External Form of the Brain in Japanese Salmonoid Fishes and its Ecological Meaning

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One of the authors, UCHIHASHI (1953) has observed the external form of the brain in 72 Japanese teleosts species and noticed that the organ concerns intimately with the behaviour of fish. Since then, we have collected Japanese salmonoid fishes in various waters and studied external anatomy of the brain of these fishes in order to investigate the correlation between the external form of the brain and the behaviour.

Materials and methods

The fishes collected were fixed with 10% formalin and the brains dessected were fixed again with 10% formalin and their external character was observed by the aid of magnifying glass. Some samples were sectioned 20 μ in thickness and stained by the pal-weigelt double dying method for particular observation. (Table 1)

Table 1 Materials of study by forms and its locality of samplng. Identification of species follows MATSUBARA (1955); Species with ○ was studied previously by UCHIHASHI (1953) and in these with △ the section of the organ was made.

Genus	Remarks	Forms	Locality	Total length in cm. (Average)
Oncorhynchus		*O. nerka* (WALBAUM)	North Pacific Ocean	48.2
		O. gorbuscha (WALBAUM)	North Japan Sea	42.0
	○△	*O. keta* (WALBAUM)	Shinano River	51.5
		O. masou var. masou (BREVOORT)	North Pacific Ocean	40.5
	△	*O. masou var. ishikawae* (JORDAN *et* MCGREGOR)	Agano River	23.2
Salmo *Salvelinus*	○△	*S. gairdnerii irideus* GIBBONS	Tajima (cultured)	33.5
	△	*S. pluvius* (HILGENDORF)	Agano River	40.2
	△	*S. fontinalis fontinalis* (MITCHILL)	Shinano (cultured)	25.2

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Results of observation

Oncorhynchus nerka (WALBAM)

The fatty tissue covering the brain is considerably large in quantities and the brain as a whole is slightly depressed. The slope of the line connecting the top of olfactory lobe with that of corpus cerebelli is slightly slant forward, and the top of optic lobe is situated nearly on this line. The order of size of various parts of brain is as follows: 1) optic lobes 2) medulla oblongata 3) corpus cerebelli 4) olfactory bulbs plus olfactory lobes and 5) infundibulum plus inferior lobes.

Olfactory bulb, triangular shape in lateral view, is one half as long as olfactory lobe in size and joins closely with the latter, which is oval in form and is moderately developed, and its back side looks a triangular shallow hollow by the railing fissure limitans telencephali (KAPPERS, 1936). Fissura endorhinalis, Sulcus ypsiliformis and tuberculum taeniae are not clear.

Saccus dorsalis is not visible in external view, and epiphysis swelling in the front is comparatively large. Chiasma opticus is in a single cross, the right nerve cord over the left and these nerves are consisted of many small fiber bundles which show elliptic form in the cross section. Infundibulum lying rear of chiasma opticus is of small horseshoe form and covered with hypophysis which is very large and resembles a chestnut in shape. Sulcus recessus hypophysis is large in size. Inferior lobe small in size is thin and elliptic, but swells considerably, having a weak fovea nervi oculomotorii on the lateral side. Succus vasculosus, with a rather shallow groove, is of thin elliptic form and extends to the middle part of the median line between the inferior lobes in pair.

Optic lobe, growing larger posteriorly, has an elliptic form in dorsal view and "Lateralen Einschnurung" (LISSNER, 1923) is not perceivable, because both optic lobes extend to the side, a part of dorsal torus longitudinalis appearing between them.

Corpus cerebelli is large; lobus anterior cerebelli is not clearly seen and lobus posterior cerebelli extending backward like a tang covers dorsal medulla oblongata. Valvula cerebelli which lies in the optic ventricle shows pattern of a stone-flooring (UCHIHASHI, 1953) as there are perceived 6 swells by fissure in its dorsal surface, and it is divided into anterior and posterior lobes laterally, and in the latter are observed still more 3 swelling portions. Eminentia granularis is ear-like and prominently swells.

Medulla oblongata is very large and the well developed crista cerebelli resembles a long bank, and ventriculus quartus is situated between them.
Both facial and vagal lobe are not noticed clearly but their parts where they locate are markedly swelled.

Oncorhynchus gorbuscha (WALBAUM)

The fatty tissue lying over the brain is considerably large in quantities and the brain as a whole is some what depressed. The slope of the line connecting the top of olfactory lobe with that of corpus cerebelli is slightly slant forward, and the top of optic lobe is situated nearly on this line. The order of size of various parts of brain is as follows: 1) optic lobes 2) medulla oblongata 3) corpus cerebelli 4) olfactory bulbs plus olfactory lobes and 5) inferior lobes plus infundibulum.

Olfactory bulb, triangular shape in lateral view, is two thirds as large sa olfactory lobe in size and joins closely with the latter, which is rice-like in form and is moderately developed, and its back side looks a triangular shallow hollow by the railing fissura limitans telencephali. Fissura endorhinalis, sulcus ypsiliformis and tuberculum taeniae are not clear.

Saccus dorsalis is small in size and epiphysis swelling in the front is comparatively large. Chiasma opticus is in a single cross, the left nerve cord over the right and these nerves show elliptic form in the cross section. Infundibu lum lying in rear of chiasma opticus is of considerably small horseshoe form and covered with hypophysis which is very large and looks like a globe. Sulcus recessus hypophysis is large in size. Inferior lobe small in size looks like a horseshoe in form but swells considerably, having a weak fovea nervi oculomotorii on the lateral side. Succus vasculosus, with a rather shallow groove, is of wheat shape and extends to the middle part of the median line between the inferior lobes in pair.

Optic lobe has an elliptic form in dorsal view and "Lateralen Einschnurung" is not pereceivable, because both optic lobes extend to the side, a part of dorsal torus longitudinalis observed between them.

Corpus cerebelli is large, lobus anterior cerebelli is not clearly seen and lobus posterior cerebelli extending backward like a tang covers dorsal medulla oblongata. Valvula cerebelli shows a pattern of a stone-flooring as there are perceived 6 swells in the dorsal surface, and it is devided into anterior and posterior lobes laterally, and in the latter are observed still more 2 swelling portions. Eminentia granularis is ear-like and remarkably swells.

Medulla oblongata is very large and well developed crista cerebelli resembles a long bank, and ventriculus quartus is situated them. Both facial and vagal lobe are not discovered clearly but their parts where they locate are makedly swelled.

Oncorhynchus keta (WALBAUM)

The fatty tissue covering the brain is large in quantities and the brain as

a whole is slightly depressed. The slope of the line connecting the top of olfactory lobe with that of corpus cerebelli is slightly slant forward, and the top of optic lobe exists a little higher on this line. The order of size of various parts of brain is as follows: 1) optic lebes 2) medulla oblongata 3) corpus cerebelli 4) olfactory bulbs plus olfactory lobes and 5) infundibulum plus inferior lobes.

Olfactory bulb, dull trianglar shape in lateral view, is two thirds as large as olfactory lobe in size and joins closely with the latter, which is ellipse in form and is moderately developed, and its back side looks a triangular shallow hollow by the railing fissura limitans telencephali. Fissura endorhinalis, sulcus ypsiiformis and tuberculum taeniae are not cleare.

Saccus dorsalis is small and epiphysis swelling in the front is considerably large. Chiasma opticus is in a single cross, the right nerve cord over the left and these nerves are consisted of many small fiber bundles which show obtuse elliptic form in the cross section. Infundibulum lying in rear of chiasma opticus is of small heart shape and covered with hypophysis which is very large and thick and resembles a chestnut. Inferior lobe moderate in size is of elliptic form but swells considerably, having a weak fovea nervi oculomorii on the lateral side. Succus vasculosus with a rather shallow groove, is of wheat shape and extends to the middle part of the median line between the inferior lobes in pair.

Optic lobe has a long elliptic form in dorsal view and "Lateralen Einschnurung" is not perceivable, because both optic lobes extend to the side, a part of dorsal torus longitudinalis seen between them.

Corpus cerebelli is large, lobus anterior cerebelli is not clearly seen and lobus posterior cerebelli extending backward like a tang covers dorsal medulla oblongata. Valvula cerebelli shows a pattern of a stone-flooring as there are 6 swells in its dorsal surface and it is divided in to anterior and posterior lobes laterally, and in the latter are observed still more 2 swelling portions. Eminentia granularis is of elliptic form and markedly swells.

Medulla oblongata is very large and well developed crista cerebelli resembles a long bank, and ventriclus quartus is situated between them. Facial and vagal lobe are not noticed clearly but their parts where they locate are markedly swelled.

Oncorhynchus masou var. masou (BREVOORT)

The fatty tissue covering the brain is large in quantities and the brain as a whole is slightly depressed. The slope of the line connecting the top of olfactory lobe with that of corpus cerebelli is slightly slant forward, and the top of optic lobe is situated neraly on this line. The order of size of various parts of brain is as follows: 1) optic lobes 2) medulla oblogata 3) corpus cerebelli 4)

olfactory lobes plus olfactory bulbs and 5) inferior lobes plus infundibulum.

Olfactory bulb, triangular shape in lateral view, is two thirds as large as olfactory lobe in size and joins closely with the latter, which is rice-like in form and is moderately developed, and its back side looks a triangular shallow hollow by the fissura limitans telencephali. Fissura endorhinalis, sulcus ypsiliformis and tuberculum taeniae are not clear.

Saccus dorsalis is not visible in external view, and epiphysis swelling in the front is comparatively large. Chiasma opticus is in a single cross, the left nerve cord over the right and these nerves show elliptic form in the cross section. Infundibulum lying in front of chiasma opticus is of medium horseshoe-like form and covered with hypophysis which is very large and resembles a cone in shape. Sulcus recessus hypophysis is large in size. Inferior lobe, small in size is elliptic, but swells considerably, having a weak fovea nervi oculomotorii on the lateral side. Saccus vasculosus, with a rather shallow fissure, is of elliptic form and extends to the middle part of the median line between the inferior lobes in pair.

Optic lobe has an egg-like form in dorsal view and "Lateralen Einschnurung" is not perceivable, because both optic lobes extend to the side, a part of dorsal torus longitudinalis appearing between them.

Corpus cerebelli is large, lobus anterior cerebelli is not clearly seen and lobus posterior cerebelli extending backward like a slender tang covers dorsal medulla oblongata. Valvula cerebelli presents a stone-flooring look. There are perceived 6 swells in its dorsal surface, and in lateral view it is divided into anterior and posterior lobes, and in the latter are observed still more 2 swelling portions. Eminentia granularis is oval form and markdly swells.

Medulla oblongata is large and the well develped crista cerebelli resembles a long bank, and ventriculus quartus is situated between them. Facial and vagal lobe are not noticed clearly but their parts where they locate are markedly swelled.

Oncorhynchus masou var. ishikawae (JOLDAN et Mc GREGOR)

The fatty tissue covering the brain is moderate in quantities and the brain form is a little depressed. External form of this brain almost resembles to that of *Oncorhynchus masou var. masou*. The slope of the line connecting the top of olfactory lobe with that of corpus cerebelli is slightly slant forward, and the top of optic lobe is situated nearly on this line. The order of size of various parts of brain is as follows: 1) optic lobes 2) medulla oblongata 3) corpus cerelli 4) olfactory bulbs plus olfactory lobes and 5) infundibulum plus inferior lobes.

Olfactory bulb, triangular shape in lateral view, is one half as large as olfactory lobes and joins closely to the latter, which is thin ellipse in form and is

somewhat small, and its back side looks a triangular shallow hollow by the fissura limitans telencephali. Fissura endorhinalis sulcus ypsiliformis and tuberculum taeniae not clear.

Saccus dorsalis is not visible in external view, and epiphysis swelling in the front is comparatively large. Chiasma opticus is in a single cross, the right nerve cord over the left and is of a round shape in the cross section. Infundibulum is moderate in size and like a heart in form and covered with hypophysis which is very large and resembles a ball in shape. Sulcus recessus hypophysis is medium in size. Inferior lobe small in size is of thin and elliptic having a weak fovea nervi oculomotorii on the upper side. Saccus vasculosus, with a weak shallow groove, is of square shape and does not reach the middle part of the median line between the inferior lobes in pair.

Optic lobe is of oval and "Lateralen Einschnurung" is not conscious, and as the both optic lobes extend to the side, a part of dorsal torus longitudinalis is seen between them.

Corpus cerebelli is large, lobus anterior cerebelli is not perceivable and lobus posterior cerebelli stretching out backward like a tang covers dorsal medulla oblongata. Valvula cerebelli presents a stone-flooring look as there are perceived 6 swells in its dorsal sarface, and it is divided into anterior and posterior lobes laterally, and in the latter are considered to be present still more 3 swelling portions. Eminentia granularis is oval and large swells.

Medulla oblongata is considerably large and the well developed crista cerebelli resembles a long bank, and ventriculus quartus is placed between them. Facial and vagal lobe are not observed in external view but their parts where they locate are markedly swelled.

Salmo gairdnerii irideus GIBONS

The fatty tissue lying upon the brain is of very small quantities and the brain as a whole is a little depressed. The slope of the line joinning the top of olfactory lobe with that of corpus cerebelli is slightly slant forward, and the top of optic lobe is placed nearly on this line. The order of size of various parts of brain is as follows: 1) optic lobes 2) medulla oblongata 3) corpus cerebelli 4) olfactory bulbs plus olfactory lobes and 5) infundibulum plus inferior lobes.

Olfactory bulb, triangular form in lateral view, is one half as large as olfactory lobe and joins closely with the latter, which is of thin elliptic form and is moderately developed, and its back side looks a triangular shallow hollow by the fissura limitans telencephali. Fissura endorhinalis, sulcus ypsiliformis and tuberculum taeniae are not clear.

Saccus dorsalis is not visible in external view and epiphysis swelling in the front is large. Chiasma opticus is in a single cross, the right nerve cord over

the left one and these nerves show elliptic form in the cross section. Infundibulum lying in rear of chiasma opticus is of medium heart-like form and covered with hypophysis which is very large and resembles a chstnut in shape. Sulcus recessus hypophysis is large in size. Inferior lobe small in size is pillow-like form (UCHIHASHI 1953) but swells considerably, having a weak fovea nervi oculomotorii on the upper side. Saccus vasculosus, with a small shallow groove, is of thin elliptic form and extends to the middle part of the median line between the inferior lobes in pair, but many vacuoles exist in it.

Optic lobe has on elliptic form in dorsal view and "Lateralen Einschnurung" is not perceivable. Both optic lobes extend to the side, and part of dorsal torus longitudinalis is observed between them.

Corpus cerebelli is large, lobus anterior cerebelli is not clearly seen and lobus posterior cerebelli extending backward like a tang covers dorsal medulla oblongata. Valvula cerebelli shows pattern of a stone-flooring as there are perceived 8 swells by fissure in dorsal surface and it is divided still more 4 swelling portions. Eminentia granularis is ear-like and is moderately developed.

Medulla oblongata is large and the well developed crista cerebelli which shows a bank form is placed outside of ventriculus quartus. Facial and vagal lobe are not observed in the external look but their parts where they locate are markedly swelled.

Salverinus pluvius (HILGENDORF)

The fatty tissue covering the brain is a little in quantities and the brain as a whole is a little depressed. The slope of the line connecting the top of olfactory lobe with that of corpus cerebelli is a little slant forward, and the top of optic lobe juts out slightly. The order of size of brain parts in out look is : 1) optic lobes 2) medulla oblongata 3) corpus cerebelli 4) olfactory bulbs plus olfactory lobes and 5) infundibulum plus inferior lobes.

Olfactory bulb, obtuse triangular shape in lateral view, is one half as long as olfactory lobe in size and joins closely with the latter, which is thin ellipse in form and is somewhat small, and its back side looks a triangular shallow hollow by the railing fissura limitans telencephali. Fissura endorhinalis, sulcus ypsiliformis and tuberculum taeniae are not clear.

Saccus dorsalis is not visible in external view, and epiphysis swelling in the front is comparatively large. Chiasma opticus is in a single cross, the right nerve cord over the left and shows an elliptic shape in the cross section. Infundibulum is moderate in size, is like heart in form and covered with hypophysis which is very large and looks like an ellipse. Sulcus recessus hypophysis is medium in size. Inferior lobe is small in size is elliptic, having a weak fovea nervi oculomotorii on the lateral side. Saccus vasculosus, with a weak shallow

groove, is of oval shape and does not extends to the middle part of the median line between the inferior lobes in pair.

Optic lobe is of thin elliptic form and "Lateralen Einschnurung" is not censcious. As the optic lobes extend to the side, a part of dorsal torus longitudinalis is appeared between them.

Corpus cerebelli is large, lobus anterior cerebelli is not perceivable and lobus posterior cerebelli stretching out backward like a tang covers dorsal medulla oblongata. Valvula ceredelli presents a stone-flooring look as there are considered to be present still more 6 swells in dorsal view, and it is divided into anterior and posterior lobes laterally, and in the latter there are 3 swelling portions. Eminentia granularis is ellipse in form and prominently swells.

Medulla oblongata is considerably large and the well developed crista cerebelli resembles a long bank, and ventriculus quartus is placed between them. Facial and vagal lobe are not visibled in external view but their parts where locate are markedly swelled.

Salvelinus fontinalis fontinalis (MITCHILL)

The fatty tissue covering the brain is of a small quantities and the brain form is a little depressed. The slope of the line connecting the top of olfactory lobe with that of corpus cerebelli is a little slant forward, and that top of optic lobe juts out slightly on this line. The order of size of brain parts is: 1) optic lobes 2) medulla oblongata 3) corpus cerebelli 4) olfactory bulbs plus olfactory lobes and 5) iofundibulum plus inferior lobes.

Olfactory bulb, triangular shape in lateral view, half as long as olfactory lobe in size and is connected closely with the latter, which is ellipse in form and is moderately developed, and its back side looks a triangular shallow hollow by the fissura limitans telencephali. Fissura endorhinalis, sulcus ypsiliformis and tuberculum taeniae are not discovered.

Saccus dorsalis is not clear in external view, and epiphysis swelling in the front is comparatively large. Chiasma opticus is in a single cross, the right nerve cord over the left and these nerve show round shape in the cross section. Infundibulum lying in rear of chiasma opticus is of medium horseshoe form and covered with hypophysis which is somewhat small. Sulcus recessus hypophysis is large in size. Inferior lobe medium in size is elliptic, but swells considerably, having a weak fovea nervi oculomotorii on the lateral side. Saccus vasculosus, with a rather shallow groove, is of raindrop form and extends to the middle point of the median line between the inferiof lobes in pair.

Optic lobe is of an elliptic form in dorsal view and "Lateralen Einschnurung" is not perceivable, because both optic lobes extend to the side, a part of dorsal torus longitudinalis appearing between them.

Corpus cerebelli is large; lobus anterior cerebelli is not clearly seen and lobus posterior cerebelli extending backward like a tang covers dorsal medulla oblongata. Valvula cerebelli which lies in the optic ventricle shows pattern of a stone-flooring as there are perceived 6 swells in its dorsal surface, and it is devided into anterior and posterior lobes laterally, and in the latter observed still more 2 swelling portions. Eminentia granularis is ear-like and large swells.

Medulla oblongata is very large and the well developed crista cerebelli resembles a long bank, and ventriculus quartus is situated between them. Facial and vagal lobe are not noticed clearly but their parts where they locate are markedly swelled.

The external form of brain and the behaviour in salmonoid fishes

1) Cranial cavity and volume of the brain

The volume of the brain which occupies the cranial cavity in teleosts various greatly by species and this fact arises from the quantity of fatty tissue covering the brain. One of the authors, UCHIHASHI (1953) has examined the fatty tissue in cranial cavity of some fishes and stated that it is in close relation with the depth of water they dwell, and a remarkable growth in fatty tissue is discoverd among the fishes living in the greater depth of the sea, further the tracing of the development of teleost brain revealed the fact that its volume changes during the growth of fish within a species.

The salmonoid fishes are in general classified into the groups with medium and lesser quantities in fatty tissue (UCHIHASHI, 1953), more over precise observation, in this group are observed still more two sub-groups, i.e., the subgroup with higher quantity of fatty tissue, (*Oncorhynchus nerka, Oncorhynchus gorbuscha, Oncorhynchus keta* and *Oncorhynchus masou var. masou*) and the sub-group with lesser quantity of fatty tissue, (*Oncorhynchus masou var. ishikawae, Salmo gaidnerii irideus, Salvelinus pluvius* and *Salvelinus fontinalis*).

According to the ecological observation in salmon, the former includes oceanic species and the latter fresh water fishes, and this fact seems to agree well with the opinion of UCHIHASHI (1953) above-mentioned. Especially, the fact that the volume of fatty tissue in *Oncorhynchus masou var. masou* is larger in quantities than that in *Oncorhynchus masou var. ishikawae*, the land-locked form of the former, can be considered to correspond to the difference in the behaviour and habitat.

2) Type of the brain

The brain in 8 forms of salmonoid fishes we have examined are slightly depressed and accords with morphnlogical character of brain in the surface fishes (UCHIHASHI, 1953).

3) The degree of development in each part of the brain

Table 2. External characters of brain in eight species of salmonoid fish.

Parts		Fatty tissue	Order in size of various part of brain	T-C line		Lateral view
Genous	forms			Slope	Situation of optic lobes	Olfactory bulb
Oncorhynchus	*O. nerka*	much quantity	O-M-C-T-D	a little slant forword	on T-C line	trianglar
〃	*O. gorbuscha*	〃	〃	〃	〃	〃
〃	*O. keta*	〃	〃	〃	a little higher than T-C line	〃
〃	*O. masou val. masou*	〃	〃	〃	on T-C line	〃
〃	*O. masou val. ishikawae*	medium quantity	〃	〃	〃	〃
Salmo	*S. gairdnerri irideus*	a very little quantity	〃	〃	〃	〃
Salvelinus	*S. pluvius*	a little quantity	〃	〃	jut out from T-C line	〃
〃	*S. fontinalis fontinalis*	〃	〃	〃	〃	〃

T-C line ……The line connecting the top of olfactory lobe with that of corpus cerebelli
O……Optic lobes
M……Medulla oblongata
C……Cerebellum
T……Olfactory bulbs plus olfactory lobes
D……Inferior lobes plus infundibulum

(See foot-note for the definition abbreviated letters in table).

Dorsal view			
Olfactory lobe	Optic lobe	Corpus cerebelli and eminentia granularis	Valvula cerebelli
ellipse	thin ellipse		
thin ellipse	ellipse		
ellipse	thin ellipse		
rice-like	oval		
thin ellipse	〃		
〃	ellipse		
〃	thin ellipse		
ellipse	oval		

According to the result of comparative investigation on the development of the various parts of brain (telencephalon, mesencephalon, diencephalon and medulla oblongata etc.), the salmonoid fishes are believed to belong to the category carrying in mesencephalon well-grown as UCHIHASHI has mentioned (1953). The species which has a well developed mesencephalon is found among many teleosts, and these 8 forms of salmons have medulla oblongata second in order of size followed by large cerebellum among 5 parts of brain (Table 2). As will be mentioned later, the fact that the medulla oblongata is considerably well de veloped in spite of the absence of prominent swells in crista cerebelli may show the gastatory sence highly inportant to these fishes among other function in mode of life.

4) Telencephalon

A) Olfactory bulb

In all species examined, the olfactory bulbs combine closely with olfactory lobes and olfactory region joins with the former by long olfactory nerves. According to UCHIHASHI (1953), the degree of the olfactory faculties in fishes has an intimate relation with the developments not only in olfactory lobes but also in olfactory bulbs. The fishes in this family have a well developed olfactory bulbs which are of triangular shape in lateral view, and it is significant to see that *Oncorhynchus gorbuscha*, *Oncorhynchus keta* and *Oncorhynchus masou var. masou* have large bulbs compared with the olfactory lobes, and the former are two thirds as large as the latter in size.

B) Olfactory lobe

The size and shape of the olfactory lobes which occupy the main portion of telencephalon vary forms. The organ in salmonoid fishes are simple comparatively and divided clearly into two hemisphers, further some species have olfactory lobes consisted of small epistrata and large substrata on the whole these strata not clearly observed. The back side olfactory lobes in all species of salmon shows a triangular shallow hollow formed by fissura limitans telencephalli, and fissura endorhinalis, sulcus ypsiliformis, tuberculum taeniae are not discovered in these species. However, the fact that olfactory bulbs comparatively well develop an mentioned above and that olfactory lobes are comparatively large (especially in oceanic salmon) are leading to interpret they depending upon the olfactory sence more than in other surface fishes such as mackerels, sardines, and etc.. Moreover, that the homing instinct or orientation in salmon is attributed to smell sense (HASLAR, 1954, 1955) and that recently *Oncorhynchus gorbuscha* is frequently fished in Hokkaido by long line during the night (NIWA, 1955) may be due to the structures of telencephalon and medulla oblongata as will be referred later.

5) Diencephalon

A) Saccus dorsalis

The tiny saccus dorsalis is discovered in *Oncorhynchus gorbuscha* and *Oncorhynchus keta* but in other species it is difficult to find with our naked eye and its ecological meaning is not understood at presents.

B) Epiphysis

The epiphysis of all these species developes well, and swells in the top, in some species extending to near the olfactory bulb. Reciprocity between this organ and the behaviour is not understood clearly.

C) Saccus vasculosus

Saccus vasculosus is classified to the type of thin elliptic form (as in *Oncorhynchus nerka* and *Salmo irideus*) and that of wedge (*Oncorhynchus gorbuscha* and *Oncorhynchus keta*) or that of square (*Oncorhynchus masou var. ishikawae*) or that of oval (*Oncorhynchus masou var. masou* and *Salvelinus pluvius*) or that of raindrop (*Salvelinus fontinalis*), and all species have longitudinal shallow on the ventral surface. In external view, *Oncorhynchus nerka, Oncorhynchus keta* and *Salmo irideus* have a large saccus vasculosus, *Oncorhynchus gorbuscha* and *Oncorhynchus masou var. masou* a considerably large one, *Salvelinus fontinalis* a moderate and *Oncorhynchus masou var. ishikawae* and *Salvelinus pluvius* a small one. In general oceanic salmons are inclined to have a large saccus vascalosus. In *Salmo irideus*, saccus vasculosus is large in size but many vacuoles exist in it. UCHIHASHI (1953) has noticed that in the teleosts the size and shape of succus vasculosus and their havitual water have an established interrelation, and this is the organ that has been stated, according to KAPPERS (1936), by some authors including BOEKE (1901), JHONSTON (1906) and DAMMERMAN (1910) probably to serve forthe perception of fluid pressure and, the perception of depth since the pressure increases with the depth of water. As mentioned above in salmonoid fishes, saccus vasculosus of landlocked and fresh water forms is either very small in size or not solid as compared with that of oceanic fishes and these facts show that progress of this organ has accordance with the behaviour. Especially, it is interesting to note that saccus vasculosus of *Oncorhynchus masou var. masou* is more progressed than that of *Oncorhynchus masou var. ishikawae*, the landlocked-form of the former, also that the above-mentioned relationship between the quantity of fatty tissue and the ocean-going habit is also applicable to these forms.

D) Infundibulum

Infudibulum is an organ which is most remarkably swollen in the ventral portion of diencephalon. In salmon these are covered with large hypophysis and are horseshoe, heart, or ellipse in form and sulcus recessus hypophysis is recognized on them. It is smaller than inferior lobe in size and its connection with the behaviour is not clear.

E) Inferior lobe

In salmonoid fishes, inferior lobes are of elliptic or pillow-like form and are small in size, but they swell considerably having a weak fovea nervi oculomotorii on the lateral side. The degree of growth and swelling the inferior lobe has a positive correlation with the behaviour in the nocturnal fish (UCHIHASHI, 1953), and in these salmonoid forms inferior lobe is medium or small in size but swells comparatively in form, differing form that of surface fishes. Therefore, the salmonoid fishes do not seem to carry on feeding on purely visual sence.

6) Mesencephalon (Optic lobes)

In teleost there are many species which have the well developd optic lobes. These salmonoid fishes, however, entirely lack them but the optic lobes are developd more remarkably than other parts of the brain and are thin-ellipse, oval or ellipse in form and show some features charactaristic to salmon, that is, the optic lobes extends to the side, a part of dorsal torus longitudinalis seen between them. By the reasons of the charactaristic of optic lobes in these fishes and of their behaviour to bite feather hook, *Oncorhynchus masou var. masou*, *Oncorhynchus masou var. ishikawae*, *Salmo irideus*, *Salverinus pluvius* and *Salverinus fontinalis* seem to have a visual perseption for feeding. And other salmons such as *Oncorhynchus keta*, *Oncorhynchus nerka* and etc. may also be fished by the same method, but we have not yet heard they actually are.

7) Cerebellum

A) Corpus cerebelli

Corpus cerebelli in these fish is classified as "large bend backward type" (UCHIHASHI, 1953), lobus anterior cerebelli is not clearly seen and lobus posterior cerebelli extending backward like a tang covers all of ventriclus quartus, and exsits a big longitudinal riseing on that.

The degree of development of this organ is said to be related to speed and ability of swimming and to balance of body (TUGE, 1934, UCHIHASHI, 1952, 1953). Therefore that the corpus cerebelli is large in salmonoid fishes seem to agree the behaviour of thses fishes which are wide-range migrators.

In the dark *Salmo irideus* stays still in some position and seems to keep the balance of body facing forward the water flow (UCHIHASHI, TUGE, INOUE and II, 1954). *Salverinus fontinalis*, *Oncorhynchus masou var. ishikawae* also seem to have a similar behaviour, and oceanic salmon such as *Oncorhynchus keta*, *Oncorhynchus gorbuscha*, *Oncorhynchus masou var. masou* should have the same behaviour judging from our observation on corpus cerebelli.

B) Valvula cerebelli

Valvula cerebelli is a part of the cerebellum which extends in optic ventricle, but not found externally. Its function and structure have been described by UCHIHASHI (1953) who stated that the size which occupies on optic ventriclus

has relation to the behaviour of the species, that is, the larger in size and the more complicated in structure the quicker in the swimming. So far as the 8 forms in salmon are concerned this organ occupies more than half of area in optic ventriclus and appears like a stone-flooring and is divided into two portions, anterior and posterior lobe. In the latter are observed more than 4 to 6 portions by which we can classify them into some refferent groups, also the structure of valvula cerebelli in these fishes shows the characteristic of the behaviour which is quick in action.

C) Eminentia granularis

In salmonoid fishes the eminentia granularis which are swelled into a lump is ear-like in shape (*Oncorhynchus nerka, Oncorhynchus gorbuscha, Salmo irideus* and *Salvelinus fontinalis*), ellipsoid (*Oncorhynchus keta* and *Salvelinus pluvius*) and oval (*Oncorhynchus masou var. masou* and *Oncorhynchus masou var. ishikawae*) in form, and is more or less larger in size as compared with that in other fishes. This organ substitutes functionally for auricles (KAPPERS, 1936) and is important organ in sense of equilibraium and together with lateral line (UCHIHASHI, 1953). The fact that salmonoid fishes have a well developed eminentia granularis agrees with their behaviour which is categoristed as surface swimmer.

7) Medulla oblongata

A) Crista cerebelli

In salmonoid fishes the crista cerebelli well-developing resembles a long bank and ventriclus quartus is situated between them but develops in a poorer degree compered with other members in the group with a prominently developed crista cerebelli which looks like a bridge. The development of crista cerebelli is stated by KAPPERS (1936) to have connection with the great development of lateral line system. Those fishes depend not only on the visual sense for the forming of school but also the lateral line system when schooling is made at night by feeling the wave of vibration caused by swimming (UCHIHASHI, 1953). Therefore the development of crista cerebelli has reciprocity to schooling behaviour at night.

According to these views the fishes in Genus *Oncorhynchus* seem to have some schooling behaviour which, however, is not considered to prevail in a same degree as in other pelagic fishes. In fact, in these fishes the nocturnal schooling is not found clearly at night.

B) Facial and vagal lobes

Facial and vagal lobes are not clearly visible externally but their places are well swollen as compared with other surface fishes such as yellowtail, fanacuda and mackerel. The fact that these species are fished by long line at night or in the daybreak (SOEDA, 1954) show relation to the development of gustatory sense organ in medulla.

Summary

The external character of the brain was observed in 8 forms of salmonoid fishes and its relation to the behaviour was discussed.

1) The morphological characteristics of the brain may be briefed as follows:

A) Concerning the fatty tissue the fishes are classified into a group with medium amount and other with lesser amount; each group is further subdivided into sub-group, with higher quantity of fatty tissue and the sub-group, with lesser quantity of fatty tissue.

B) The brain is slightly depressed, and the slope of the line connecting the top of olfactory lobe with the same of corpus cerebelli is slightly inclined anteriorly.

C) Olfactory lobes join closely to the front of olfactory lobes and they are the largest among fishes of surface water or of migratory behavior. Olfactory lobes have a fissura limitance telencephali on its dorsal surface.

D) Inferior lobes, rather small ellipsoid and swell considerably carring weak fovea nervi oculomotorii. Saccus vasculosus is horseshoe, heart or oval in shape.

E) Optic lobes are a little smaller than in other surface fish. Torus longitudinalis is seen between the rear part of dorsal optic lobes.

F) Corpus cerebelli is large in size. Lobus anterior cerebelli is not clearly seen, and lobus posterior cerebelli, tang like, covers all surface of ventriclus quartus; valvula cerebelli resembles stone-pavement in appearance. Eminentia granularis swells to an ellipsoid or oval body.

G) Crista cerebelli, well developed, appears in an elongated bank. Externally facial and vagal lobes are not visible, but their location is discernible by swelling on the surface.

2) External character of brain and the behaviour of fish may be summarised;

A) The fact that telencephalon is moderately developed and inferior lobes are small but swell comparatively well in the salmonoid fish will lead us to believe these fish depending in greater extent on olfactory sense than other surface or migrating species such as sardine, mackerel, Pacific saury and etc.

B) The size of saccus vasculosus in the salmonoid fish has cleary shown to very relating to the behaviour of fish observed in sea-going, land-lock or freshwater life.

C) The fact that crista cerebelli is well developed but in a poorer degree as compared with those members in the group of prominent development asdefined

by UCHIHASHI (1953) and that it does not show the bridge-form (UCHIHASHI 1953) gives rise to question to the prominent schooling habit refered to these fishes, the habit which is though considered to be somewhat comparatively intensified by progress of lateral line sense.

D) In shape and size valvula cerebelli varies by forms to the salmonoid fish and its development appears to bear a relation to the speed of fish in movement.

We wish here to express our deep thanks to messrs. Dr. K. Kuronuma (Tokyo), M. Amano (Niigata), H. Fukataki (Niigata), I, Oya (Hokkaido) and Miss A. Honda (Niigata).

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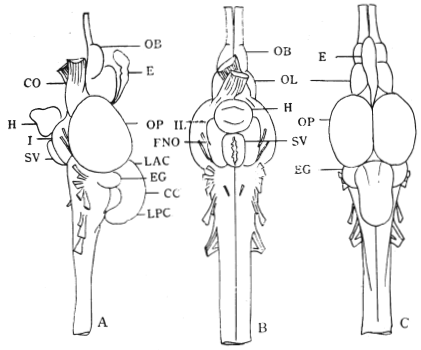
Plate 1. The external form of brain in salmonoid fishes.

A) Lateral view, B) Ventral view, C) Dorsal view

1.	*Oncorhynchus nerka*	1.4×
2.	*Oncorhynchus gorbuscha*	1.4×
3.	*Oncorhynchus keta*	1.6×
4.	*Oncorhynchus masou var. masou*	1.6×
5.	*Oncorhynchus masou var. ishikawae*	2.8×
6.	*Salmo gaidnerii irideus*	2.0×
7.	*Salvelinus pluvius*	1.6×
8.	*Salvelinus fontinalis fontinalis*	2.8×

Abbreviations used in the explanation of figures:

CO, Chiasma opticum. CC, Corpus cerebelli. EG, Eminentia granularis. E, Epiphysis. FNO, Fovea nervi Oculomotorii. H, Hypophysis. IL Inferior lobe. I, Infundibulum. LAC, Lobus anterior cerebelli. LPC, Lobus posterior cerebelli. OB, Olfactory bulb. OL, Olfactory lobe. OP, Optic lobe. SV, Saccus vasculosus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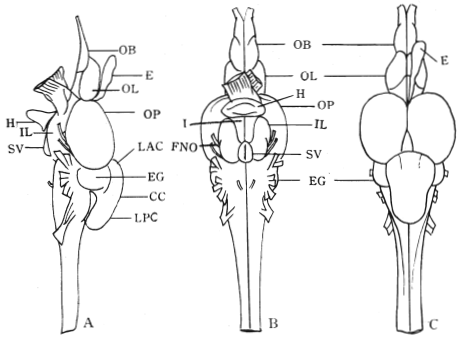
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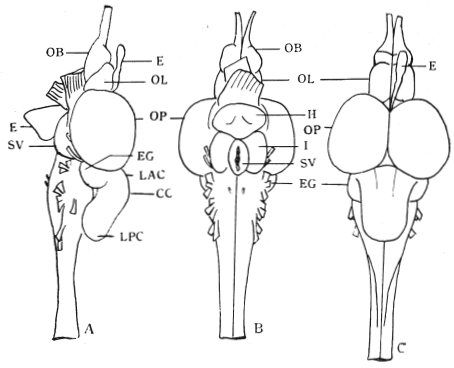
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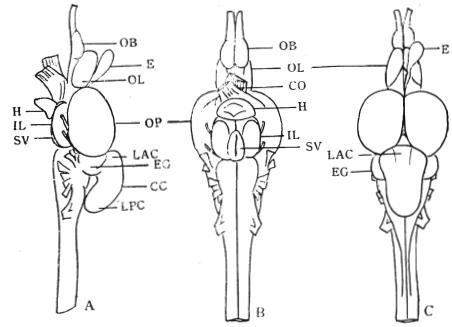
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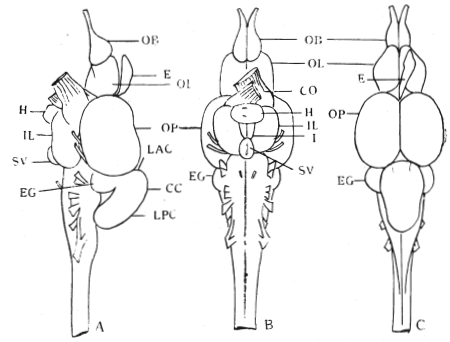
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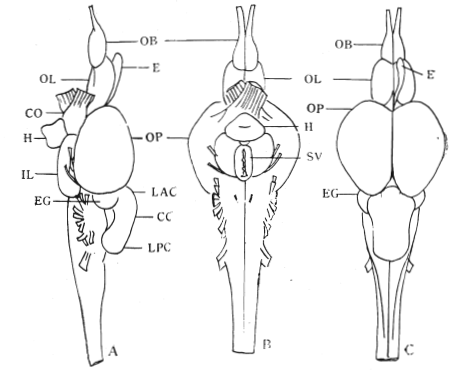
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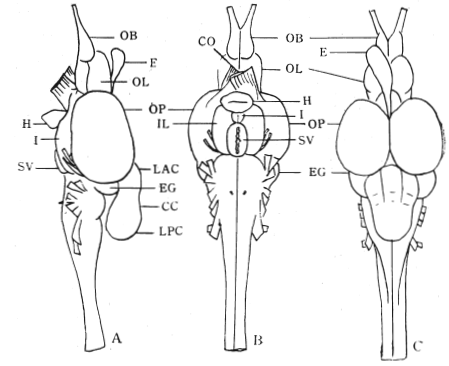
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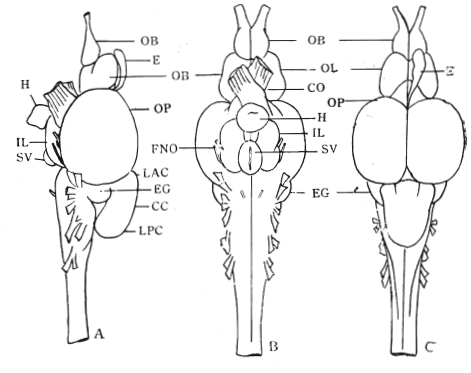
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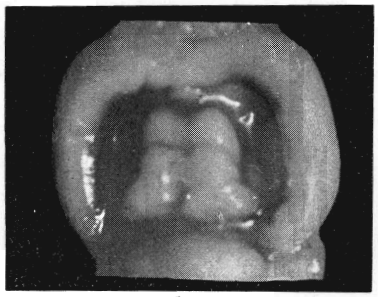
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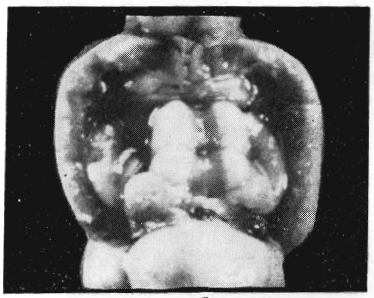
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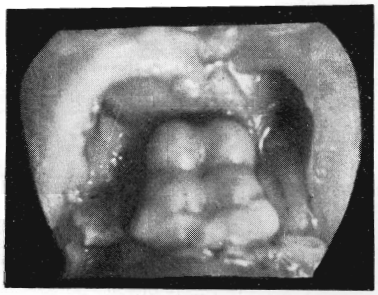
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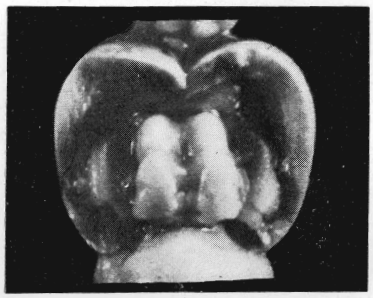
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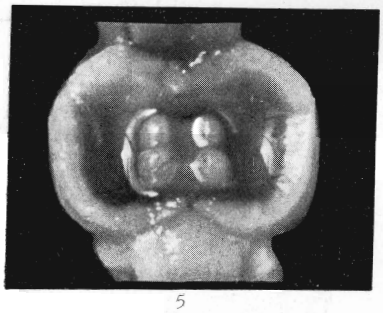
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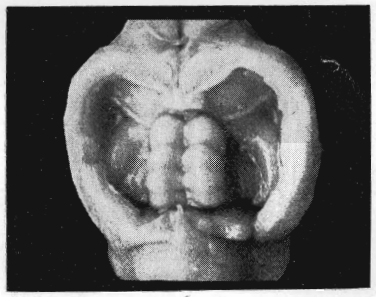
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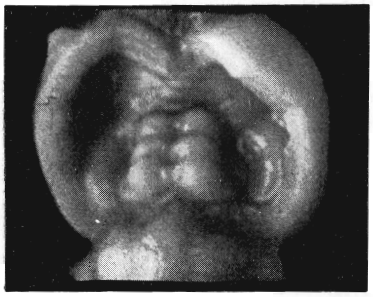
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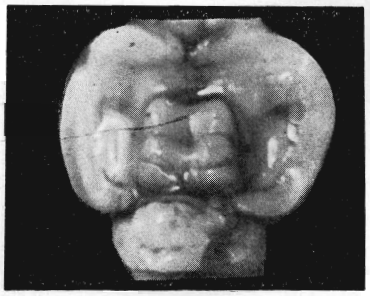
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Plate 2. Dorsal view of valvula cerebelli in salmonoid fishes

1. *Oncorhynchus nerka* 4.0 ×
2. *Oncorhynchus gorbscha* 3.5 ×
3. *Oncorhynchus keta* 4.4 ×
4. *Oncorhynchus masou var. masou* 3.7 ×
5. *Oncorhynchus masou var. ishikawae* 4.5 ×
6. *Salmo gairdnerii irideus* 3.4 ×
7. *Salvelinus pluvius* 3.6 ×
8. *Salvelinus fontinalis* 4.2 ×