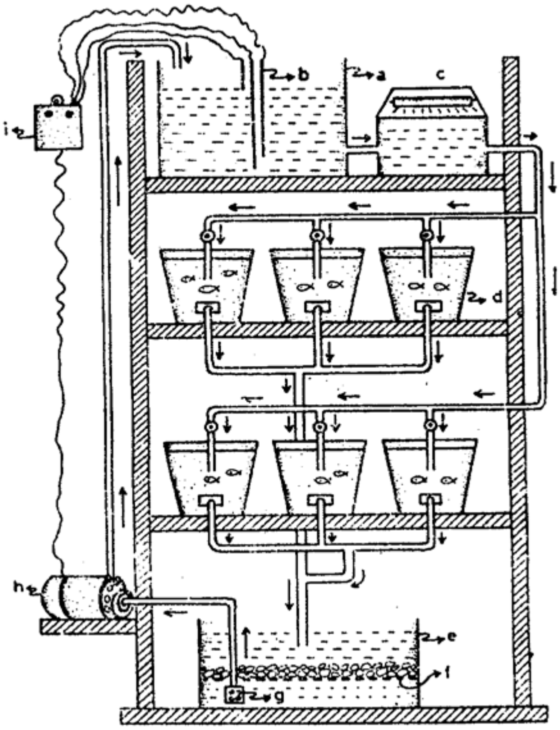


Figure 2 : Indoor water recirculation system
(a) Upper reservoir; (b) Probes; (c) U.V. Chamber; (d) Experimental trough; (e) Lower reservoir; (f) Biological filter; (g) Foot valve; (h) Pump; (i) Water level controller

A constant water level controller is connected to prevent overflow of water and also to maintain a constant supply of water to the troughs. The controller has two probes of different heights to monitor water levels at the highest and lowest levels of water in the reservoir, besides a neutral probe. There is automatic system to maintain the water level at a constant level.

An advantage of the indoor system is that high quality water could always be maintained. The most important water quality parameters such as dissolved oxygen, ammonia content of upper reservoir are kept at desired level for fish culture at > 5 mg/1 and < 0.2 mg/1, respectively. Under such condition, high stocking density of 2500 fry/m^2 or 100 fingerlings/m^2 could be maintained. The survival rate of fry is very high and may be up to 90% against 15-25% in conventional system. As a result, growth rate of cultures species could by enhanced, if supplementary feeding using protein rich diet is practiced.

Outdoor water recirculatory system

The principle of this system is similar to that of indoor system. In general, the unit consists of four tanks of which two are used for fish culture, one for upper reservoir and the rest for lower reservoir. However, certain modifications can be made according to the requirement.

Biological filter is set up on a basal porous partition on the left side of the upper reservoir (Fig. 3). Filtered water from the biofilter flows into different culture tanks through a cascade (corrugated surface) by gravitation. The water is well oxygenated by splashing while water is flowing downwards. The inlet and outlet devices are provided to maintain the desired water level in fish culture tanks. The overflowing water from all the culture tanks is collected in the lower reservoir where coarse particles are settled. The water from the lower reservoir is then pumped up by 1/4 HP motor into the right side of the reservoir.

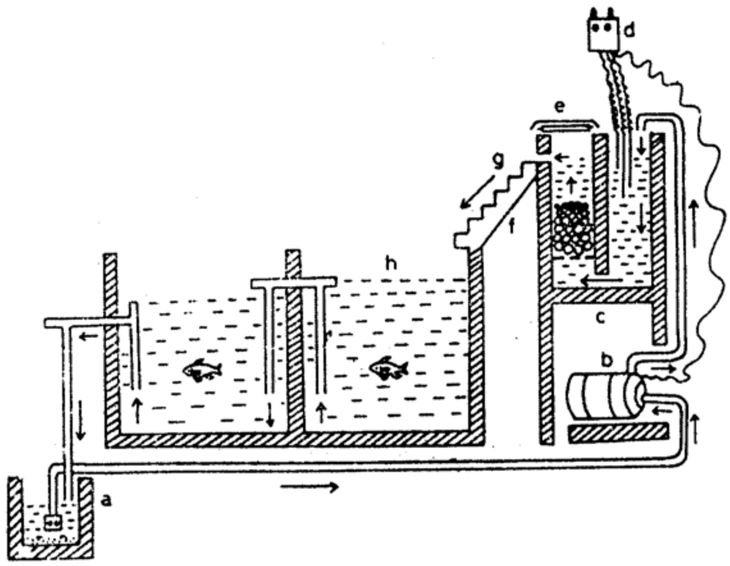


Figure 3 : Outdoor water recirculation system
(a) Lower reservoir; (b) Pump; (c) Upper reservoir; (d) Water level controller; (e) U.V. Light; (f) Biological filter; (g) Cascader; (h) Fish tank

Benefits

Under this culture system. high stocking density of fish is possible and thus the fish yield can be enhanced per unit area. The general problems of fish mortality and disease that are most common in natural nurseries can be solved in the recirculating system and therefore more profitable. More important is water conservation by repeated use of small volume of water in aquaculture practice.

9.2 Cage and pen culture

Pens and enclosures

Pens are fenced enclosures or a confined bay where the shoreline is typicaly closed off by a net or a screen barrier on all sides except the bottom so that water circulates freely between the pen and water body. The bottom of the pens is bound by the bed of water bodies where it is placed and thereby providing a natural habitat of the water bodies. Pens are somewhat transitional structures between ponds and cages used for the culture of finfish and shellfish. Pen culture is of considerable importance and useful in large and suitable watersheds where management is hardly possible for fish culture. The design of the structure and its operation are strongly influenced by the water quality, floods, waves and currents, prevalence of predatory animals, etc.

Though pens and enclosures are often considered as synonyms, there are some differences between the two; enclosures refers to a natural ecosystem with provision of barrier screen in both ends of the canal, arms of the sea (Fig 4), estuary or river, whereas pens are fenced enclosures created among the margins of watersheds for the culture of finfish and shellfish. However, the terms enclosure, pen and case are virtualy synonymous and sometimes referred as enclosures.

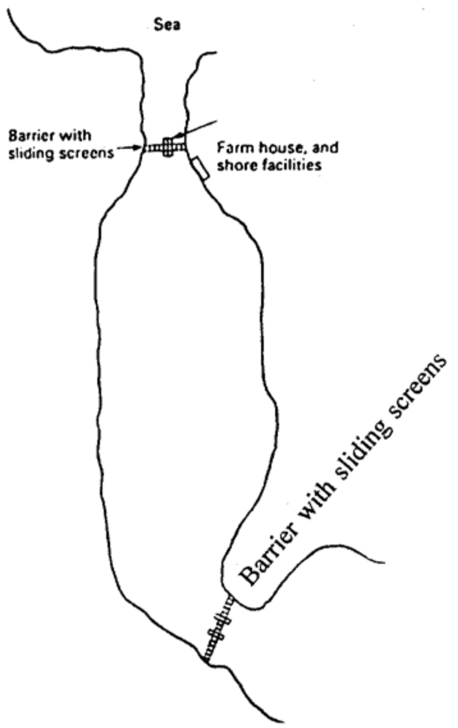


Figure 4 : Diagram of an enclosed arms of the sea

Pens are installed in flat or slightly sloping bottom with muddy clayey loamy soil substratum of about 50 cm and water depth of 1.2 m during the growing period of 4-6 months. Pens are normally small units and arranged in the order of tens.

The method of erection of pens can be of two types : (i) on wet ground with water column and (ii) dry surface where submersion up to 1.2 m is expected.

Pen size and shape

The individual pen segment may be of any shape and of varying sizes. The supporting structure is constructed by strong poles (length 2.5 m; diameter-30-40 mm) into bottom, fixed 1.5 m apart, and braced with long and straight split-bamboo horizontally at every 30 cm height from gound level.

Small pens are better than larger ones as they can be managed in a better way, but the bigger pens facilitate better growth of fish and is more profitable as they support more fish biomass per unit cost. It is suggested that pens measuring 500 m^2 are found to be both economical and manageable.

Pen structures

Pens are constructed enclosures with a rigid framework using the materials that are strong and durable enough to hold collective weight of fish stock and allow unrestricted exchange of water between pen and water body. Generally, materials used for screen and other accessories should be: strong, light, rot, corrosion and weather resistant, fouling resistant, repariable, non-abrasive to fish or cultured animals, inexpensive and easily available. The materials used are polyurethane/polystryene foam filled plastic and synthetic rubber pipes. Sometimes, galvanized steel and aluminum alloy pipes are used for strength of the structure. Under Indian conditions, it is very cheap and useful to construct the pen structure from wood or bamboo which serves as the rigid framework for maintaining the shape and supports the weight of the structure. Using bamboo scaffolding, pen structure of diferent sizes has been made in the lakes in China (Fig. 5). Rigid PE pipe is commonly used in European countries.

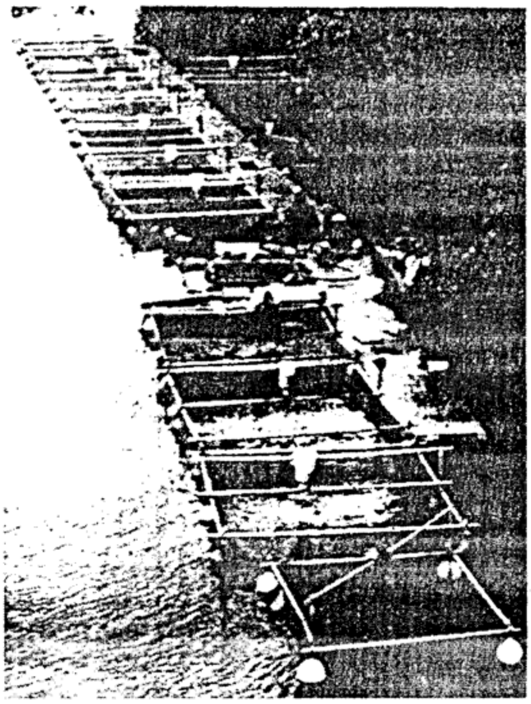


Figure 5 : A series of cages moored to a jetty along the shore

Pen screen structure

The screen materials required for pen construction are fencing screen of suitable materials, like bamboo and wooden poles to support and hold pen screen in position against water current, wind and wave actions. The screen materials should be resistant to crabs and other animals and easy to handle and support. HDPE mono-filament webbing materials are commonly used as the materials that are resistant to damages by crabs, sunlight, saline water and other stretching tension.

In a dry pen, a trench of 30 cm wide and deep may be dug, having 50 cm pits at every 1.5 m distance for firmly driving poles into bottom soil before the onset of monsoon.

Construction of pens

A suitable area of 500 m is demarcated and bamboo poles (5-8 cm dia) are driven into the beel or jheel bottom after every 1.5-2.0 m length. At least 50 cm of poles should remain above water surface. The main frame of the pen is made by tying half split or full bamboo (5 cm dia) on to the poles. The screen for encircling the pen is made by weaving split bamboo strips (8-10 mm thickness) with coir ropes. To prevent movement of fishes to and from the pens, cheap polyethlene mosquito netting is stitched into the inner wall of the split bamboo screen. Additional support may be provided to the pens in some water bodies that are exposed to strong winds or water currents or where the height of screen exceeds 2 m.

Pen culture in beels of Assam

Pen culture in practiced in some places of India particularly in large beels and jheels of Assam. Most of these water bodies remain unutilized for the lack of knowledge of scientific exploitation of fish culture. Pens and cages are suitable methods for using these large water bodies for economic activities of fish farming.

Site selection

Selection of suitable site is important for the success of pen culture. A gently sloping site having water depth of 1-2m at least for 4 months is selected for pen culture in the beels of Assam. A mild water flow in the site without strong wind and wave action is preferred.

Culture period

The rainy season and winter months are not congenial for pen culture. It is practiced in the beels of Assam during September to December and from February to May.

Pre stocking management

It includes cleaning of macrophytes within the pen. This is followed by removal of perdatory and weed fishes by repeated netting with small mesh sized nets. For correcting the soil acidity, lime should be applied with quick lime@ 500-600 kg/ha based on the pH of water.

Stocking

Though the scientific data about the stocking density and ratio of species cultured is hardly possible, by experience, it is recommended that for Indian carp polyculture, the fry of mrigal, rohu and catla should be in the ratio of 1:2:3 For fingerling production, carp fry (4-6 cm long) are stocked @ 20,000 - 30,000/ha. For growing table fish, carp fingerlings (8-10 cm) are released @ 8000-10,000/ha.

Post stocking management

The stocked fishes are given supplementary feed @ 4-5% of the total body mass using rice bran and mustard oil cake mixed in equal proportion. It may be applied in the form of soaked balls that may be kept in submerged feeding trays made of bamoboo to minimize wastage and to observe feeding intensity. Fishes are fed twice a day at a fixed time of the day (8 am and 4 pm). The fishes should be periodically checked for growth performance. Submerged and emergent macrophytes should be cleared at regular intervals. It is also recommended to apply lime, if necessary, at periodical intervals.

Harvesting

The fishes are harvested after rearing for 3- 4 months. Average fish production of about 200 kg/ha in 4 months has been recorded.

Economics

It is estimated from the cost benefit analysis that approximate total expenditure for fish culture in 500 m^2 pen is Rs. 3200 yielding gross return of Rs. 6282.00 and a profit of Rs. 3022.00 in 4 months.

Cages

Cages are basically similar to that of pens, the cages are extensively used in vast water areas like oceans and lakes, beels and large reservoirs where management for fish culture is hardly possible. The fish rearing cages are of serveral types such as cages resting on bottom, submerged cages and cages floating at water surface. The later ones are mostly used in vast oceans, lakes, etc.

Hodling or rearing fish in cages is a traditional practice in some Asian countries. Initially it developed as a practice to hold the commercially valuable fish in bamboo cages to be sold alive. The cages were trailed in water behind a fishing boat for transport to the markets. With advancement of knowledge it has now developed for long term rearing of various commercial fishes like catfish, carp, yellowtail, grouper and sea bass in several Asian countries. In some countries, it has become a major source of aquaculture production espcially high valued species like salmon, trout, sea bass and groupers. This is gaining importance the world over for intensive exploitation of fresh, brackish water and marine resources.

Cage structure

Several types and designs of cages and cage farms have been developed during the last two decades. Depending on the need, various shapes and sizes of cages have been used successfully.

In most cases, they have a collapsible frame structure to hold cage bag in shape, and screen is of nylon or other synthetic webbing of various mesh sizes. The bags are fitted to upper rigid framework and are made up of plastic mesh or nylon netting. Nets generally extend one meter or more above the waterline all round the cages to prevent the fish from escaping. On the top of the cage, bird netting is also placed to prevent predation by fish eating birds and other animals.

Different types of devices such as empty barrels, HDPP jerry cans or tight PVC pipes, fiberglass or Styrofoam floats are used as buoys to keep cages afloat. A bamboo framework floated by empty oil barrels, is built around a battery of cages or they are freely floated with plastic cans in mid water with some mooring device. It is preferable to moor cages to a jetty with direct access to a quay (Fig. 6)

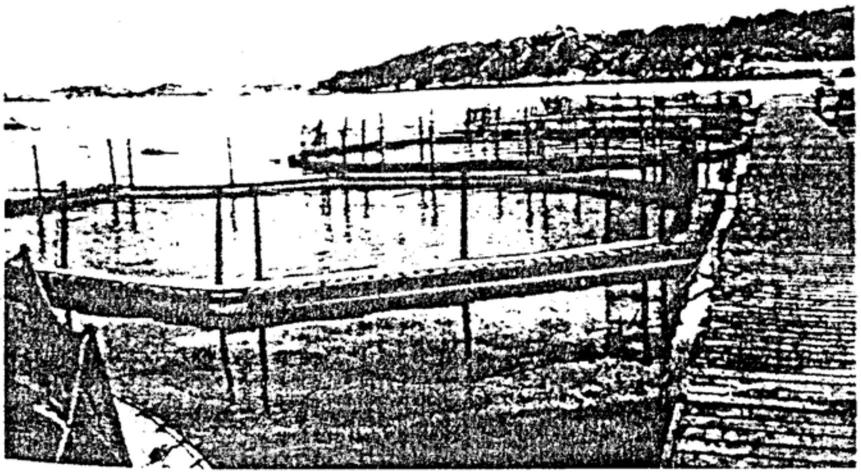


Figure 6 : A cage farm in Norway. Note the hexagonal cages with wooden framework moored along side a walkway from a jetty

Construction of cage frame

Empty PVC or metallic drum (200-250 1), 13 m long bamboos, nuts and bolts are required to construct cage frame. Twelve floats should be placed longitudinally 3 m apart in 3 rows on a clear area of about 150 sq m near the bank of the water body. Now 13 m long bamboo poles are placed in parallel manner, 153 m apart over the drum and tie them temporarily with coir rope. Another 3 pairs of same size bamboo poles are placed maintaining the same gap. The bamboos are now drilled and tied them with each other with nuts and bolts. Bamboos are placed over the floats in such a manner that tightly holds the float in the gap.

For raising fry to fingerlings, good quality nylon net having 1 mm meshes size is used. A convenient net cage should be of 6 m × 3 m × 1.5 m. This net cage is then fitted into the cage frame constructed. A top cover is also prepared to prevent predatory birds and reptiles and also escape of fish by jumping.

Cage setting

The prepared cage is now gently dragged into the water. The rectangular bottom frame made of split bamboo is then fitted with bottom frame by nylon rope. It is now kept in the selected site and tighly fastens floats with frame using iron wire. It is required to anchor the cage with bottom poles.

The cages are now ready for fish stocking. It is suggested to stock the fish after a week as periphyton growth on cage wall may prevent bruising of young fish's tender skin by rough surface of the net.

Stocking

As a general practice, it is to stock at the density of 550-750 fry per cage of 18 cubic meter (6 m × 3 m × 1 m) @ 3-4 lakh/ha. Indian major carps like catla, mrigal rohu and minor carps such as reba, bata, gonius, calbasu in addition to grass carp, common carp and java punti can be stocked. Fry of 1-1.5 cm size are stocked in fine mesh net cage and reared up to advanced fingerling stage (10-15 cm)

Post stocking management

In general, post stocking protocols in cages followed are the same as the of pen culture. The stocked fishes are fed with conventional feed mixtures of rice polish and mustard oil cake (1:1) at the rate of 4% of the total body weight of fish. The ration level should be readjusted every 15 days on the basis of increased fish biomass, as the fish grows bigger. Feed should be given in a tray, feed twice a day, usually in the morning and afternoon at fixed time preferably 8.00 am and 4.00 pm.

Harvesting

Fishes are grown to advanced figerlings size (10-15 cm) within 2 months. The culture period may be extended to 2-3 months for table size fish proudction. In that case, it is also necessary to use bigger mesh size (1 cm) net to facilitate better waste removal. Nylon net of 1 mm mesh may be used at the bottom.

Production cycle

Same fish can be used for several crops in a year. Fingerling production should start with the availability of fry during April. Three crops of advanced fingerlings, after every 2 months of rearing, can be obtained during April to October. A crop of table size fish can be obtained by rearing for 5 months from November to March.

Economics

It is based on the fact that nylon cages shall last for 2 years and floats for 5 years. Therefore, three crops of advanced fingerling and one crop of table size fish can be produced in a year. Calculating the total capital investment and recurring expenditure, it is possible to obtain net income from first year Rs. 25,225.00, from second year Rs. 40,025,00 and total income for 2 years is Rs. 62,250.00

9.3 Wastewater recycling through aquaculture

Definition

Domestic wastewater is defined as a cloudy fluid containing mineral and organic matter either in solutions or particles of soild materials floating or in supspension or in colloidal or in pseudocolloidal form in dispersed state. The domestic sewage is the main source for wastewater that can be recycled and reused for aquaculture.

Wastewater generation

Rapid growth in population and urbanization resulted in sharp increase in generation of sewage. About 26,254 million litres of sewage is generated every day from 921 cities/towns of India.

Composition of wastewater

Wastewater generating from municipal sewage, soft agro-industries, agriculture, industries and other sources contains a vast array of essential nutrient elements and hence may be considered as a store house of fertilizers. The composition of wastewater may vary depending upon the source of origin. In general, the water content of domestic sewage is about 99 per cent and the rest consists of organic and inorganic constituents. The organic constituents are the main component comprising 75% of the total quantity. THe common gases and salts present in sewage are carbon dioxide, hydrogen sulphide, ammonia, nitrite, nitrate and phosphate. The biological constituents of raw sewage are various microorganisms like bacteria, viruses, protozoan cysts, yeasts and other moulds, algae, eggs of helminths, etc. and they may pose a threat on the ecosystem health.

The heavy metals present in traces in industrial efflents are zinc, copper, chromium, manganese, nickel, lead, mercury, pesticides, insecticides, etc which pose serious eco-toxicological risk and health risk on human beings. Some pharmaceutical drugs found in traces are also harmful to aquatic flora and fauna. The persistent and non degradable toxicants are particularly harmful as they may cause bioaccumulation and biomagnification in the aquatic animals through grazing and detritus food chain and eventually affect the human health in the long run.

Sewage treatment

Because raw sewage is rich in organic load and thereby anaerobic in nature, the raw sewage is not suitable for direct application in fish growing ponds. Therefore, it is essential to treat the sewage before being applied in fish growing ponds. The following methods are used to treat the sewage for fish culture.

(a) cascading sewage through a series of ponds

(b) filtration of sewage in two stages followed by sedimentation

(c) aeration of sewage

(d) dilution of sewage with freshwater (one part sewage with 4-5 parts of freshwater)

Among these treatments, treatment of sewage through stabilization is easier and more effective than other methods. In this method, the sewage is treated in the oxidation pond (Fig. 7) as follows :

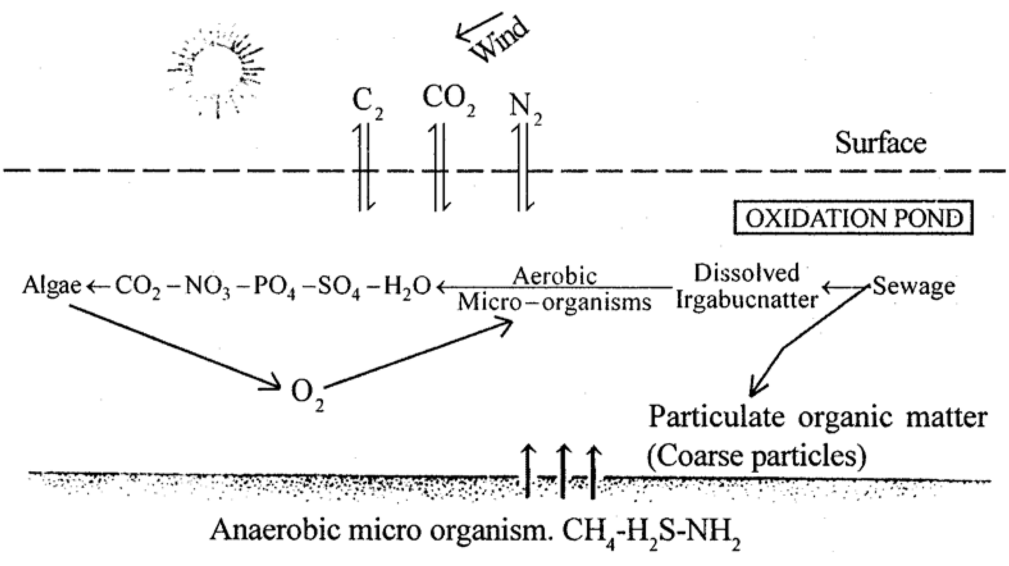


Figure 7 : Processes involved in sewage treatment in oxidation pond

Sewage is stagnated in oxidation pond at least for 10 days to allow the particulate matter to settle down in the bottom of the pond. In the mean time, the dissolved organic matter is decomposed by aerobic heterotrophic microorganisms resulting in the release of inorganic elements like phosphate, nitrate, sulphate, etc. The settled particulate organic matter at the bottom is also partially degraded into various organic gases like methane, hydrogen sulphide, ammonia, owing to limited availability of oxygen. Some other modifications of the oxidation ponds are also available for improving the efficacy of the sysem. For example, it is recommended to grow water hyacinth *Eichhornia crassipes* at one corner of the oxidation ponds to remove toxic heavy metals.

Decomposition of sewage effluent in sewage-fed ponds

The manner by which decomposition of sewage takes place in sewage-fed ponds is the same as that of a normal fish pond following organic manure application. Because of high oxygen requirement for decomposition of sewage effluents, there is sharp rise in BOD level in pond water, immediately after application of sewage effluents. Decomposition of organic matter, is started by the heterotrophic bacteria, starts following the application of sewage effluents resulting in the release of essential nutrients necessary for phytoplankton growth.

Biotic community in wastewater-fed aquaculture ponds

Sewage-fed pond is characterized by the dominance of phytoplankton represented by Chlorophyceae, Myxophyceae and Bacillariophyceae to some extent. The dominance of each group of phytoplankton was variable depneding upon the actual nutrient status of the sewage fed ponds. For example, Myxophyceae bloom may appear in response to eutrophication caused by excessive phosphorus and nitrogen load. Under normal conditions, the most dominant genera of Chlorophyceae are : *Ankistrodesmus, Scenedesmus, Chlorella, Closterium.* Myxophyceae is the next dominant group mostly and represented by *Oscillatoria, Spirulina* and *Nostoc.* Bacillariophyceae or diatoms are represented by *Navicula, Nitzchia* and *Synedra.*

Among zooplankton, cladocerans are the most dominant and represented by *Monia* and *Daphnia.* Among copepods, *Cyclops* and *Diaptomus* and among rotifers *Brachionus, Keratella, Filinia* and *Asplanchna* are common.

Food chain and food web

Sewage-fed pond are complex ecosystem with the predominance of microbial diversity. Though there are basically three feeding pathway, such as direct feeding on organic matter, heterotrophic and autotrophic pathways, feeding through heterotrophic pathway is of greater importance in waste water-fed aquaculture ponds than the autotrophic grazing food chain.

With increase in the concentration of nutrients, the phytoplankton population is stimulated.

The phytoplankton population starts appearing in greater abundance within 3-5 days of sewage application and generally continues to grow up to 15-20 days. In order to maintain nutrient status, it is imperative to supply sewage at regular intervals so that adequate nutrient level is maintained for primary productivity. This is accompaned by the increase in the production of consumers in the form of zooplankton, insects, benthic animals, etc. Apart from the grazing food chain, detritus food chain is strongly involved in sewage fed ponds. In fact, microbial detritus food chain is very dominant in sewage fed ponds. The small particles of mctrofines, which are basically assemblage of bacterial colony, provide direct source of food to zooplankton and benthos.

Though the level of oxygen is sewage fed ponds remains quite low in the beginning due to decomposition of sewage effluent, phytoplankton bloom developed within a few days caused increase in oxygen level by photosynthesis, killing many pathogenic anaerobic bacteria and thus the sewage fed ponds are now become suitable for fish culture.

Design and construction

There are different methods for utilization of sewage in fish culture. In many cases, the oxidation pond serves as storage of incoming sewage ponds. For using the treated sewage from oxiation pond for fish culture, it is suggested that the number of fish ponds should be calculated in such way that the total area of fish ponds is equal to the area of oxidation pond.

Construction modification is also available in the form of waste stabilization ponds which in general consists of anaerobic pond, facultative pond and maturation pond. Fish culture is practiced in the maturation pond as stocking pond (Fig. 8) This approach has been found to be better so far as the water quality is concerned.

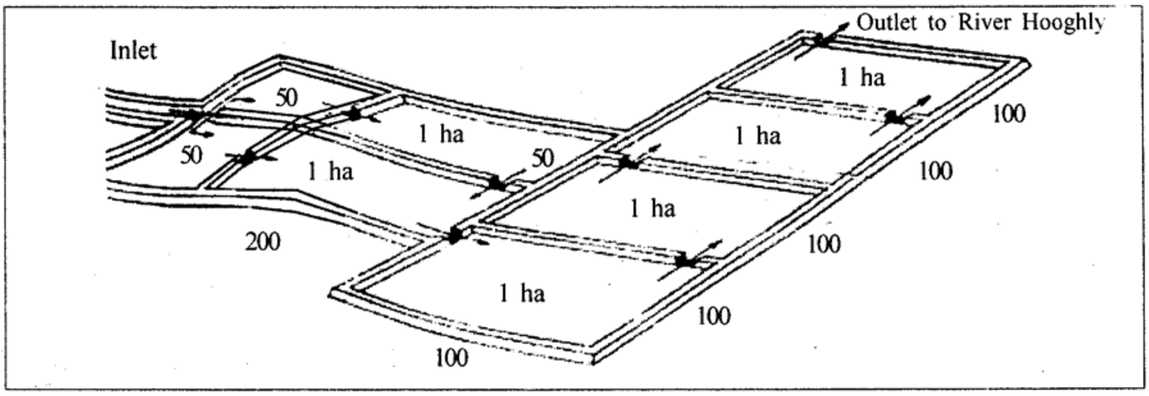


Figure 8 : Sewage-fed fish farm in Kalyani

In West Bengal, there are more than 130 sewage-fed fish culture units where sewage is extensively used as the fertilizer for fish ponds. Simultaneously, sewage-fed fish farms also started in Nagpur, Chennai and Bhopal. In Calcutta, sewae-fed fisheries are very popular and large number of fish farmers earn their livelihood by culturing fish in East Calcutta bheries-fed by municipal sewage.

Fish culture practices

In general, before stocking, bheries are dried up and sewage is allowed to enter here. The effluent are stabilized for a few days (5-7 days) and after observing the plankton populations, stocking is done.

For a better utilization of nutrient resource through diverse food organisms of sewage-fed pond as well as for maintaining ecological balance, stocking of different species of fish should be done in judicious way so as to utilize the food spectrum of different ecological niches. Since monoculture or one fish species cannot utilize all natural food resources resulting in unutilization of much of the food organisms and therefore imbalance of organisms may develop. For this reason, selection of many fish species with diverse feeding habits in a polyculture is a better practice for sustainable fish production in sewage-fed ponds. The best combination of species mix is silver carp, a prolific phytoplankton feeder, rohu, catla, mrigal and common carp. The bottom feeder common carp and mrigal should be stocked in greater proportions for utilization of bottom food resources.

Though no specific recommendation for stocking density and ratio are available, a general practice is to follow carp poly culture with stocking density of 7000-10000/ha. In some cases, the stocking density may go up to 15,000/ha. Normally multiple stocking and multiple harvesting practices is adopted in most of the Kolkata wetland bheries and fishes are raised for 4-5 months depending on the growth of the fishes to reach to the marketable size of 250-400 g. Under such condition, a fish yield of 5000 to 7200 kg/ha/year is obtained.

In Chennai, stocking density of carp fingerling can be 20,000/ha (catla - 5000, rohu–10000, and mrigal 5000) with a total fish production of 6 ton/ha. Alternatively, the Indian major carp, silver carp, grass carp, common carp and fringe-lipped carp may also be stocked in sewage-fed fish ponds at a stocking density of 10,000/ha.

Air breathing and low oxygen tolerating fish like murrels and catfish may also be grown along with other species. In this case, these fishes should be introduced only after the fingerlings of other fish have grown to a considerable size. In oxidation ponds, murrels can be directly introduced along with tilapia, the young of which form food for murrels.

In rice fields, fertilized with domestic sewage and improved environmental conditions, high yield of giant freshwater prawn *Macrobrachium rosenbergii* could be obtained.

General management

The advantage of the sewage-fed fish ponds is that application of fertilizer and supplemental feeds are not required as the ponds are already rich in nutrient sources. As nutrient enrichment occurs due to input of sweage, it is most important to carefully regulate the sewage input at periodical intervals so that too much nutrient level or eutrophication state does not develop in sewage-fed ponds. Periodical raking and aeration may be quite beneficial for improved water quality and enhancing fish production cost of fish becomes much cheaper.

Aesthetic considerations may often limit the use of sewage cultured fish. This can be overcome by transferring the harvested live fish to freshwater pond and keeping them for a couple of weeks when objectionable odors and pathogens, if any, will be removed so as to make the fish marketable.

Public health consideration

The available information suggests that the average bacterial loads in respect to total coliform and fecal coliforms may range from 91.69–99.50 and 87.77-99.05/100 ml raw sewage in different sewage-fed farms in West Bengal. It is further reported that the digestive tract of fish contained a larger number of bacteria than other organs. In order to assess the fish for human consumption, the counts of bacteria should always be less than the counts recommended by WHO guidelines for wastewater aquaculture. It is also reported that *Salmonella* was not present in any of the fish grown in sewage-fed ponds, though *Shigella* was isolated from them. But neither *Salmonella* nor *Shigella* was present in cooked fish.

Apart from pathogenic bacterial load, other health problems are related with heavy metals and other toxic contaminants that are present in wastewater. They may pose a threat to fish life through bioaccumulation and bio-magnification. Therefore, it is essential to monitor the ecotoxical risk factors associated with fish raised in sewage-fed ponds.