OSTEOLOGY OF THE INDIAN MACKEREL, *RASTRELLIGER KANAGURTA* (CUVIER)

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Rastrelliger kanagurta (the Indian Mackerel) is a fish of great commercial importance and of wide geographical distribution in the Indo-Pacific region. The study of the biology of the mackerel has been receiving considerable attention in this region during recent years. One of the important aspects of such work is the study on raciation. While the skeletal characters are of importance in such investigations, no standard description of the skeletal system of *R. kanagurta* or of any allied Indian species has been available so far for reference. It was therefore necessary to undertake a detailed study of the skeletal system of *R. kanagurta* as a preliminary to studies on raciation in this species. The present paper deals with the osteology of the Indian mackerel. It is proposed to publish a detailed comparative study of the osteology of the different genera and species of the family Scombridae. The descriptions of the various bones are dealt with in such a way that they may be of value as a guide for comparison with the skeleton of other genera or species of mackerel.

Among the important contributions to our knowledge of the osteology of some of the related species of Scombridae from other countries mention should be made of those of Allis (1903) on *Scomber scomber* (Linnaeus), Starks (1910) on *Scomber japonicus* (Houttuyn) and *Rastrelliger brachysoma* (Bleeker), Kishinouye (1923) on *Scomber japonicus* (Houttuyn) and *R. chrysozonus* and Godsil (1954) on *Pneumatophorus diego* (Ayres). Certain other works which have been of valuable aid to this study were Starks (1901), Regan (1909), Gregory (1933), Ford (1937), Clothier (1950), Frasser-Brunner (1950), Roedel (1952), Godsil (1954), Murakami and Hayand (1956), Hottoa, Abe and Takashima (1958), and Kramer (1960).

Material and Methods

The specimens for this study were obtained mostly from the local catches at Calicut on the west coast of India and some from other centres

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along the Indian coast. Fishes of the size range 60 to 240 mm. have been examined.

Skeletons were prepared for study by simmering the fresh fish in water just long enough to loosen the tissues from the bones. Later they were bleached in a dilute solution of hydrogen peroxide. The different bones of the neurocranium were disarticulated and studied. In the case of preserved specimens Alizarine staining technique used by Hollister (1936) referred to by Clothier (1950) was followed. In naming the various bones no new terms are employed and those used by Starks (1901, 1910) and other workers cited earlier are followed.

Skull

The skull of *R. kanagurta* is triangular in general outline both in dorsal and lateral views, its anterior end being bluntly pointed. Ventrally the skull is compressed, the inferior edges of dentaries, articulars and opercular bones almost meeting in the mid-ventral line. The interopercle forms the lower edge of the skull in the opercular region and its inferior edge is almost straight and forms a third of the ventral edge of the skull. The hind end of the lower jaw lies far behind the middle of the ventral edge of the skull and the height of skull at this point is less than 2½ times the neurocranium in the same place. The bones of the skull are thin and most of them are porous.

Neurocranium

(Fig. 1)

The neurocranium of *R. kanagurta* is moderately elongate and more or less triangular in shape in the dorsal, ventral and lateral views. The dorsal surface of the anterior half is flat and bears a median depression which is sculptured with a network of grooves and ridges. A slit-like elongated foramen between the hind end of the frontals and another broad foramen where the frontals approach the dermethmoid are conspicuous on the dorsal side. The mid-ventral profile of the neurocranium is convex. On the ventral side the prootic pit is absent and the myodome opens by a large foramen posteriorly. The anterior end of the neurocranium is narrow and its breadth increases gradually upto the postorbital region where the lateral edges of the sphenotics are directed downwards as sharp projections. Beyond the sphenotics, the breadth decreases a little but again it increases

as the two posterior pterotic processes divaricate outwards. The hind portion of the new neurocranium is elevated.

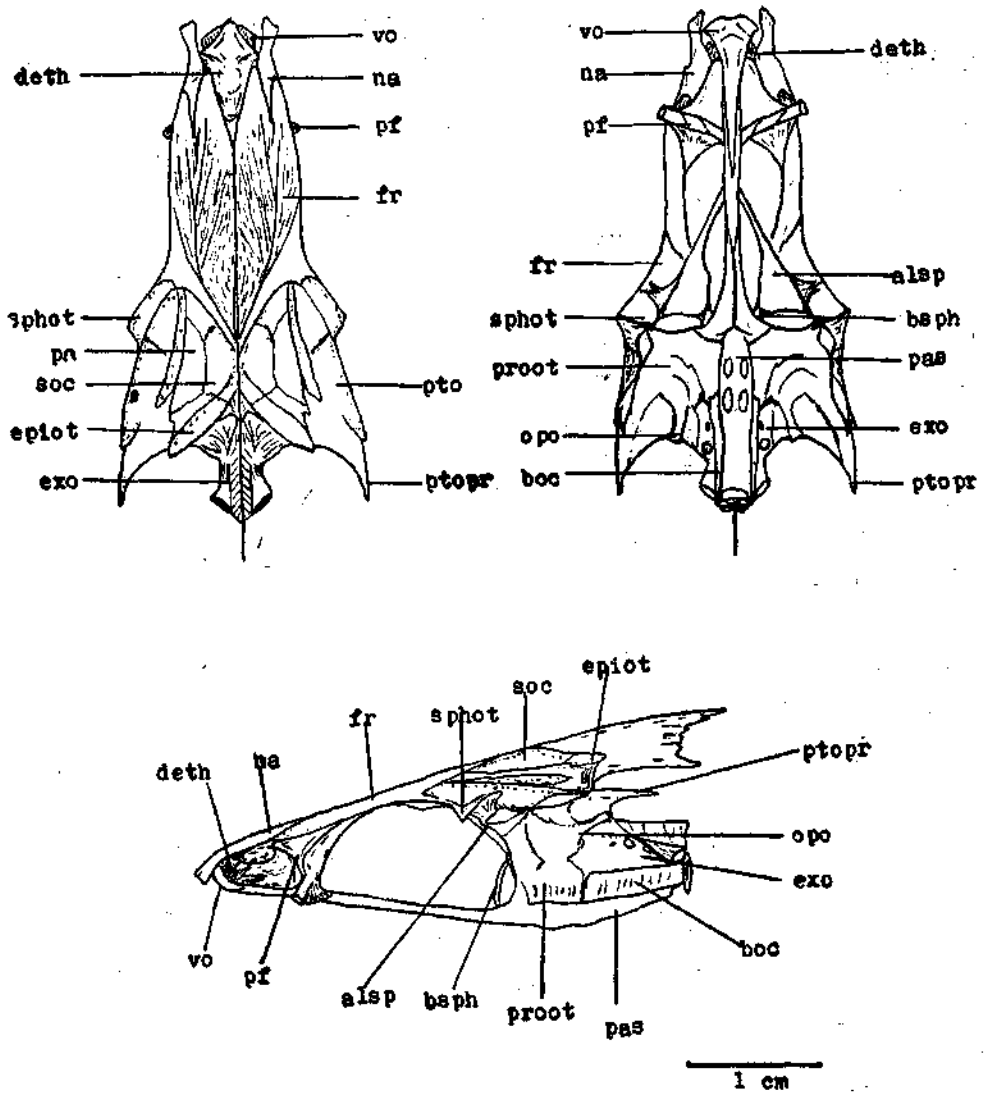

FIG. 1. Neurocranium *of Rastrelliger kanagurta*.—dorsal, ventral and lateral view. (For explanation of abbreviations see page 26).

Behind the orbit, the neurocranium is dome-shaped and encloses the cranial cavity. Its dorsal surface is marked by a median ridge and three grooves on either side, the dilator, temporal and supratemporal. These grooves on either side are separated by inner temporal and external pterotic

ridges. The pterotic ridge is raised slightly from the base of the pterotic process. The median ridge separating the grooves on either side of the neurocranium is continuous with the supraoccipital crest posteriorly. Between the temporal and pterotic ridges lies a thin auxillary crest. Anteriorly the temporal and pterotic ridges and the three grooves extend upto the mid-level of the orbit and are directed towards the lateral edge of the neurocranium. The dilator groove is the shortest and runs outwards over the frontal, sphenotic and pterotic and terminates above the articular facet of the pterotic for the hyomandibular. An upwardly directed process of the sphenotic divides this groove into superior and inferior portions. The temporal groove is the deepest and lies between the dilator and supratemporal grooves. The hind portion of this groove is deeper than the anterior portion. It runs over the frontal, parietal and pterotic bones to open at the hind end of the neurocranium. The supratemporal groove, which is the innermost, is much shallower than the others.

The hindmost end of the neurocranium bears the concavity of the basioccipital, the two flat exoccipital facets and the foramen magnum. Above the foramen magnum the hind surface of the neurocranium has two distinct concavities on either side. The orbits are large and occupy more than one-third the length of the neurocranium.

Individual Bones of the Skull (Figs. 2 & 3)

Olfactory region.—The *dermethmoid* (*deth*) is a median bone with a solid anterior part sloping downward and forward and a broad posterior part which is porous. The anterior part bears a median and a pair of lateral protuberances which fit into corresponding depressions on the vomer. Behind the sloping part, the dorsal surface of the bone is roughly rectangular with a median depression. Its anterior corners are produced into horn-like projections.

The *prefrontals* (*pf*) lie behind the juncture of the vomer and dermethmoid. They are massive, irregular bones forming the anterior limit of the orbits and posterior and mesial walls of the nasal cavity. Each prefrontal is longer than broad having a posterior and a ventro-lateral extension, the former supporting the frontal and the latter forming the anterior boundary of the orbit and bearing articulating surfaces for the palatine and the lacrymal. Medially both the prefrontals are connected to each other and to the dermethmoid through intervening cartilage anteriorly and to the parasphenoid ventrally. Each prefrontal is pierced by a foramen for the passage of the olfactory nerve.

The *nasals* (*na*) are long, narrow, curved, flat bones articulating with the anterolateral edges of the frontals. Mesially, the hind half of each nasal adjoins the dermethmoid. The middle portion of the nasal is narrower than the anterior or posterior ends.

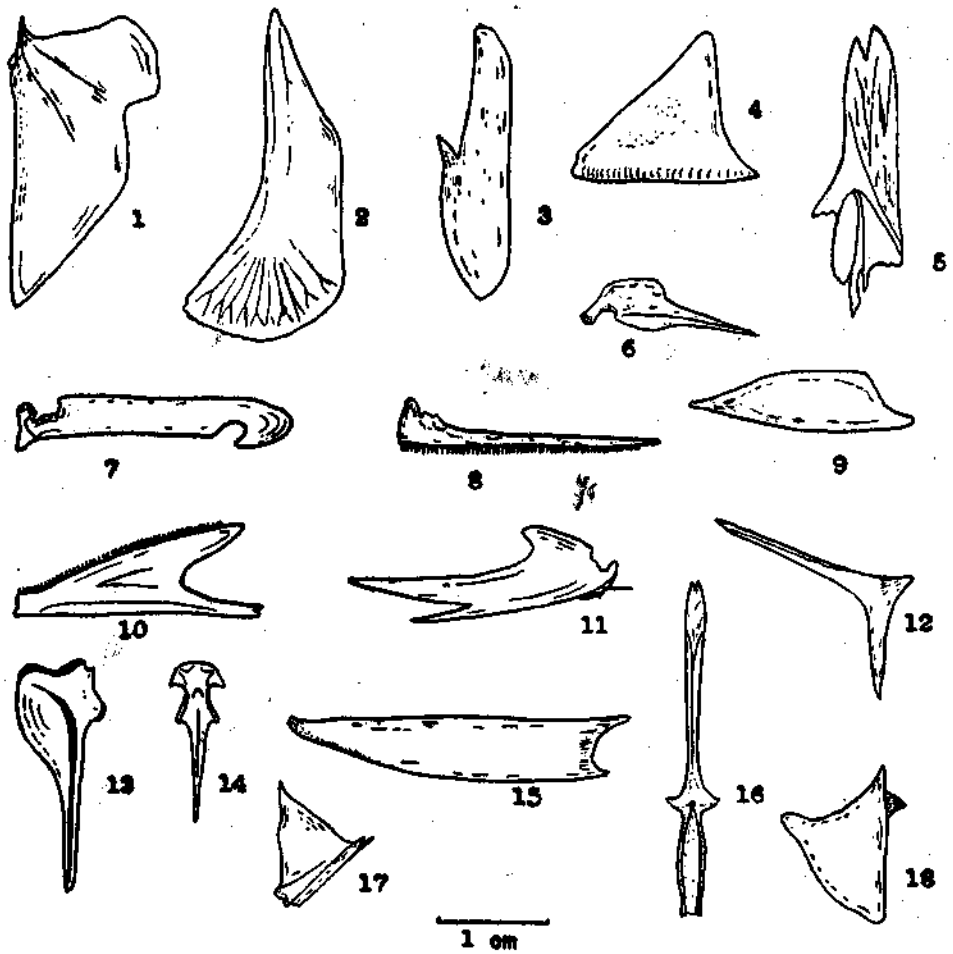

FIG. 2. Disarticulated bones. 1. opercle, 2. preopercle, 3. sub opercle, 4. interopercle, 5. frontal, 6. palatine, 7. maxilla, 8. premaxilla, 9. entophery goid, 10. dentary, 11. articular, 12. ectopterygoid, 13. hyomandibular, 14. vomer, 15. urohyal, 16. parasphenoid, 17. quadrate, 18. metapterygoid.

The *vomer* (*vo*) is a median bone with a short, stout anterior portion and a long thin posterior portion tapering to a sharp point. Anteriorly, it bears a pair of oblique articulatory heads separated by a median notch for the articulation of maxillae. A little behind the articular head, the

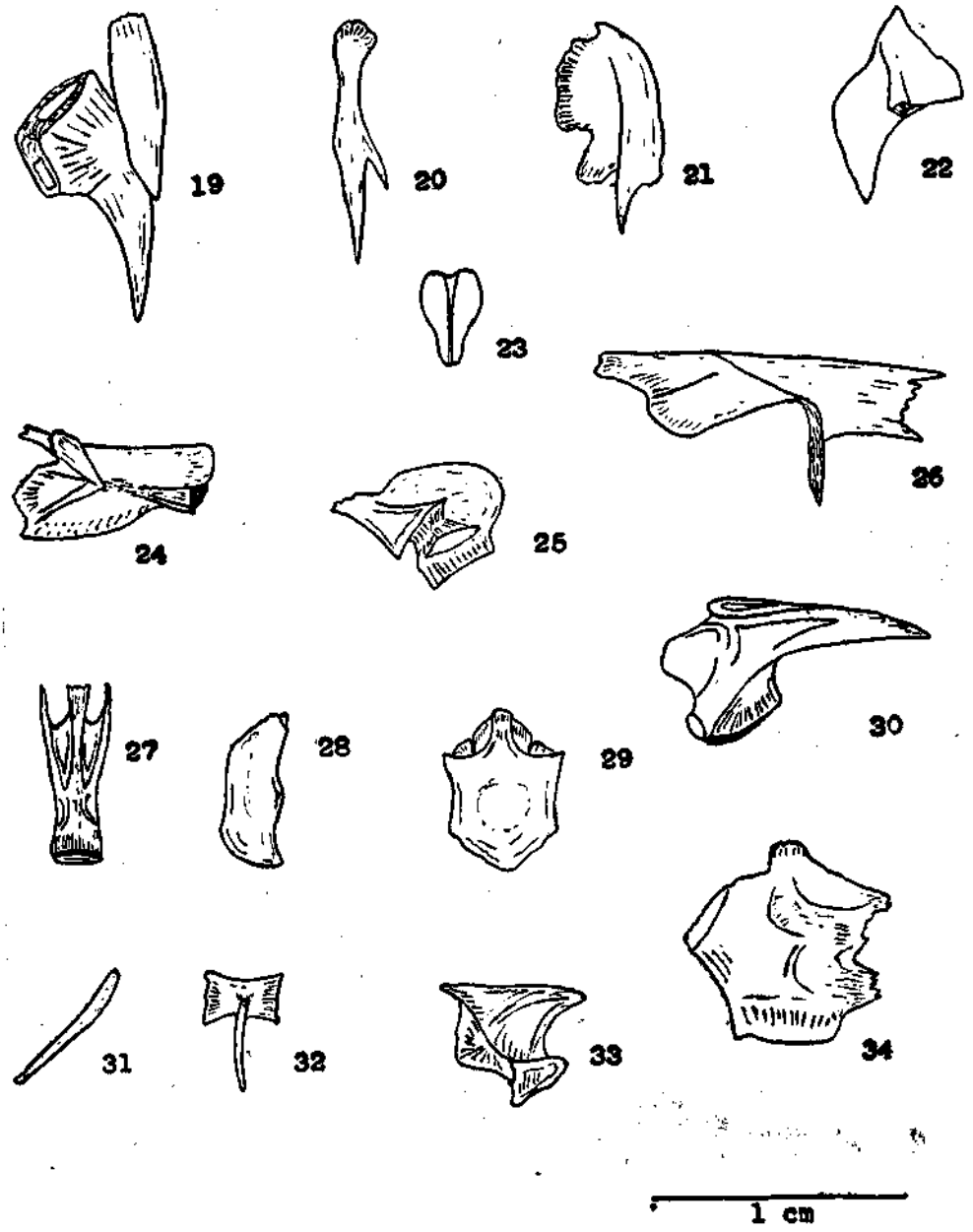

FIG. 3. Disarticulated bones (*Contd.*). 19. pterotic, 20. nasal, 21. parietal, 22. opisthotic, 23. rostral, 24. exoccepital, 25. spenotic, 26. supraoccipital, 27. basioccipital, 28. alisphenoid, 29. dermethmoid, 30. prefrontal, 31. symplectic, 32. basisphenoid, 33. epiotic, 34. pro otic.

lateral edges of vomer are raised into wings which occupy one-third the length of the bone. The vomer is devoid of teeth.

The *rostral* is a small, triangular flat piece of cartilage connected to the anterior median protuberance of the dermethmoid.

Orbital region.—The *frontals* (*fr*) are extensive bones forming more than half the dorsal roof of the neurocranium. On the dorsal side each frontal has a network of grooves and ridges. Anteriorly the bone is attenuating and bifurcated to form two limbs, the inner one is only slightly longer than the outer. Posteriorly the frontals are irregular, joining the supraoccipital, parietals, pterotics, sphenotics and alisphenoids. The two frontals are imperfectly sutured along the mid-ventral line leaving a slit in front of the supraoccipital.

The *alisphenoids* (*alsp*) form the anterior sides of the cranial cavity. They are small bones having the dorsal end of their anteromesial edge thickened. The inner edge of each bone has a tiny projection roughly in the middle of its dorsoventral extent.

The sclerotic capsules are round, thin and divided into anterior and posterior portions.

The *circumorbital series* of bones are usually made up of eight or nine pieces. Except the lacrymal, all the bones are very thin and delicate with their anterior edges turned inwards. The bones lying between the ventral side of the sphenotic and lacrymal form the postorbital and suborbital bones (Allis, 1903). The lacrymal is the largest of the series and the next largest is the fourth bone from below. The first bone behind the lacrymal extends below the eye to a certain extent and its anterior end bears a small knob directed ventrally which is overlapped by the hind corner of lacrymal. This bone, the first one posterior to lacrymal, is the suborbital and the rest of the series are postorbital (Allis, 1903).

The *lacrymal* (*la*) is the largest and the anteriormost bone of the circumorbital series on each side covering the maxilla and premaxilla to a great extent. Its anterior and posterior ends are rounded, and its ventral and hind edges are thinner than the rest of the bone.

The *orbitosphenoid* is absent.

Otic region.—The *parietals* (*pa*) are situated behind the frontals overlapping it and also the supraoccipital, epiotics and pterotics. Each parietal

is thin and bears a dorsal ridge which projects posteriorly and contributes to the temporal ridge of the neurocranium.

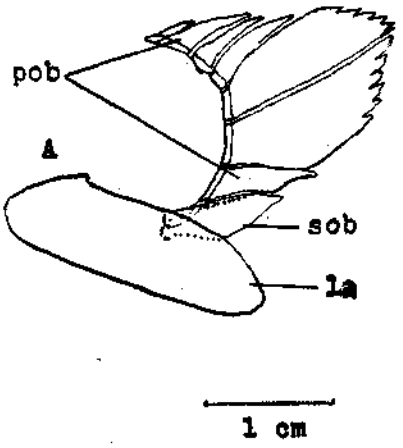

FIG. 4. Circumorbital series of bones.
(For explanation of abbreviations see page 26).

The *supraoccipital* (*soc*) is a broad bone in the median line of the dorsal hind end of the neurocranium. Dorsally the bone is convex with a ridge in the median line which expands posteriorly into a thin occipital crest. The dorsal edge of the crest terminates in a sharp point at its hind end. From the hind end a portion of the bone extends downwards meeting the mesial edges of the epiotics and to a certain extent the exoccipitals also.

The *pterotics* (*pto*) are long bones located behind the sphenotics. Each pterotic possesses a superior plate-like part terminating in a needle-like pterotic process applied to the ventral body of the bone. The body is thick and encloses a narrow passage for the semicircular canal of the auditory organ. An elongated shallow articular facet for the hyomandibular is situated laterally. Above the base of the pterotic process lies a short elevated projection upon which rests the anterior end of the supratemporal.

The *prootics* (*proot*) are massive irregular bones on the ventral side of the neurocranium, the edges of which are serrated. Each bone has an inner thick horizontal extension uniting with its fellow of the opposite side in the median line. The inner surface of the prootic is concave and irregular with ridges and depressions accommodating the major portion of the auditory organ. The trigemino-facial chamber (Allis, 1903) is spacious and well defined immediately dorsal to the line of origin of the horizontal wing. The wall separating the chamber from the cranial cavity is perforated by two

large and a small foramina. Another small foramen occurs at the junction of each prootic with the corresponding alisphenoid.

The *epiotics* (*epiot*) are small conical bones each with pronounced process on its dorsal hind edge. This process supports the dorsal branch of the post-temporal. Internally the epiotic encloses a passage for a semi-circular canal. The bone is bounded anteriorly by the parietal and pterotic, ventrally by exoccipital and anteromesially by supraoccipital.

The *sphenotics* (*sphot*) form part of dorsal and hind walls of the orbit. Each bone is irregular with a lateral conical projection directed downward and pointed at its free end. From the base of this projection the bone extends upwards into the dilatator groove on its dorsal surface. A deep facet for the articulation of the hyomandibular lies at the hind lateral side of the bone. Internally the bone has two deep cavities separated by a vertical ridge.

The *opisthotic* (*opot*) are small thin bones of irregular shape. The hind edge of each bone is thick and bears a more or less pronounced pro-turberance to which the slender lower arm of the post-temporal is attached.

The *exoccipitals* (*exo*) are a pair of complicated bones broader anteriorly than posteriorly and uniting in the median line directly beneath the supra-occipital. The foramen magnum which separates the median suture between these bones is separated from the basioccipital by a small ventral expansion of the exoccipitals. Posterolaterally they bear the vertebral or paraoccipital condyles to the first vertebra which are almost flat. The foramina for the vagus and trigeminal, the former larger than the latter, occur in front of the base of these condyles.

Basicranial region.—The *parasphenoid* is a long ventromedian bone connecting the otic and olfactory regions. This is the longest bone in the cranium and has two ascending wings from the posterior third of its length. Behind the wings, the bone is wide with a smooth upward curvature. Below the wings the ventral edge of the bone is sharp and a little behind it bears two pairs of rounded thickenings. The bone thickens in front of the wings and is constricted for a short distance beyond which it becomes thin and broad with its anterior end bifurcated. The anterior portion is grooved on its ventral surface to receive the hind portion of the vomer. The hind edge of the bone does not close the myodome.

The *basisphenoid* (*bsph*) is a small median Y-shaped bone at the lower anterior end of the cranial cavity, the shank of Y being slender, laterally

compressed and slightly curved. The arms are broader than the shank and fixed to the prootics.

BRANCHIOCRANIUM

Oromandibular region.—The *premaxilla* is a long, slender, curved bone with a broad triangular anterior head where it presents articular surfaces on the inner and outer sides. Behind the head the bone becomes abruptly slender tapering to a point posteriorly. Numerous minute teeth are arranged in a single row along the ventral edge of the bone.

The *maxilla* is a broad, elongated, curved bone lying behind and above the premaxilla. It is shorter than the premaxilla. Behind the articular head lies a deep depression where the bone is narrowest. Posterior to the depression the bone is broad and has a deep indentation at its ventral margin near its hind end. Anteriorly the bone is thick and extends dorsalwards the mesial surface of which is deeply scooped within which the dorsal edge of the anterior head of the premaxilla is fitted.

The *dentary* is an elongated, laterally flattened large bone forked posteriorly. Its upper margin bears a row of minute, pointed teeth. The upper arm of the forked portion is broader and shorter than the lower arm. The hind end of the lower arm is bifid. At the junction of the two arms the dentary contains a large pocket which is open posteriorly and into which projects the anterior process of the articular.

The *articular* is roughly a spear-shaped bone with a broad posterior part and a long tapering anterior process which fits into the pocket of the dentary. The upper margin of the posterior end of the bone bears a depression for articulation with the quadrate. The bone is concave internally and convex externally and from its hind end arise two processes, one projecting dorso-anteriorly and the other ventro-anteriorly.

The *angular* is a small bone firmly fitted against the posteroventral edge of the articular.

The *metapterygoid* is a large flat bone roughly triangular in shape with a straight posterior edge, a concave dorsal or superior edge and a convex anteroventral or inferior edge. The upper half of its hind edge is grooved to receive the stem of the hyomandibular. Posterodorsally it bears a strong process projecting backwards and fitting firmly against the inner surface of the stem of hyomandibular. Above this process the bone is produced into a strong projection directed upward and lies external to the hyomandibular,

The convex margin of the bone adjoins the quadrate ventrally and ectopterygoid dorsally through intervening cartilage.

The *ectopterygoid* is a roughly Y-shaped bone, the shank of Y forming its anterior end which is wedged between the ectopterygoid and palatine. Of the two arms of Y the lower one is conspicuously long and runs downwards and backwards adjoining the quadrate and metapterygoid. The upper arm is shorter and directed backward and upward and fits in a triangular recess on the inner surface of the dorsal part of the metapterygoid.

The *entopterygoid* is a thin papery bone with a pointed anterior end and a broad rounded posterior end. Its dorsal surface is concave and ventral surface convex.

The *palatine* is an elongated bone with an anterior thick and broad portion and a posterior thin and tapering portion. It is knobbed at the anterior end which articulates with the anterior end of maxillary. The bone is devoid of teeth and lies anterior to the ectopterygoid.

The *quadrate* is a triangular bone articulating dorsally with metapterygoid, ventrally with articular, anteriorly with ectopterygoid and posteriorly with preopercle. Its inferior corner has a saddle-shaped articular head for the articular. The bone is thickened near its posterior edge which is grooved on the inner side and presents a process directed upward.

The *symplectic* is a slender rod-like bone situated in the groove of the quadrate. Its upper part is broader than the lower part and projects beyond the groove of the quadrate.

Hyoid-opercular region.—The *opercle* is a large, thin bone roughly triangular in shape. Its anterior dorsal corner is thickened bearing a round facet for articulation with the hyomandibular. Above the facet the bone projects as a slender process. The inner surface of the opercle presents two ridges starting from the articular facet. The anterior edge of the bone is straight while its hind edge is notched at about its middle. Immediately below the notch the hind margin of the bone is round and further below it is nearly straight.

The *preopercle* is the strongest and tallest bone of the opercular series, its anterior edge being thicker than the other regions and bearing a groove in which is firmly fitted the hind edge of the hyomandibular. Its bluntly pointed dorsal end does not extend beyond the dorsal end of the hyomandibular ridge. The bone can be divided roughly into a vertical and a hori-

zontal arm, the angle between the two being broader than the other parts. The horizontal arm is very short with its anterior extremity rounded.

The *subopercle* is a thin, tall bone, its ventral half being broader than the dorsal half. A thin pointed process extends forward and upward from its anterior edge.

The *interopercle* is also a thin bone which is roughly triangular. Its narrow anterior edge is indented by a notch and connected to the articular. The inner surface of the bone has a depressed area for providing articulation to the ceratohyal. Its hind concave margin overlaps the subopercle.

The *hyomandibular* is a strong bone consisting of a broad upper portion and a slender tapering rod-like lower portion or stem, the former with three condyles. The two dorsal condyles articulate with the neurocranium by means of facets in the sphenotic and pterotic. The third condyle lies below the posterior dorsal condyle and articulates with the opercle. A strong ridge extends from the ventral end of the bone to almost its dorsal end without projecting dorsally. The broader portion of the hyomandibular bears a rounded foramen on its inner side. The hind edge of the stem is grooved into which is fitted the anterior edge of the preopercle and its ventral end adjoins the symplectic and interhyal through intervening cartilage. The stem is long, slender and nearly straight. A wide lamella is present between the anterior dorsal condyle and the stem of the hyomandibular. The lamella extends downwards on the stem of the hyomandibular to about half the distance.

The hyoid arch or Cornu (Fig. 5) consists of the glossohyal, embedded in the tongue and four separate bones the basihyal, ceratohyal, epihyal and interhyal, all connected together by means of cartilage. Anteriorly the basihyals of the two sides are connected to the first basibranchial.

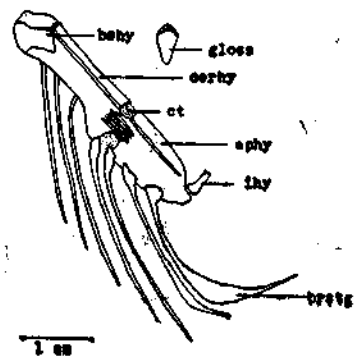

FIG. 5. Hyoid arch.
(For explanation of abbreviations see page 26)

The *glossohyal* (*gloss*) is a short flat bone, convex anteriorly and pointed posteriorly. The cartilage present at the anterior end of the glossohyal is blunt.

The *basihyal* (*bshy*) is composed of two components, the dorsal and ventral, firmly united by a thin strip of cartilage. The hind end of the dorsal half articulates with the dorsal part of the ceratohyal by a thin strip of cartilage. The ventral half is larger and overlaps the anteroventral part of the ceratohyal.

The *ceratohyal* (*crhy*) is a long flat bone, thicker than the epihyal. Its hind end is broader and bears four or five long splints. The dorsal margin of the bone is concave and a little below it runs a groove. The ceratohyal and epihyal are more or less equal in length.

The *epihyal* (*ephy*) is a broad, somewhat triangular, thin bone, its hind end being narrower than the anterior end. Similar to the ceratohyal it bears anteriorly long splints and a longitudinal groove on its external surface near the dorsal edge.

A broad piece of cartilage is present between the ceratohyal and epihyal which is interrupted by splints arising from the two bones.

The *interhyal* (*ihy*) is a short, thin, narrow bone, running obliquely upward and articulating the hyoid arch with hyomandibular and symplectic.

The *urohyal* is a thin, long bone lying medially between the basihyals. Its ventral edge is thicker than the other regions. Its anterior end is narrow while its posterior end vertically elongated and embedded in the muscles of the throat.

The *branchiostegal rays* (*brstg*) are seven in number, the first four attached proximally by their bases to the ventral edge of the ceratohyal and the remaining three to the epihyal. They are curved downward and backward and free distally. Except the first three, each ray has a flat enlarged base. The last and the penultimate rays bear well developed wings near the hind end.

Branchial region (Fig. 6).—Of the five branchial arches the first four form a framework for the gills and are composed of small pieces of bone while the fifth arch persists only in part as a single bone on each side, the lower pharyngeals.

The *basibranchials* (bb_1-bb_3) are three in number arranged in a median row to form the basal support for the lower branchial apparatus. The first basibranchial is the longest joining anteriorly the glossohyal and laterally the basihyals. Its anterior end is slender, bent downward and tipped with

cartilage whereas it is broader posteriorly. The second basibranchial is the shortest, roughly rectangular and bears oblique concavities on its sides to receive the first pair of hypobranchials. The third basibranchial is broad anteriorly and narrow posteriorly where it is bent downward. It is slightly longer than the second basibranchial and its lateral concavities receive the second pair of hypobranchials.

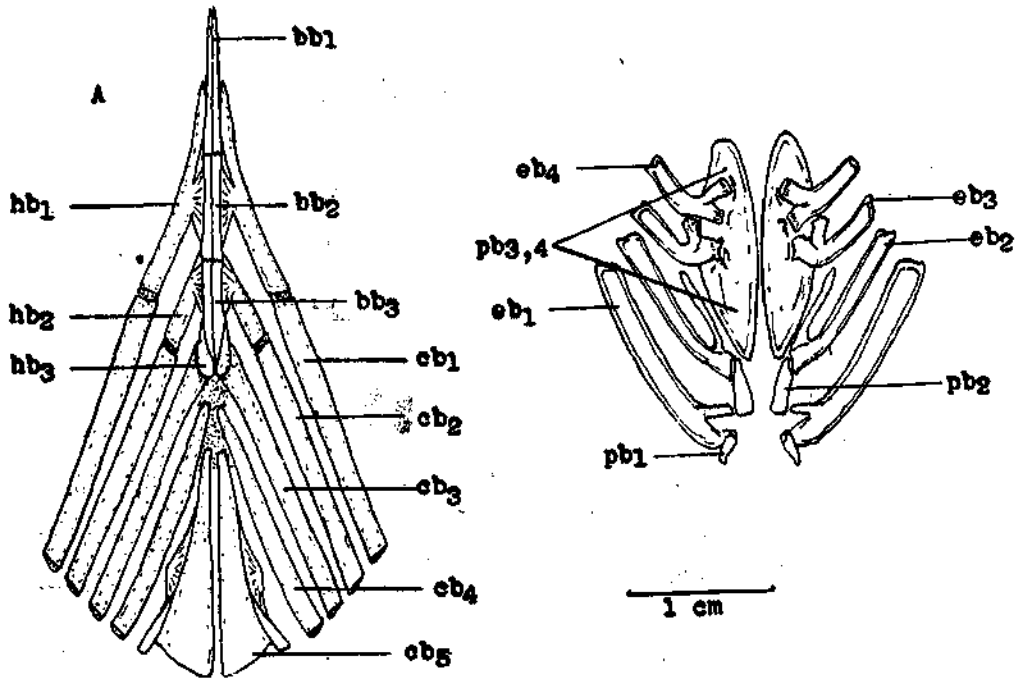

FIG. 6. Branchial arches.
(For explanation of abbreviations see page 26).

The first *hypobranchial* (nb_1) has a broad irregularly shaped articular nead fitting tightly into the oblique depression on the second basibranchial on each side. Anteriorly it is produced into a thin long process with a rounded extremity which along with its fellow of the opposite side embraces the first basibranchial ventrally.

The second *hypobranchial* (hb_2) is shorter than the first and possesses a broad articular head which fits into the oblique depression of the third basibranchial. The anterior process noticed in the first hypobranchial is absent.

The third *hypobranchial* (hb_3) is a small flat piece of bone situated on each side of the hind end of the last basibranchial. Its posterior end is broad and convex while its anterior end is pointed and turned ventrally.

The *ceratobranchials* (cb_1-cb_5) are slender, long, gently curved bones, grooved on their ventral surface like the hypobranchials and diminishing in length from the first to the last. But for the fifth ceratobranchials which are modified to form the lower pharyngeals all the other bones resemble each other closely. The third and fourth pairs are more curved than the first two. The lower pharyngeal bones are flattened anteriorly and lie close to each other. Posteriorly they get broadened. Its ventral surface presents a wing along its lateral edge and its dorsal surface is densely beset with villiform teeth.

The *epibranchials* (eb_1-eb_4) extend upward and forward from the angle of arch. They are curved bones bearing a spicular process near the anterior end of each epibranchial of the first three arches. The anterior ends of all the epibranchials are twisted. The third epibranchial is the shortest and the most slender bone of the series. The fourth epibranchial is the strongest.

The four *upper pharyngeals* or *pharyngobranchials* (pb_1-pb_4) differ markedly in shape and size and bear fine villiform teeth, except the first. The first pharyngobranchial is a tiny piece of bone fitting against the base of the parasphenoid wings with its pointed tip and attached to the first epibranchial by its expanded end. The second pharyngobranchial is flat and articulates with the second epibranchial. The third pharyngobranchial is narrow anteriorly and broad posteriorly. The inner edge of its posterior end bears a strong process which overlaps the fourth pharyngobranchial dorsally. The fourth pharyngobranchial is more or less of the same length as the third and has a broad anterior end and a rounded posterior end. The dorsal surfaces of both the third and fourth pharyngobranchials bear articular surfaces for the corresponding epibranchials.

The gill rakers are arranged on the inner margin of each gill arch in a single series. Those on the first branchial arch are highly elongated and numerous and look like a bunch of feathers in the buccal cavity as the mouth is opened. The number of these gill rakers forms one of the important taxonomic characters and hence they are considered here although they do not form part of skeleton. Each gill raker is a long, thin, flat bony element that tapers to a point at its distal end, bearing minute spine-like processes along the oral border. The base of each raker is inverted V-shaped. The number of gill rakers in the first arch of *R. kanagurta* shows great variation. They vary from 17 to 24 on the upper limb and 34 to 41 on the lower limb of the first arch.

THE VERTEBRAL COLUMN

(Plate I)

The vertebral column of *R. kanagurta* is composed of thirty-one vertebrae, thirteen precaudal (abdominal) and eighteen caudal including the urostyle. The fourteenth vertebra from the anterior end which is the first caudal vertebra possesses a long haemal spine articulating with the first interhaemal. The number of precaudal, caudal and total number of vertebrae in the Indian mackerel is fairly constant. Very rarely a total of thirty or thirty-two vertebrae is seen.

The vertebral column is short and the vertebrae are firmly connected by ligaments affording slight flexture. The first six precaudal and the last six caudal vertebrae are normally shorter than the remaining vertebrae. The penultimate vertebra, *i.e.*, the thirtieth vertebra, is the shortest of all the vertebrae.

The centrum of each vertebra is amphicoelous. The neural spines of the precaudal vertebrae are more slender than those of the caudal vertebrae. The first two neural spines are less inclined posteriorly than the rest. The spines show progressive increase in length upto the thirteenth or fourteenth spine from whence they gradually decrease in length upto the twenty-sixth spine which is a short trenchant spine. The neural spines of the twenty-seventh and twenty-eighth vertebrae lie almost parallel to the long axis of the vertebral column in this region. The neural spine of the twenty-ninth vertebra is modified into an epural to support the caudal fin. The neural arch of the thirtieth vertebra is reduced to a low-lying crest. The anterior and posterior faces of the neural spines are grooved. The neural canal of all the precaudal vertebrae is divided into two distinct and separate canals by a horizontal partition.

The haemal spine of the first caudal vertebra is shaped like a long S with a spinous process on the posterior side near its middle directed upwards. The first three haemal spines are more compressed laterally than the others. As a result of this, the grooves on the anterior and posterior faces in the first three haemal spines do not extend to the extremities, as in the case of the other spines. The haemal spine of each of the first twelve caudal vertebrae is longer than the respective neural spine. The haemal spines of the twenty-sixth, twenty-seventh and twenty-eighth vertebrae are of the same length as the neural spines of the same vertebrae. The haemal spines of the twenty-ninth and thirtieth vertebrae form the hypurals.

The neural and haemal pre- and post-zygapophyses are developed as dorsal and ventral antero-lateral and postero-lateral projections on each centrum and are modified in different regions of the column. These processes in the last four or five vertebrae are progressively reduced. The neural pre-zygapophyses of the few anterior caudal vertebrae are forked at their anterior ends. In the first vertebra the pre-zygapophyses are modified to form a pair of strong processes which are firmly ankylosed to the paraoccipital condyles. The haemal pre- and post-zygapophyses are well developed from the first caudal vertebra onwards. They are rudimentary in the posterior precaudal and the posterior caudal vertebrae. The haemal prezygapophyses of a few anterior caudal vertebrae are forked at their anterior ends.

A pair of parapophyses is present in each of the first nine precaudal vertebrae as small lateral bony projections on each side of the anterior ends of the centra. They are rudimentary in the first seven vertebrae and are elongated ventrally in the eighth and ninth vertebrae. In the tenth vertebra they lengthen to form the first haemal arch enclosing the haemal canal. The haemal canal of the tenth vertebra is more or less rounded. In the succeeding three vertebrae it shows progressive elongation. From the fourteenth vertebra onwards the haemal canal is gradually reduced towards the posterior end.

The haemal brace (Roedel, 1952) which is a bony connection between the centrum and the base of the haemal arch on either side is present usually from the fourteenth vertebra onwards, sometimes from thirteenth or fifteenth. This structure may be present on one or both sides, occasionally incompletely developed in the vertebra where it occurs first.

The last three vertebrae of the column are specially modified to support the caudal fin. The antepenultimate vertebra bears an epural on the dorsal side and a hypural on the ventral side which is autogenous (Ford, 1937). The neural arch of the penultimate vertebra is reduced to a low-lying crest. It also bears an autogenous hypural. The ultimate urostylar segment bears a conical centrum with a rod-shaped urostyle directed posterodorsally, and a hypural plate fused to it below. Two dorsal caudal radials arise between the urostyle and the epural bone. Below the hypural plate lies hypural bone which is also autogenous. Between the hypural plate and the urostyle is present another hypural plate.

A pair of *ribs* is present on each precaudal vertebra except the first two. The first five pairs fit into rounded sockets at the antero-lateral ends of the centra of the third to seventh vertebrae. The sixth and seventh pairs are

attached to the parapophyses of the eighth and ninth vertebrae. The remaining four pairs are attached to the distal ends of the haemal arches of the four posteriormost precaudal vertebrae. Each rib has a flattened knob proximally which is attached by ligaments to the vertebrae. The distal part of each rib is round and tapers to a point. The proximal ends of the ribs of the four posterior pairs are closely connected whereas they are separate in the anterior pairs. Eleven pairs of ribs are present in the Indian mackerel.

The *intermascular bones* or the *epipleurals* are a series of paired slender bones borne by the first twenty-two vertebrae. In the first two vertebrae they are placed in deep sockets on the vertebra. In the succeeding seven vertebrae the points of attachment of the ribs and the epipleurals lie closely one above the other. From the tenth vertebra onwards they are widely separated from the ribs, being attached to the distal end of the haemal arch.

Pectoral Girdle and Fin

The pectoral girdle (Fig. 7) lies behind the posterior angle of the gill cover and is connected with the neurocranium by means of the post-temporal.

The *post-temporal* (*ptm*) is the key suspensory bone of the pectoral girdle bearing two strong anterior projections, a dorsal and a ventral, the former

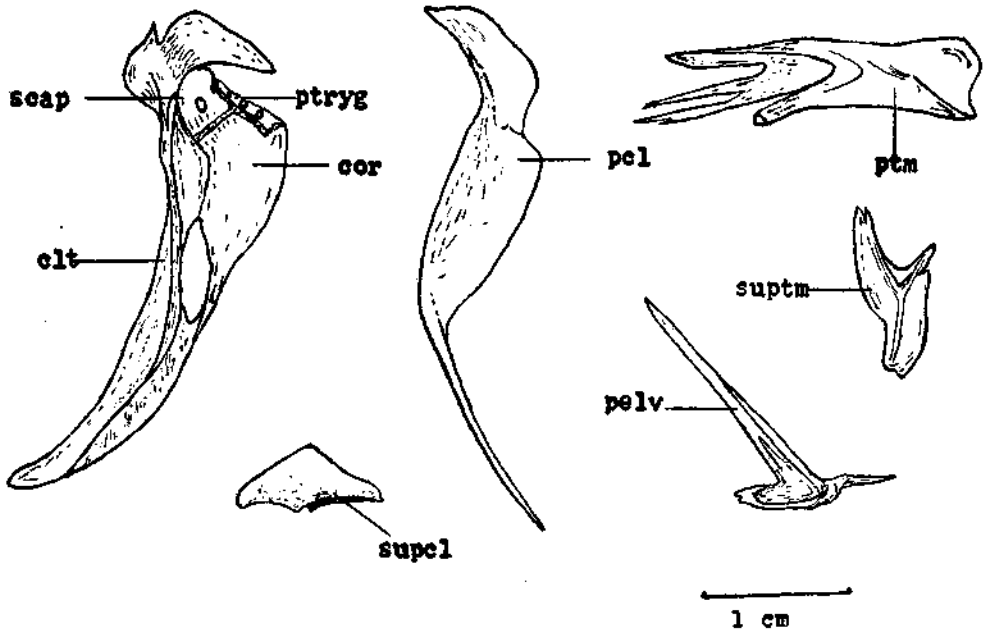

Fig. 7. Pectoral and pelvic girdles.
(For explanation of abbreviations see page 26).

resting well over the conical projection of the epiotic and the latter joining with the posterior projection of the opisthotic. Between these two projections there are two other thin processes which are divided anteriorly. The hind part of the bone is broad with a notched posterior margin.

The *supratemporal* (*stm*) or scale bone is flat and thin lying on the outside of the anterior end of the post-temporal just beneath the skin. It is forked anteriorly and bears a small notch posteriorly.

The *supracleithrum* (*supcl*) is a small bone below the hind part of the post-temporal extending downward. Its posterior end is narrower than the anterior end and rests on the dorsal part of the cleithrum. The ventral edge of its hind half is considerably thickened.

The *cleithrum* (*clt*) is a tall, curved irregular bone which runs downward for most of its length, then turns anteromesially and meets its fellow along the median line. It is bent on itself for most of its length so that there is an outer and an inner lamina. Dorsally the cleithrum is bent backward as a wing-like extension which is thicker than the rest of the bone. In front of this extension lies a sharp projection directed forward and upward.

The *scapula* (*scap*) extends between the posterior margin of cleithrum and coracoid. Near about its centre it is pierced by a round foramen. Two of the four pterygials supporting the pectoral fin are located on the scapula.

The *coracoid* (*cor*) is a long bone with a broad upper part and a tapering lower part. The upper part adjoins the scapula and the lower part the outer lamina of the cleithrum. The upper part bears a cone-like projection directed postero-dorsally and its hind edge is thicker than the rest of the bone, receiving the lower two pterygials.

The *post-cleithrum* (*pcl*) is made up of two pieces. The upper piece is pointed dorsally and broad ventrally. The lower piece consists of an upper broad portion and lower slender, rod-like curved portion.

The four *pterygials* (*ptryg*) diminish in size from below upwards. Small foramina are located between the pterygials.

The fin consists of seventeen to twenty fin rays of which the first or the preaxial ray is unbranched while the other rays are branched. Each ray, like those of the median fins, is composed of two halves which diverge proximally to articulate with the cartilagenous piece at the distal end of the pterygials and scapula. All the rays are segmented. The first ray is shorter

than the second, the fourth or fifth is the longest and the last or the post-axial ray is the shortest. The entire fin is roughly triangular in shape.

Pelvic Girdle and Fin

The pelvic girdle (Fig. 7) consists of a pair of small irregular pelvic bones which are attached obliquely to the muscles of the body wall. The lower edges of these bones lie parallel while the upper edges taper to a point and adjoin the cleithrum of the pectoral girdle. Each bone bears a posterior styliform process. The fins are attached to the posterior thickened edge of the bones.

The pelvic fin is composed of a spine and five soft rays. The spine is shorter than the ray lying inner to it. Between the bases of the two pelvic fins lies a small median blade-like inter-pelvic process (Frasser-Brunner, 1950).

First Dorsal Fin

The *first dorsal fin* commences a little behind a vertical at the base of the pectoral fin. It is usually composed of ten weak spines, the last spine or, rarely, the last two spines lie hidden in the flesh and are not easily detectable in fresh specimens. The second spine is the longest in the series. The succeeding spines fall in length abruptly, the hindmost being the shortest.

Each spine is supported internally by a radial which also serves for the articulation of the preceding spine. There are eleven radials in the first dorsal fin of which the first supports two spines and the last two do not correspond to any spine. Each radial consists of two pterygiophores, the proximal and distal. The proximal pterygiophore (interneural) is a large, linear or dagger-shaped bone with its proximal end thin and pointed, and the distal end broad and flattened. The interneural bears a short horizontal portion distally which points slightly upwards and backwards articulating with the distal piece. The horizontal portion of the posterior few interneurals are elongated. Each interneural consists of four ridges, two lateral, one anterior and one posterior, which extend the entire length meeting along its axis. The anterior ridge of the first interneural is very large and keel-like. According to Kramer (1960) the first interneural is formed by the fusion of two bones in the case of *Pneumatophorus diego*.

The distal pterygiophore, as in the other scombroids, is peculiar in being greatly expanded transversely. The lateral edges of the distal pterygiophores are produced into wings forming a groove into which the spines of the fin

are received when the fin is folded. The distal pterygiophore of the first radial is the smallest and V-shaped with its wings divided into two or three villiform processes. The size of the distal pterygiophores increases towards the posterior end, the longest being that of the eighth, ninth or tenth spine. The lateral wings are reduced in the distal pterygiophores of the eleventh radial. A minute spiny process arises at the hind end of each distal pterygiophore and is inserted into the foramen at the root of each spine.

The most common arrangement of the interneurals between pairs of neural spines is one between a pair except for the third and fourth interneurals which are usually placed between the fourth and fifth neural spines. Rarely two interneurals are found between the third and fourth or fifth and sixth neural spines instead of fourth and fifth neural spines. The first interneural bearing the first two spines occurs usually between the second and third neural spines and the last between the eleventh and twelfth neural spines.

The spines are grooved on their anterior and posterior sides except the first which has a groove only on the posterior face. The spines are weak, each bearing a foramen at its base except the first.

Second Dorsal Fin

The commencement of the second dorsal fin is a little in front of the origin of the anal fin. It consists of a weak spine and eleven rays, supported by twelve radials. As in the first dorsal fin, each radial is composed of a distal and a proximal pterygiophore. The distal pterygiophore of the radial corresponding to the spine is a flat piece of bone while those of the following rays are highly reduced and clasped by the bifurcate base of the rays. The radials are weaker than those of the first dorsal.

The spine of the second dorsal fin is weaker than that of the first. All the rays are branched distally, the number of branches increasing in the posterior rays. The base of each ray is bifurcated and bears a pair of tiny processes.

The interneural corresponding to the spine of the second dorsal fin is between the twelfth and thirteenth neural spines. The arrangement of the interneurals of the rays between succeeding pairs of neural spines is usually two between a pair except the last one or two which are placed separately between a pair of neural spines, the last one being between the nineteenth and twentieth neural spines. The arrangement of the interneurals of the second dorsal fin is variable within the species.

Anal Fin

The anal fin resembles the second dorsal externally. It is composed of a spine and eleven rays. A minute spine is however noticed in front of the first spine in young specimens clearly visible in stained material only. In the adult specimens in the place of this spine only a flat thickening could be noticed.

Internally, twelve radials support the fin. As in the other fins, each radial consists of a proximal (interhaemal) and a distal pterygiophore. The large size of the first interhaemal, the presence of a narrow slit along its longitudinal axis and two spines at its distal end in young specimens indicate the formation of the first interhaemal by the fusion of two interhaemals.

Usually, two or sometimes three interhaemals are present between pairs of haemal spines. The last one or two interhaemals may be placed separately between a pair of haemal spines, the posteriormost being between the nineteenth and twentieth haemal spines.

Dorsal and Anal Finlets

There are five distinct and separate finlets behind the second dorsal and anal fins which are essentially similar. Hence the description of only the dorsal finlets is given below.

Each finlet is formed of a multibranched ray except the posteriormost one, which has two branched rays with their bases close to each other and connected by a thin membrane externally. But internally the two rays of the last finlet have two distinct radials supporting them. Although osteologically this last finlet may be considered as two separate finlets, for all external purposes it is only practical to consider it as a single finlet. According to Kramer (1960) it is one-half ray of the last bifurcate finlet and he calls it the sixth finlet in *Pneumatophorus diego*.

Unlike the radials of the fins, the radials of the dorsal finlets have three pterygiophores, proximal, middle and distal. The interneurals are large with well-developed anterior, posterior and lateral ridges. Distally they are bent almost at right angles and lie parallel to the dorsal body wall. The middle pterygiophore of each radial is long and slender articulating with the interneural anteriorly and with the distal pterygiophore posteriorly. The distal pterygiophores are tiny and clasped by the bifurcate bases of the rays. A rudiment of bone is found immediately below the base of the last ray.

Caudal Ray

The caudal fin of *R. kanagurta* is sublunate as in other species and is composed of about thirty-four to thirty-eight rays, the anterior two or three rays in both the lobes being very much reduced. Each lobe consists of seventeen to nineteen rays of which the anterior ten or eleven are unbranched while the rest are profusely branched. All the rays except the anterior seven in each lobe are striated. Each ray, like that of the dorsal and anal fins, consists of two mirror-image halves, each separable from one another longitudinally. The fin rays are thick proximally and thin distally. The two posterior median rays are attached to the hypural plates by cartilage while other rays straddle the hypurals, epurals and caudal radials proximally.

Summary

The entire skeleton of the Indian mackerel, *Rastrelliger kanagurta*, has been described in detail so as to provide a basis for comparison with other forms of mackerel.

A third of the ventral edge of the skull is formed by the inferior edge of the interopercle. The hind end of the lower jaw lies far behind the middle of the ventral edge of the skull and the height of the skull at this point is less than $2\frac{1}{2}$ times the neurocranium in the same place.

The olfactory region is short. The nasals are narrow in the middle and broad at the extremities. The vomer is devoid of teeth. The rostral is triangular. Of the two limbs of the bifurcated anterior end of the frontal the inner one is only slightly longer than the outer. The circumorbital series of bones are usually made up of eight or nine pieces, the lacrymal being the largest followed by the fourth one from the lacrymal. The plate-like part of pterotic is not much raised from the base of its posterior process. The sphenotic presents laterally a conical projection directed downwards.

The lower arm of the dentary is very long and slender and bifid at its extremity. The metapterygoid is tall and roughly triangular in shape. Of the two arms of the Y-shaped ectopterygoid the lower one is conspicuously long running downwards and backwards adjoining the quadrate and metapterygoid. The angle between the long arm and the stem of Y lies at the upper edge of the metapterygoid. Teeth are absent in palatine. Immediately below the notch at the hind edge of the opercle the margin of the bone is rounded and further below it is nearly straight. The preopercle is elongated dorsoventrally, its ventral portion being only a little produced

anteriorly. The interopercle is roughly triangular. The hyomandibul stem is long and straight and its lamella extends downwards on the stem to about half the distance.

The glossohyal is convex anteriorly and pointed posteriorly. The cartilage at its anterior edge is rounded. The ceratohyal and epihyal are more or less equal in length and are separated from each other by a very broad cartilaginous piece. The last two branchiostegal rays bear well developed wings.

The first basibranchial is the longest and the second the shortest. The dorsal edge of the basibranchials are somewhat sharp. The articular head of the first hypobranchial is deep, its anterior process very long. Gill rakers are very long and their count of the upper and lower limbs of the first outermost branchial arch are 17–24 and 34–41 respectively.

The vertebral column is normally composed of thirty-one vertebrae, thirteen precaudal and eighteen caudal including urostyle. The fourteenth vertebra from the anterior end, which is the first caudal vertebra, possesses a long haemal spine which is like a long S with a spinous process on its posterior side near its middle directed upwards. The first three haemal spines are more compressed laterally than the rest. The neural spines of the precaudal vertebrae are more slender than those of the caudal vertebrae The first haemal canal occurs on the tenth vertebra. Eleven pairs of ribs are attached to the abdominal vertebrae.

In the pectoral girdle the lower piece of the supracleithrum is not greatly expanded in its middle portion.

The first dorsal fin is supported by a complement of eleven radials. Except for the third and fourth interneurals which occur between the fourth and fifth neural spines other interneurals are arranged one in each pair of neural spines. The first interneural lies between the second and third neural spine and the last between the eleventh and twelfth neural spines. The second dorsal fin is supported by twelve radials like the anal fin. The anal fin is composed of a spine and eleven rays.

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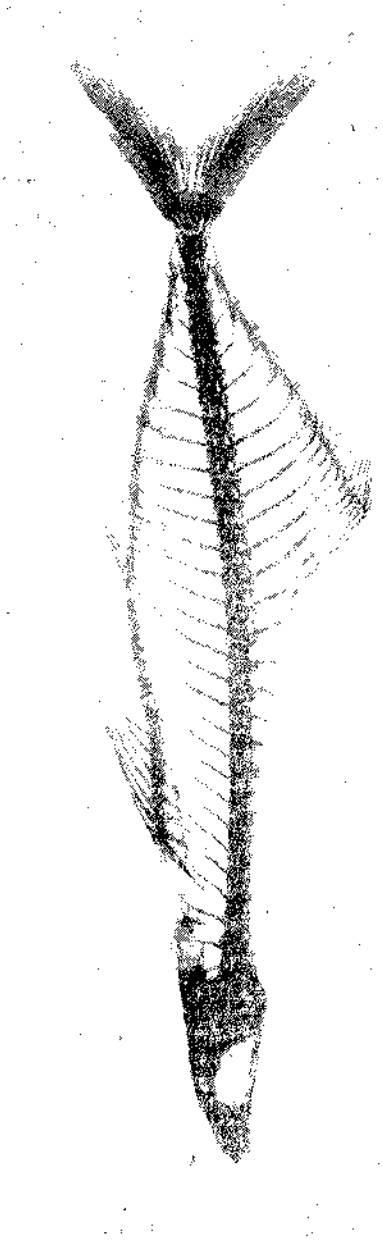

PLATE I. Vertebral column, first dorsal, second dorsal and anal fins of *R. kanagurta*.

List of Abbreviations

alsp., alisphenoid; *bb*$_1$-*bb*$_3$, basibranchials 1–3; *boc.*, basi-occipital; *brstg.*, branchiostegal rays; *bshy.*, basihyal; *bsph.*, basisphenoid; *cb*$_1$-*cbs*, ceratobranchials 1–5; *cerhy.*, ceratohyal; *cit.*, cleithrum; *cor.*, coracoid; *ct.*, cartilage; *deth.*, dermethmoid; *eb*$_1$-*eb*$_4$, ephibranchials 1–4; *ephy.*, epihyal; *exo.*, exoccipital; *epiot.*, epiotic; *fr.*, frontal; *gloss.*, glossohyal; *hb*$_1$-*hb*$_3$, hypobranchials 1-3; *ihy.*, interhyal; *la.*, lacrymal; *na.*, nasal; *opo.*, opisthotic; *pa.*, parietal; *pas.*, parasphenoid; *pb*$_1$-*pb*$_4$, pharyngobranchials 1–4; *pc.*., postcleithrum; *pel.v*, pelvic girdle; *pf.*, prefrontal; *pob.*, postorbital; *ptm.*, post-temporal; *ptryg.*, pterygials; *scap.*, scapula; *soc.*, supraoccipital; *sob.* suborbitals; *sphot.*, sphenotic; *supcl.*, supracleithrum; *stm.*, supratemporal; *vo.*, vomer.