UNIVERSITY OF TORONTO
BIOLOGICAL SERIES NO. 59

SOME ASPECTS OF THE PHYSIOLOGY OF FISH

By

W. S. HOAR, V. S. BLACK, and E. C. BLACK
(From the University of British Columbia)

Publications of the
Ontario Fisheries Research
Laboratory, No. LXXI

UNIVERSITY OF TORONTO PRESS: 1951

Printed in Canada
London: Geoffrey Cumberlege
Oxford University Press

FOREWORD

This number of the publications of the Ontario Fisheries Research Laboratory contains three reviews which were presented under the same title in a symposium sponsored by the Canadian Committee on Freshwater Fisheries Research at Ottawa, January, 1949. Two other reviews were presented at the same symposium. One of these "The Growth, General Chemistry and Temperature Relations of Salmonid Eggs" by F. R. Hayes, has been published in the *Quarterly Review of Biology*, 24:281-308 (December, 1949). The other, "Temperature Relations of Fish" by F. E. J. Fry, has not yet been prepared for publication.

CONTENTS

I. Hormones in Fish

II. Osmotic Regulation in Teleost Fishes

III. Respiration in Fishes

I. HORMONES IN FISH

BY

WILLIAM S. HOAR

Department of Zoology, University of British Columbia

INTRODUCTION

CHEMICAL regulators, known as hormones, have now been identified in every major group of animals. These chemicals are of importance in regulating reproduction, development, growth, metabolism and behaviour. The mammalian hormones have been most extensively studied because of their intimate relation to man's health and well-being. However, comparable regulators are well known in the invertebrates (86, 209) and the literature on the lower vertebrates is now voluminous.

In figure 1 an attempt has been made to summarize the present information concerning the hormones of fish. The investigated topics may be grouped under: (1) colour responses; (2) metabolic regulation; (3) reproductive activity and behaviour; (4) growth; and (5) migration. The first topic is not dealt with here since colour responses have been the subject of several recent and comprehensive reviews (169, 170, 226). Our knowlege of the humoral control of the internal steady states of the fish's body is still meagre and the literature on metabolic regulation will be summarized very briefly. This section is followed by a more comprehensive discussion of the endocrine physiology of reproduction, growth, and migration.

METABOLIC REGULATION

Hormones play a predominant part in the maintenance of steady states of the internal environment of the animal. Fish are no exception. Although the field has not been comprehensively investigated, there is sufficient work to show that controlling mechanisms, comparable to those found in the mammals, are present. There are, however, differences in detail and in certain cases the regulation in fishes seems to represent a primitive stage in the evolution of conditions found in the higher vertebrates.

Thyroid and the rate of metabolism

Thyroid treatment has failed repeatedly to produce any change in the metabolism of fish as measured by their oxygen consumption. Both goldfish (*Carassius auratus*) and guppies (*Lebistes reticulatus*) have been studied. For the former a continuous flow type of apparatus was used and the "standard" metabolism determined (52, 89) while oxygen consumption of the guppies was measured by the

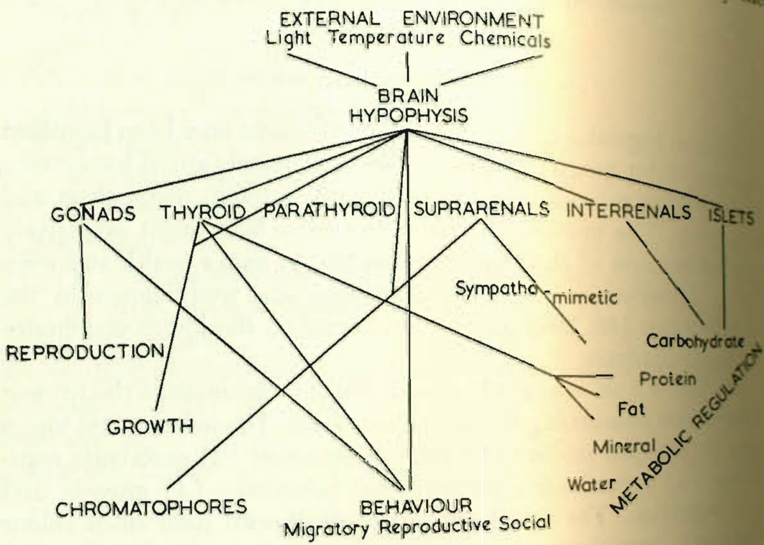

FIGURE 1

Warburg technique (198). In addition, it has been shown that the thyroid inhibitor, thiourea, produces no reduction in the oxygen metabolism of *Fundulus* (142), although it does inhibit thyroid activity in fish as in the higher vertebrates (66, 124). Results of experiments with other chemicals suggest that the failure to demonstrate an effect with thyroxine is not due to technical difficulties. An effective agent will produce changes in oxygen consumption which are readily detected by the techniques used in the above experiments. Toadfish (*Opsanus tau*), injected with 2-4 dinitrophenol, show a rise of almost 100% in oxygen consumption (182) while gonad stimulation in the goldfish will produce a mean increase of as much as 36% (89).

It is possible that the thyroid hormone of fish is group- or species-specific and that mammalian thyroid preparations are not physiologically active. Indeed, Smith and Matthews (200) have recently investigated this by injecting white grunts (*Bathystoma*) with extracts of the thyroid gland from the Bermuda parrot fish and reported significant rises in the oxygen consumption of fish in certain definite sizes. This work is by no means conclusive and the question must await further studies. It is perhaps worthwhile pointing out that fish thyroid has been shown to accelerate metamorphosis of frog tadpoles (79, 191). Moreover, mammalian thyroid preparations bring about characteristic changes in the histological picture of the thyroid of the salmon (97), induce premature metamorphosis in gobies (87), alter the body proportions of fish (77, 197), the chloride metabolism (93, 119) and the nitrogen metabolism as indicated by the deposition of guanine in the skin (121, 180, 197). These changes, comparable to those which have been associated with physiologically active thyroid glands, do not support the theory that the thyroid hormone of fish is physiologically different from that of other groups. The thyroid is evidently involved in the regulation of the metabolism of fish, whether or not it is involved in the control of oxidative metabolism.

Islets of Langerhans and carbohydrate metabolism

An endocrine control of carbohydrate metabolism is well established in fishes. "Follicles of Langerhans," found in the wall of the alimentary canal of the ammocoete larva of *Petromyzon marinus unicolor*, are evidently related to carbohydrate metabolism and represent a primitive stage in the evolution of the typical vertebrate islet tissue (8). Well developed islets of Langerhans have been identified in both selachians (107, 205, 222) and teleosts (21, 144). Removal of this tissue has been shown to produce a marked hyperglycemia in both groups (134, 146, 147, 194). The fact that the hyperglycemia which follows isletectomy is alleviated by hypophysectomy (removal of the anterior lobe) indicates that insulin secretion and the insulin-antagonizing or glycotrophic hormone of the pituitary (14) are related in fish as in the higher vertebrates (2, 104, 166).

The insulin content of the islet tissue of teleost fishes is evidently much lower than the insulin content of the mammalian islets (81). However, since the islet tissue is separate from the enzymatic tissue of the pancreas in many fish, the islets have been shown to be as potent a source of insulin—weight for weight—as mammalian pancreas (145).

Insulin, extracted from fish tissue, alleviates the symptoms of diabetes in both fish and man (147). The effect of insulin injected into normal fish seems to vary with the species (74, 163). According to Gray and Hall (74) the "more active species" show a marked fall in blood sugar with convulsions while the "sluggish ones" show only a slight fall in blood sugar. Brunn and Hemmingsen (24) found that much larger doses of insulin were required to produce convulsions in *Lebistes* than in mammals. Male *Lebistes*, used in these experiments, weighed 50 to 100 times less than the mice but required 50 to 100 times as much insulin in intraperitoneal injections (10 times as much in intramuscular injections) to produce comparable effects. The fish experiments were carried out at 33°C. These workers feel that the insulin mechanism is not fully differentiated in the teleosts as a group or that there may be species specificity. The subject has not been adequately investigated but present evidence does not support the latter suggestion and it seems safe to conclude that the insulin control of carbohydrate metabolism is universal in the vertebrates. There are, however, still many problems in carbohydrate metabolism to be investigated for different groups of fish.

Parathyroid and calcium metabolism

Parathyroid tissue is not generally recognized in fish and no one seems to have been concerned with the control of calcium metabolism in this group. Schereschewsky (188) has described epithelial tissue of a glandular nature in the superficial part of the isthmus of *Lebistes* between the two first gill arches which she believes to be parathyroid tissue. A thorough study of the factors involved in the regulation of the calcium metabolism of fish is indicated.

Chromaphil system and the effects of adrenalin

In fishes the two components of the adrenal complex are clearly distinct anatomically (1, 14, 221) as well as physiologically (132). The suprarenals or chromaphil corpuscles produce adrenalin, while the interrenals or cortical bodies produce adrenal cortical steroids.

Adrenalin of fishes seems to be the same physiologically as the adrenalin from the mammalian adrenal. Gaskell (68) demonstrated that extracts of the chromaphil tissue from *Petromyzon fluviatilis* which could be matched caused a rise in blood pressure of the cat by measured adrenalin injections. It can be assumed that the chromaphil tissue of fish is physiologically active and that the adrenalin mechanisms in this group are comparable to those of the higher vertebrates. However, the significance of adrenalin, under normal conditions, is by no means clear. Although the pharmacological effects have been studied in several species of fish, there are no data for variations in the adrenalin concentration of normal fish blood.

In general, parenteral injections of adrenalin are sympathomimetic in fish as in higher vertebrates. The effects have been studied more frequently in elasmobranchs than in teleosts. The work is briefly summarized here. Differences found between the action of adrenalin in fish and in mammals can usually be related to differences between the autonomic nervous systems of the groups (131, 153, 231, 232). For the Selachii, injections of adrenalin produce a pronounced rise in blood pressure, which is sustained for a relatively longer time than in the mammal (133, 230), and is brought about by contraction of the muscular arteries arising from the aorta (5). Likewise, on injection of adrenalin, there is dilation of the pupil (233); increased (105) or decreased (130, 132) heart rate, possibly depending on the concentrations used (94); increased gastric and intestinal motility (131, 152, 153); but no effect whatever on the secretion of the pancreas (4).

For teleosts, adrenalin accelerates the heart beat of *Fundulus* embryos (22); brings about a vasodilation of the blood vessels in the gills and a vasoconstriction of the systemic vessels of the eel (114), constriction of the pupil of the isolated eye (234), relaxation of the intestine contracted by mechanical stimuli (13), depression of the oxygen consumption of *Girella nigricans* (199), and produces a polyuria only in glomerular fish (207). The depression in oxygen consumption of *Girella nigricans* is interesting. This does not seem to be related to peculiarities in the autonomic nervous system of the teleost and is contrary to results expected on the basis of mammalian experiments. In the experiments on *Girella*, control animals, injected with saline, showed a pronounced rise in oxygen consumption associated with increased activity. Further, the amounts of adrenalin injected were sufficient to produce a definite colour change. This would seem to be a worthwhile subject for additional study. If such a mechanism exists, it might be of value to the fish in some emergency situations.

Cortical bodies and the action of cortin

Biedl (15), Kisch (115, 116) and Dittus (50) have described the effects of removing the interrenal bodies from *Torpedo ocellata* and *T. marmorata*. Total extirpation of the interrenal tissue in these fish brings about a muscular weakness followed by early death due to respiratory failure. The lethal times reported by these workers vary somewhat but, in all cases, are less than three weeks. In addition, changes in pigmentation are described. Extracts of the interrenal tissue were shown to relieve the respiratory symptoms and muscular weakness and to restore normal skin colouration (115, 116). These studies demonstrate the vital role which the interrenal bodies of *Torpedo* play. The symptoms of interrenalectomy observed in this selachian indicate a fundamental similarity between the physiology of the interrenals and the cortex of the mammalian adrenal. Grollman, *et al.* (78) have provided additional evidence for the existence of interrenal cortical hormones in the selachians with action similar to those found in the mammalian adrenal cortex. Acetone extracts of fresh material from several different species of *Raja* were shown to maintain normal growth in bilaterally adrenalectomized young rats. Conversely, Dittus (50) found that mammalian cortical extracts prolong the life of the interrenalectomized *Torpedo*. It is evident that the interrenals are vital to the selachian and probable that the hormones of the mammalian adrenal cortex and the selachian interrenal are, at least in part, chemically similar or identical.

Although the vital nature of the interrenal bodies of the selachian has thus been demonstrated, evidence for the several cortical functions recognized in the mammals (14, 209) is meagre or absent. Hartman *et al.* (88) have made the only important contribution to our knowledge of the physiological chemistry of interrenal function in fishes. These workers were unable to show that the interrenals of the skate (*Raja erinacea*) played any part in electrolyte balance. On the other hand, they may be necessary for normal carbohydrate metabolism. Liver glycogen studies, in the skate, indicated that the interrenals are involved in gluconeogenesis.

It is possible that cortical function, as known in the mammals is not fully evolved in fishes and that only a part of the biologically active compounds produced by the mammalian cortex are formed by the interrenals of fish. From Hartman's studies it would seem that the interrenals of *Raja* produce corticosterone or a related compound but that desoxycorticosterone and the amorphous fraction are not formed or physiologically active in the skates. Santa (186) has obtained some evidence for the existence of a compound similar to or identical with desoxycorticosterone in *Scyllium*. Although the test which Santa used, a melanophore reaction in teleosts, is probably not specific, Grollman's work, referred to above, also provides suggestive evidence for the presence of desoxycorticosterone. Salt metabolism in the selachians may be independent of the adrenal mechanism.

It can be assumed from the histological studies of Fancello (56), Pitotti (173) and Ranzi (176) that the interrenal tissue of fish is related in some way to sexual activity. These workers have demonstrated characteristic changes at sexual maturity in the interrenals of several different species of selachians. These changes are comparable to the changes reported for mammals (14). However, the role of the interrenals in the normal reproductive physiology of fish is as completely unknown in fish as in higher vertebrates.

Pituitary—the "master gland"

Like the pituitary gland of mammals, the pituitary gland of the fish seems to control the other endocrine glands involved in the regulation of metabolism. Gonadotropic and thyrotrophic functions are well recognized and will be discussed below. The glycotrophic effect has already been mentioned. Dittus' (50) work indicates the presence of a corticotrophic pituitary hormone. Studies of other interrelationships, such as the ketogenic and diabetogenic functions, have not been undertaken. Regulation of water balance which, at certain stages, is controlled by the pituitary (neurohypophysis) in some higher vertebrates does not seem to be affected by the pituitary in fish (92). A more thorough study of this point is, however, essential since it has been shown that fish pituitary gland does contain a component which will influence water balance in the amphibia (91).

Reproductive Activity and Behaviour

The close parallel which exists between the development of the gonads of fish and the appearance of secondary sexual characters and reproductive behaviour strongly suggests that the gonads are responsible for these features. The hooked snout, humped back, and vivid colouration of the male salmon (*Oncorhynchus gorbuscha*) appear only with the approach of spawning. The red abdomen of the male stickleback (*Gasterosteus aculeatus*) and the glands of nidification, used to build a nest, develop as the gonads mature (39, 40). The viviparous teleost, *Neotoca bilineata*, exhibits a regular breeding cycle which follows the maturation of the gonads and which Mendoza (148) likens to the estrous cycle of the female mammal. The breeding tubercles on the snout, head and back of the common shiner (*Notropus cornutus*) disappear within two weeks after spawning (174). The examples could be multiplied. It might seem self-evident that the gonad is responsible for these sex characteristics but experimental evidence is necessary since both gonad development and sex characters might be controlled by a third, distinct factor or mechanism.

The literature on sex endocrinology forms the most voluminous portion of the work on fish hormones. For the most part this literature is scattered. The two comprehensive reviews on the subject are devoted to specialized groups or phenomena. Regnier's (177) memoir on the cyprinodonts contains a valuable bibliography and considerable new experimental work on this group. It is, however, based on a group of fish which are initially entirely females and later differentiate into two sexes. As pointed out later, this condition, although specialized, is not as rare as some authors (75) seem to believe. The other comprehensive work on sexual endocrinology of fishes is likewise devoted to a specialized phenomenon. Bretschneider and Duyvené de Wit (22) have recently reviewed the investigation of the "Werkmenschrap voor Endocrenologie" in Holland during the past ten years. These workers have made a concerted attempt to explain the development of the gonopodium and spawning activity of the female bitterling (*Rhodeus amarus* Bloch). The bitterling is a cyprinid fish which at spawning time develops an elongated urogenital papilla (ovipositor) with which it lays its eggs in freshwater mussels. Before and after spawning the ovopositor is a scarcely visible protuberance. This response, however, has been shown to be a non-specific one brought about by a great many factors including temperature and light (120) and, although there are many valuable sections in the book, all of the conclusions cannot be accepted until more work of a comparative nature has been carried out.

Sex determination and sex differentiation

The mechanism of sex determination is more labile in fish than in higher vertebrates. Sex chromosomes, in many species, are either in a primitive stage of evolution (51, 227) or express themselves

through the soma only after an intersexual stage (45). The gonads may pass through an intersexual stage during development with the co-existence of male and female elements. Numerous references are given in articles by Eberhardt (51), D'Ancona (44), and Padoa (167, 168).

In the eel, of about 270 mm., D'Ancona (45) describes and pictures sections of the gonad containing male and female elements mingled without evident order. A similar situation has been noted in salmonids, cyprinids, cyprinodonts (43, 46) and cyclostomes (159). Later the elements of one sex are emphasized and the sexuality of the gonad gradually stabilized. Thus, it is suggested that the germ cell sexuality does not descend from the germ-lineage but is induced by the soma. Inductive hormone-like substances, arising from the soma of the gonad, are considered responsible for sexual differentiation. D'Ancona (45) refers to these substances as *androgenin* and *gynogenin* for male and female respectively. Similar inductive substances acting on the indifferent germ cells of higher vertebrates have been referred to as *medullarin* and *corticin* (44, 227).

Another interesting situation has been described in which all of the individuals of a stock are initially of the same sex and later the two sexes appear in about equal numbers. This situation has been observed, under certain conditions, in some cyprinodonts (177) and salmonids (168).

The studies of sex determination and differentiation are of both theoretical and practical interest. Divergent sex ratios are sometimes observed in fish populations. The work summarized above suggests that both external and internal environmental factors may modify sex ratios. This would seem to be a fruitful and valuable field for further research.

Demonstration of gonad hormones

The presence of gonad hormones may be demonstrated by observing the effects of gonadectomy, or the pathological atrophy of these organs, or by injecting gonad extracts into immature animals.

The effects of gonadectomy have not been extensively studied because of the technical difficulties of operating on fish. Moreover, unless all of the gonad tissue is removed the organ regenerates rapidly (236). However, the operation has been carried out on at least a dozen different species of fish and the results demonstrate the presence of gonad hormones beyond doubt. Bock (18) found that the secondary sex characters of the male stickleback, referred to above, did not develop in gonadectomized animals. Zahl and Davis (236) studied the effect of gonadectomy in both male and female *Amia calva*. The nuptial livery (colour of fins) and caudal ocellus of the male fail to appear in operated animals. That the caudal ocellus is potentially present in the female and prevented from developing by the ovarian hormones is indicated by its appearance in female castrates. Zahl and Davis (236) discuss the earlier experiments. Regnier's (177) review should also be consulted for references to the earlier literature on gonadectomies. Turner's (212) recent experiments on male *Gambusia affinis* are confirmatory. Noble and Kumpf (157) find, however, that male jewel fish (*Hemichromis bimaculatus*) and male fighting fish (*Betta splendens*) may develop nuptial colours and show typical spawning activity for several months after operation. "Spawning" in the gonadectomized male may take place as many as 13 times. Gonadectomized females show no sex behaviour. These findings for male jewel fish are in accord with a situation sometimes observed in mammals where sex activity may continue for a time after castration (14).

To our knowledge, no one has studied the effects of fish gonad extracts on immature or gonadectomized animals. It should be noted that the very numerous studies referred to below on hormone injections have all been carried out with mammalian preparations. A careful study of the comparative physiology of the gonad hormones of fish is in order.

Site of hormone production

In the higher vertebrates it is recognized that the gonad hormones are produced in the interstitial tissue of the testis (Leydig cells) or the Graffian follicle and corpus luteum of the ovary (99). Comparable cytological structures are present in the gonads of fishes and it seems probable that the gonad hormones are produced there.

Craig-Bennett's (40) detailed analysis of the reproductive cycle of the stickleback (*Gasterosteus aculeatus*) leaves little doubt as to the importance of the interstitial cells of the testis. A series of earlier papers by Courrier (37, 38, 39) are in line with accepted views on this subject. These writers have associated the development of the secondary sexual characters of the male stickleback (*Gasterosteus aculeatus*) with changes in the interstitial tissue of the testis. They

describe very narrow intertubular spaces in the immature testis which show no evidence of glandular structure. As the nuptial colouration appears these spaces widen and glandular interstitial cells become prominent. Courrier (38) examined the testes of several other genera of fish and, although the majority contained well-developed interstitial tissue, this was not universal.

Bretschneider and Duyvené de Wit (22) have made a detailed contribution to our knowledge of the histophysiology of the fish ovary. In the bitterling (*Rhodeus amarus*) they describe hormone producing follicular cells and corpora lutea comparable to those of the mammal and present physiological evidence to show that they play comparable roles. This careful correlation of the changes in ovary structure with the sexual development and activity of this fish proves that the follicular cells and corpora lutea produce the controlling hormones. The bitterling is evidently no exception in this regard for corpora lutea have now been described in the ovaries of several different species of teleosts and elasmobranchs (47, 109, 185).

It should be pointed out that the presence of interstitial hormone producing tissue in fish gonads is not universally accepted. Van Oordt (164) would not ascribe hormone production to any specific group of cells in the gonad. The controversy is dealt with by Craig-Bennett (40). It is suggested here that the interstitial gonad producing tissue recognized in the higher vertebrates has differentiated phylogenetically in the fishes and is evident in some forms but that in others, *Xiphophorus* for example, the same cells or tissues are responsible for sex functions and sex cell production.

Chemical nature of the gonad hormones

The chemical nature of the sex hormones in fish has not been studied. In the mammals, where considerable information has accumulated, these hormones belong to a well-recognized group of steroid compounds (14, 209). Testosterone is the principal male sex hormone but it produces a number of derivatives during the course of its metabolism in man. Testosterone and its compounds are collectively referred to as androgens. There are two recognized groups of female steroid hormones. Estrogens are produced by the Graffian follicle or the placenta. Progesterone is produced by the corpus luteum and the placenta.

The chemical nature of the sex hormones in fish can, perhaps, be inferred from a comparison of the physiological effects of mammalian hormone therapy, and both male and female hormones from mammals have been used extensively in experimental work on fish.

Testosterone has been shown, in several different species, to produce premature sexual development of the male or masculinization of the female. The Poeciliidae (the live-bearers of aquarists) have been used largely for this work. In this family the male has prominent secondary sex characters which include an intromittent anal fin or gonopodium. Premature sexual development in the male or modification of the anal fin of the female leading to the development of male secondary sexual characters has been induced in *Xiphophorus helleri* (6, 7, 156, 177), *Xiphophorus–Platypoecilus* hybrids (203), *Gambusia holbrooki* (83, 84, 85), *Gambusia affinis* (210, 211), *Platypoecilus maculatus* (76), *Lebistes reticulatus* (54, 55, 101, 177) and *Molliensia latipinna* (42). Female individuals thus treated assume masculine sexual behaviour. A limited number of studies on other groups of fish indicates that the responses observed in the Poecillidae are not exceptional. Thus, the nuptial colouration of the male bitterling (*Rhodeus amarus*) has been produced by the use of commercial male hormone preparations (229) and spermatogenesis induced in the immature testis of the lamprey with testosterone (117).

Physiological evidence indicates that the female hormone(s) of fish is (are) estrogen(s). The basis for the contradictory data so often obtained with progesterone and its derivatives (11, 22, 55, 117, 158, 187) is discussed in a later section. Studies with estrogens are less numerous than those with androgens but have been carried out on a more varied group of fish. Unfortunately, in some cases it is not clear just what estrogen was used and it is apparent that these materials cannot always be used interchangeably (202). In summary it has been found that estradiol benzoate hastens development of the female or produces female characters in the male *Gambusia holbrooki* (85), *Xiphophorus helleri* and *Lebistes reticulatus* (177) and oestrone has been shown to produce cloacal swelling with increased vascularization in this region (characteristic of sexual maturation) of the lamprey (117). Again, Saphir (187) was able to induce an artificial "wedding dress" and spawning in female dace (*Chrosomus erythrogaster*) with the estrone producing hormone "Yohembine."

Additional evidence for the existence of distinct male and female hormones in fish and for their relation to the androgens and estro-

gens of mammals is seen in the fact that these materials are usually destructive to gonads of the opposite sex. Berkowitz (10) found that estrogenic hormone fed to immature male guppies (*Lebistes reticulatus*) prevented the development of the male characters, inhibited spermatogenesis, and in some cases produced an hermaphroditic condition. Taylor (203) reported that estradiol caused destruction of spermatophores and temporary suppression of spermatogenesis in the red swordtail hybrid *Xiphophorus-Platypoecilus*. No changes in secondary sexual characters were observed. A complete sex reversal was frequently induced in *Xiphophorus helleri* by the treatment of female individuals with the male hormone testosterone propionate (6, 156). Taylor (203) did not achieve a sex reversal in the fish of her study but described the formation of androgen-producing cells in the ovaries of fish treated with this androgen. Additional references may be found in articles referred to above.

The effects of pregnancy urine on the gonad development of fish have been studied by several workers (20, 32, 58, 117, 121, 187, 235). It is not surprising that the findings should be contradictory since pregnancy urine contains estrogens, progesterone, and gonadotrophins in varying amounts (209). Further, one may expect both the direct effects of estrogens on the gonads and the indirect effects following pituitary stimulation by gonadotrophins and progesterone. Several workers have suggested that steroids may stimulate the pituitary to gonadotrophic activity (22, 109, 126, 202). The most detailed contribution is Bretschneider and Duyvené de Wit's (22) study of the ovipositor growth of the female bitterling (*Rhodeus amarus*).

For the bitterling, progesterone is a particularly potent stimulus but a great variety of steroids and other compounds are effective. According to Bretschneider and Duyvené de Wit (22) this reaction is not brought about by a direct stimulation of the gonopod by the steroid but by a stimulation of the hypophysis to produce a luteinising hormone, which in turn induces the development of the gonopod through the ovarian hormone (*oviductin*). Thus the steroid hormones are only effective as means of stimulating the growth of the gonopod when both the pituitary and ovary are present. Normally seasonal changes initiate this pituitary activity in the female. These writers have also described an ovipositor stimulating mechanism which is dependent upon the male. During the breeding season males produce a hormone, *copulin*, which has a direct effect on female ovipositor growth. This double mechanism insures ovipositor growth if the ovaries become exhausted. Copulin production has been demonstrated in both *Rhodeus* and *Lebistes*.

These indirect effects of steroids on the ovaries have been described for amphibia (126) as well as fish (22, 109). Tavolga (202) discusses this as an explanation for the androgenic effects of some of the estrogens administered to *Platypoecilus maculatus*, and it seems probable that the contradictory data previously mentioned for progesterone and gonadotrophins may be explained in this same manner.

It would not be surprising to find that steroids had an effect on the pituitary activity of fish. The mammalian gonad is known to act on the output of gonadotrophins by the pituitary (82). There is a reciprocal stimulation between pituitary and gonad. However, for fish the experimental data are still insufficient to establish such a relationship. In particular, information on the effect of steroids on hypophysectomized fish (22) or on isolated gonads (109) is required.

Gonadotrophins of fish

Since the gonad hormones are responsible for sexual development and reproduction the nature of the control of gonad secretions may be a subject of practical importance in certain fishery procedures. It is sometimes desirable to induce spawning prematurely or to hasten a delayed spawning (106). The evidence indicates that the pituitary gland is responsible for the production of the gonad-stimulating hormones (gonadotrophins). Matthews (138) observed that the activity of the pituitary in *Fundulus* was at a maximum just before and during breeding while removal of the gland (27, 139) was followed by regressive changes in the gonads and sexual maturation did not occur. Vivien's work (223, 224, 225), carried out at the same time, on the hypophysectomized *Gobius paganellus* and *Scylliorhinus canicula* gave similar results.[1] Likewise implants of fish pituitary (90, 103, 106, 111, 141, 224) or extracts of this gland (33, 69, 171, 225) have been shown to produce sexual maturity in a variety of teleosts. Maturation has been induced in the male as well as the female with spontaneous elimination of sexual products in both sexes (171). Acetone-dried and stored glands are as effective as the fresh tissues (69, 90).

[1]Vivien's (225) review contains detailed directions for the removal of the hypophysis from fish.

These reactions have been induced in a variety of teleosts. There seems to be very little specificity. Kazansky (111), on the basis of a large number of experiments involving several different families of teleosts, concludes that there is a certain specificity of hormones among the different families but, for the most part, the pituitary of any species of teleost is effective in stimulating the gonads of any other species. A seasonal variation in the production of gonadotrophins is indicated by both histological (113) and experimental studies (69, 149, 208). However, for practical purposes, Gerbilsky (69) finds that the formation of gonadotrophins is low only immediately after spawning and that fish pituitaries can be collected throughout the summer and winter for use in the spring. These studies have been applied frequently in fish culture work in Brazil (106) and Russia (69).

Both cytological and experimental studies show that the gonadotrophins are elaborated in the middle glandular area (*Uebergangsteil*) of the teleost pituitary in association with the development of a pronounced basophilia there (12, 113). Although several writers have failed to find any changes in the cytology of the teleost pituitary at spawning (19, 228), Kerr (113) attributes this to improper fixation and staining. Kerr (113) describes a regular change in the development of basophils in the middle glandular region (*Uebergangsteil*) of the pituitary of the roach (*Leuciscus rutilus*) in relation to its spawning activities. Bretschneider and Duyvené de Wit (22) made a careful study of the cytological changes in the pituitary of the bitterling in relation to its reproductive cycle and describe a regular alternation of acidophilia and basophilia in the "gonadotrophic zone" of the anterior lobe (*Uebergangsteil*). Kazansky and Persov (112) have provided the only experimental data on the localization of the gonadotrophic factor. These workers were able to separate the pars intermedia (22, 190) of acetone-preserved carp pituitaries from the remainder of the glandular tissue. The two portions of the glands were tested separately for gonadotrophic activity. The pars intermedia (posterior glandular area of Kerr) was completely inactive while the anterior glandular portions (*Uebergangsteil* plus anterior lobe of Scruggs) were as active as the entire organs. The gonadotrophic production is, without doubt, localized in the middle glandular area of the teleost pituitary and is associated with the appearance of large numbers of basophils there. The Selachian pituitary has not been intensively studied in this connection. For several different species, however, Ranzi (175) has described increased secretory activity and changes in the eosinophils of the pituitaries of pregnant females.

The chemical nature of the pituitary gonadotrophins of fish is unknown. It does seem evident, however, that these compounds are different from the gonadotrophins of higher vertebrates. Mammalian pituitary extracts have usually led to negative gonad effects when injected into fish. Hasler *et al.* (90) produced spawning in both male and female trout (*Salmo gairdnerii* and *S. fario*) six to seven weeks early by using fresh or acetone-dried carp pituitary but obtained only negative results with FSH from sheep or pregnant mare serum. Johnson and Riddle (110) tested rainbow trout (*Salmo shasta*?) with a variety of mammalian pituitary preparations, using doses which gave a prompt response in young doves and rats but the effects were negative in both male and female individuals. These writers conclude that the gonadotrophins elaborated by the pituitary of fish differ from those of mammals. Creaser and Gorbman (41), in their review of gonadotrophic specificity, conclude that gonad stimulation cannot be brought about in fish by mammalian pituitary hormones. They cite a number of earlier experiments and find only one report of fish (*Anguilla*) gonad stimulation by mammalian pituitary. Van Oordt and Bretschneider (165) have also investigated the effects of mammalian gonadotrophic materials on the sexual development of *Anguilla* with positive results. However, they find that the amounts of mammalian material are much greater than the quantities of fish material required to bring about a given response. These findings, taken in conjunction with the negative evidence obtained by Johnson and Riddle (110) and Landgrebe (121) seem to show definitely that the fish gonadotrophins are different from those of mammals. There seems to be little evidence to support the suggestion of Azevedo and Canale (3) that the apparent specificity is due to lower concentration, abnormal absorption, or quantitative variations in the complex fractions of the anterior pituitary.

Control of gonadotrophic secretion by environmental factors

In many of the higher vertebrates the functional activity of the pituitary gland, inherently cyclic in nature, is capable of being modified by environmental stimuli. Temperature, humidity and light have been shown to exert an influence. In some species, environmental stimuli may completely dominate the pituitary activity (9). Rowan's (183) work on the modification of the sexual cycle and behaviour of birds through the control of light is well known. Mammalian sexual cycles may also be modified by changing the intensity and duration of daily light periods (16). These effects are presumably brought about by visual impulses acting through the pituitary. Rowan's (183) review contains numerous references to the literature on this subject.

In several species of fish, illumination has been shown to have an effect on reproductive activity. Vanden Eeckhoudt (214) induced changes in the ovaries, secondary sexual characters and behaviour of sticklebacks (*Gasterosteus aculeatus*) during the winter by the control of light and Hoover and Hubbard (100) found that speckled trout (*Salvelinus fontinalis*) would spawn 1 to 4 months before the normal time if the light-dark rhythm was appropriately changed. The ovulatory cycle of the constant breeder (*Oryzias latipes*) has also been modified by changing the rhythm of illumination (181). It seems safe to conclude that illumination modifies gonadotrophic activity in many fish as in some of the higher vertebrates. However, this phenomenon is by no means universal in fish. Attempts to modify the spermatogenetic cycle of *Fundulus* by light were unsuccessful (26, 140).

It seems probable that a number of environmental factors may modify gonadotrophic activity of the pituitary. Bretschneider *et al.* (22) report that changes in temperature as well as illumination excite the hypophysis of the bitterling to increased activity. Courrier (39) was able to demonstrate development of the gonads and some, but not all, of the secondary sexual characters in the male stickleback by raising the temperature of the water. Burger (26) modified the spermatogenetic cycle of *Fundulus heteroclitus* by changing the temperature.

Chemicals, too, have been shown to influence the activity of the pituitary. The possibility that changes in salinity of the water influence pigment development in the eel through the pituitary gland has been suggested (216). The work of Bretschneider and his school (22) provides evidence of chemical control of the pituitary through a nervous centre in the brain. These workers found that hypophysectomy prevented the gonopod stimulating effects of steroid compounds, and provided histological evidence for nervous pathways from the centre in the brain to the pituitary. Unfortunately, the series of hypophysectomized animals was small and the work should be repeated.

Anatomical basis for the control of the pituitary by external environmental factors has been carefully established for the bitterling (*Rhodeus amarus*) by the Utrecht school. They have traced the nervous connections between the periphery (i.e., the outside world) and the hypophysis, through tracts running from the sense organs (olfactory, visual) to the hypothalamus and thence to the hypophysis. The glandular cells here are stimulated to produce their hormone which passes to the effector (the ovary) via the blood. The centre in the brain may also be activated by chemicals of the external environment carried to it from the gills by the blood.

Growth

Pituitary growth hormone

Pickford and Thompson (172) have made the first definite contribution to our knowledge of the pituitary hormone in relation to the growth of fish. The growth stimulation which has been observed to follow the feeding of powdered beef pituitary gland (177) may be a dietary effect and cannot be taken as evidence for a pituitary growth hormone. Likewise, Nixo-Nicoscio (155) does not give sufficient information to judge the significance of his negative findings in carp injected with beef pituitary extract.

Pickford and Thompson (172) found marked acceleration in growth of *Fundulus heteroclitus* following intraperitoneal injection of a purified mammalian growth hormone. Over a 10 week period the average increase in weight for higher doses was 12.7%. This figure is close to what one might expect on the basis of mammalian studies. "Plateaued" female rats of 250 grams should gain about 50 grams (20%) in three weeks (53). Using 12°C. as the temperature for the experiments on *Fundulus*, the reaction in rats should proceed about four times as rapidly as in the fish—or a 20% weight increase should occur in about 12 weeks in *Fundulus*. Pituitary growth hormone evidently stimulates the growth of *Fundulus* in the expected manner. Two points, however, should be considered. In the first place the treatment produced a definite stimulation of the thyroid gland and this may have been responsible for the observed effects. It has been stated (127, p. 36) that in amphibians although the synergic relationship between growth hormone and thyroid is evident, the emphasis is shifted towards the thyroid factor. In the second place, purified growth hormone may have a pharmocological effect on growing tissues but may not be produced by the fish pituitary or normally responsible for growth in this

group. This possibility cannot be entirely eliminated until a potent growth-promoting extract is prepared from fish pituitaries.

Jampolsky (108) attempted to extract growth hormone from the pituitaries of spring salmon (*Oncorhynchus tschawytscha*) and determine its growth potency. In these experiments alkaline extracts (53) of beef and of salmon pituitaries were injected into different groups of rats and goldfish. For rats, the assay methods outlined by Evans and Simpson (53) were adhered to. Goldfish (*Carassius auratus*) varying in weight from 9–13 grams were maintained at about 25°C. and were injected intra-peritoneally each day. The findings are suggestive but not conclusive. Jampolsky was unable to obtain extracts which were not toxic when injected into goldfish for prolonged periods. Furthermore, handling and weighing produced pronounced changes in the weight of the goldfish. Pickford and Thompson (172) record a loss in weight for *Fundulus* controls. The goldfish showed an initial gain in weight during the first week, followed by a decline thereafter.

In summary, Jampolsky found that rats, injected with beef pituitary extract, showed the expected gain in weight but failed to respond to comparable injections of spring salmon pituitary extract. This may indicate a specificity of hormone, a much lower concentration of hormone in the salmon pituitary or a complete absence of the hormone. In the complementary experiments, goldfish injected with alkaline beef pituitary extract showed a mean increase in weight of 12% within 8 days. This increase is more rapid than that obtained for *Fundulus* although the temperature of the goldfish experiments was at least 10°C. higher. Goldfish were now injected with salmon pituitary and a gain in weight of 5% (19 goldfish) recorded for the first 8 days. Thereafter, the mortality was high and the survivors lost weight. No change in scale growth or length of fish was evident. It is felt that the failure of rats to respond to the salmon pituitary extracts is significant. On the other hand, the goldfish experiments are inconclusive. Weight changes may have been due to disturbed osmotic balance, the imbibition of water or other factors associated with the toxicity of the extracts. The results suggest a specificity for the growth hormone if such a hormone is actually produced by the fish pituitary.

Thyroid gland and growth

In mammals, it is recognized that the thyroid and pituitary glands have a synergistic effect on growth (127). It has already been suggested that, in amphibia, the emphasis is shifted towards a thyroid control. Present evidence suggests that this is likewise true for fish. Although a pituitary growth hormone has not been conclusively demonstrated, there is ample evidence that the thyroid gland is related to growth and development of teleosts and that the pituitary gland produces a thyrotrophic hormone. Gerkilsky and Saks (70) immersed developing *Acipenser stellatus* in thyroxine solutions and, within 13 days, obtained a definite acceleration in the development of the bony plates. With time the development became progressively more pronounced. Growth changes in coho salmon immersed in thyroxine or fed thyroid gland material are discussed below. Thiourea, which inhibits the formation of thyroid hormone, has been shown to reduce the growth rate of hybrid *Platypoecilus-Xiphorphorus* (72, 154) and Pacific salmon (98). Thus, thyroid treatment modifies the growth of some fish at certain stages in their development. However, thyroxine does not always produce growth acceleration in fish (198) and cannot be considered a specific growth-promoting factor as the pituitary growth hormone is for the mammals.

In addition to the experimental evidence for a growth-promoting effect of the thyroid hormone, there is histological evidence for increased thyroid activity during periods of accelerated growth. In particular, it has been suggested that this gland may control metamorphosis or be involved in physiological changes which occur prior to migration from fresh to salt water.

Many fishes show striking metamorphic changes during development. The flatfish (Heterosomata) changes from a bilaterally symmetrical animal to one which is laterally compressed with a skull so twisted that the eyes lie close together on one side. The larval or leptocephalus stage of the eel (*Anguilla*) is very different in appearance from the adult, being ribbon-like and perfectly transparent. Most fish show less profound morphological changes during development. In some, such as the Atlantic salmon (*Salmo salar*), a physiological transformation is more spectacular than a morphological one. Following the work on amphibia (48, 57, 189) the thyroid hormone may be suspected as primarily responsible for the control of the metamorphic changes and the pituitary as the source of chemical stimulation for the thyroid activity. Methods of following changes in thyroid activity will be outlined before considering the role of the thyroid gland in the development of fish.

Activity of the thyroid gland

Both histological and chemical methods are available for the study of thyroid activity. Physiological changes are reflected very clearly in the histology of this organ. The resting gland is composed of rounded follicles with a low cuboidal or cuboidal epithelium. The follicles are filled with an acidophilic hyaline colloid material. In extreme activity the epithelium increases greatly in amount and the cells increase in height to a columnar type, the colloid is withdrawn, the follicles appear empty or contain a small amount of faintly basophilic material and the walls of the follicles become folded and tufted. One of the most characteristic features of the heightened thyroid activity occurring in normally metamorphosing amphibia is the release of the colloid from the lumen of the follicles (213). Following a state of extreme activity the gland may return to a quiescent condition (involution) in which it will show much enlarged follicles with epithelial and colloid conditions as described for the resting gland. Two points should be born in mind in relating changes in histology to physiological activity. In the first place it has been shown that radioactive iodine can be changed into thyroxine or di-iodotyrosine in the absence of the thyroid gland (150). In the second place, the thyroid is the most labile of structures and shows histological changes in response to a great variety of physiological conditions. In fishes, for example, variations in the histology of the thyroid have been related to the season (95, 128), diet (136), sexual activity (12, 65, 161, 162), and changes in salinity (125, 160). These different factors must be carefully controlled in relating thyroid activity to any particular function.

A second method of following thyroid activity has been used extensively by a group of French workers and is dependent upon a relationship which exists between the copper content of the blood and the activity of the thyroid (61, 124, 125). In addition, the iodine content of fish blood or tissues has been determined as a guide to thyroid activity (28, 65, 79), and radioactive iodine has been used for experimental work on the thyroid of fish (143).

Metamorphosis of the ammocoete

Phylogenetically the thyroid gland seems to have developed from the endostyle of the lower chordates. The ammocoete larva of the cyclostome has an endostyle but no thyroid. The latter organ has been observed to develop from the endostyle at metamorphosis.

Goldsmith (71) has recently reviewed the literature on the phylogeny of the thyroid gland. Leach (122) has considered, in some detail the earlier work on this subject and described the phenomenon for *Ichthyomyzon fossor*. The thyroid development, in this group, might be expected to be intimately related to the metamorphosis. Careful work, however, has failed to show any relation between thyroid or pituitary and metamorphosis of the ammocoete. Horton (102) treated ammocoetes of *Petromyzon fluviatilis* with thyroid extracts, iodine or potassium iodide for as long as 140 days and used amounts which produced metamorphosis of tadpoles but the results were negative. Experiments by Leach (123) and Rémy (178) gave similar results. Young and Bellerby (235) attempted to produce metamorphic changes in *Lampetra planeri* with pituitary extracts. Doses, effective in producing metamorphosis in much larger axolotols were ineffective although stimulation of reproductive structures and probably growth was achieved. The thyroid mechanism apparently plays no role in the metamorphosis of the cyclostome although the thyroid of the lamprey itself will produce metamorphosis in frogs (102).

Metamorphosis in teleosts

The possible relation between the thyroid and metamorphosis of teleosts was first investigated by Murr and Sklower (151). They record a tenfold increase in the amount of thyroid tissue of the eel (*Anguilla anguilla*) following the leptocephalus stage with storage of colloid clearly indicated (low epithelium and abundant acidophilic colloid). Extreme thyroid activity is observed at the end of metamorphosis in the *glasaal* stage. During this stage the epithelium increases in height to a columnar type and the colloid is released from the follicles. These writers do not emphasize the fact that the activity comes at the end of metamorphosis. It is perhaps pertinent that the eel begins its migration to fresh water in the *glasaal* stage when the thyroid and pituitary are active (80). The earlier stages of metamorphosis seem to involve only an increase in size of the gland and gradual accumulation of colloid which is released immediately prior to or at the time of migration. Von Hagen (80) describes changes in cytology and morphology of both thyroid and pituitary (increase in size and in numbers of acidophiles) of the larval eels but again the colloid release comes at the close of metamorphosis and preceding migration. Vilter (217, 219), from

experimental data, has concluded that the thyroid gland plays no part in the transformation from glass eel to pigmented elver.

Sklower (196) studied the thyroid in relation to the metamorphosis of the flounder (*Pleuronectes platessa*). He divided his material into ten developmental stages. The first stage was symmetrical with no evidence of metamorphosis while stages 8 to 10 included completely transformed individuals. In the earlier stages of transformation (stages 1 to 4) there is an increase in the volume of the thyroid gland with flattening of the epithelium and definite colloid storage. Increased activity and release of colloid is clearly evident in the later stages of metamorphosis. Again it is not clear that the thyroid activity initiates the metamorphosis.

Through the cooperation of Keith Ketchen of the Pacific Biological Station, samples of metamorphosing and metamorphosed starry flounders (*Platichthys stellatus*) have been obtained for study. In the youngest stages available (10 mm.) the migrating eye has already moved so that its border may be seen from the pigmented side of the body. However, the outline of this eye and its lens are clearly evident on the underside. These individuals—corresponding to the intermediate stages described by Sklower (196)—show an active thyroid with high cubic to columnar epithelium, basal nuclei and scanty colloid in the follicles. The activity in the flatfish is comparable with that of the metamorphosing salamander and tadpole as judged by the published photomicrographs (49, 213).

In the fully metamorphosed starry flounders (30 mm. and 69 mm. stages) the thyroid has undergone an involution as shown by the lower epithelium and storage of acid colloid. This finding is also in agreement with Sklower's. However, without experimental evidence, it might be a mistake to attribute the profound metamorphosis of the flatfish to the thyroid hormone since the period of metamorphosis is not the only time in the life of the flounder when the thyroid shows activity. A series of thyroids have been examined from starry flounders (280 mm. to 530 mm.) collected at the time of spawning. The histological picture indicates that the thyroids of some of these fish are as active as those of metamorphosing fish. In other specimens the gland shows every evidence of involution. It is concluded that the activity is associated with the gonad development and migration of the fish to the spawning grounds while the involution occurs with sexual maturity at the time of spawning. These conclusions are in line with evidence obtained for increased thyroid activity during sexual maturation and development and an antagonism which exists between the gonads and thyroid of teleosts at sexual maturity (34, 65). Sklower (196) did not examine the thyroids of adult fish. It is probable that a variety of factors may influence thyroid activity during the life of the flounder. Further work is necessary to establish the thyroid relationship in the metamorphosis and life history of this fish.

The studies of Harms (87) on thyroid activity of *Salarias*, *Beleophthalmus*, and *Periophthalmus* are perhaps more definitely related to migration than metamorphosis and will be considered in the next section. However, Buchmann's (25) paper on the herring (*Clupea harengus*) is particularly interesting in connection with the studies of the eel and flatfish already reviewed. In this very comprehensive paper the author finds increased thyroid activity at what he refers to as, the time of metamorphosis (38 mm. to 40 mm.). The change in thyroid cell height, release of colloid and tufting of the follicles are described in detail. An increase in volume and change in morphology of the pituitary gland are also described. The question again arises as to whether these changes actually initiate the metamorphosis. The stage of development which Buchmann associates with endocrine activity is clearly the stage in which the animal assumes its juvenile characteristics—a terminal stage in a series of metamorphic stages. It has been observed that when the Pacific herring (*Clupea pallasii*) assume juvenile characteristics (about 26 mm.) they cease to be scattered over a wide area and congregate in schools where they are much more difficult to locate (201). Thus, the endocrine activity observed by Buchmann (25) in the herring could be related as readily to migration as to metamorphosis.

Parr-smolt transformation of salmonoids

The salmonoids usually show a transformation before migrating to lake or ocean. This change occurs during the juvenile period, does not produce a change in the growth equilibrium constant (137), and consequently is not comparable to the metamorphosis of the fish discussed above. However, both superficial and internal physiological changes are marked. Fontaine (62) has summarized the pertinent literature on salmon physiology.

At the time of transformation the Atlantic salmon (1 to 4 years old) become much slimmer through a loss of their body fat, the colour of the pectoral fins changes from yellow to black, and the

prominent parr markings and body colours are completely hidden under a thick layer of silvery guanine. Internal changes have also been described. These involve changes in the body fats from those characteristic of the typical marine fish to those found in freshwater fishes (129), increased resistance to sea water (17, 62), decreased resistance to injury in fresh water (63), and a marked activity of the thyroid gland (61, 95). In addition, comparative histological studies reveal a withdrawal of fat from the liver, the development of chloride secreting cells in the gills (97), and the appearance of very large numbers of acidophilic cells in the *Uebergangsteil* of the pituitary (67, 97).

In other salmonoids changes have been observed during this period of their life history. Robertson (179) described guanine deposition in the skin and increased activity of the thyroid of *Salmo gairdnerii* during its transformation prior to migration into the lakes. Black's (17) review contains other pertinent references. The question arises as to the part played by the endocrine glands in the development of these changes. In the case of the salmonoids there is some experimental work on which to base our remarks.

Landgrebe (121) induced premature silvering of both salmon (*Salmo salar*) and brown trout (*Salmo trutta*) by injection of thyroid extract. The series of fish was small but the results seem quite conclusive. Injected fish were externally indistinguishable from sea fish. Ox anterior lobe extract was effective in producing smoltification in the salmon but not the trout. Robertson (180) has been able to obtain similar results with *Salmo gairdnerii*. It would appear from these results that the thyroid is responsible for the metabolic changes in young salmon which result in the deposition of guanine in the skin and that this thyroid activity is initiated by the anterior lobe of the pituitary gland. There are observations, however, which suggest that, although thyroid hormone may stimulate guanine production, it does not specifically control this phase of fish metabolism. In the first place, Landgrebe (121) was not able to produce a premature silvering of the yellow eel (*Anguilla vulgaris*), which normally undergoes silvering before its return to sea. In the second place, chum salmon (*Oncorhynchus keta*) show no evidence of thyroid activity in connection with silvering prior to migration, nor is the development of the silvery coat inhibited in chums by the antithyroid drug thiourea (98). Thiourea solutions inhibit growth of salmon alevins and produce characteristic changes in the histology of the thyroid gland but the guanine is deposited in the normal manner. Finally, in our experiments, thyroid, pituitary and iodide solutions sometimes failed to produce consistent and pronounced development of the guanine coat. Atlantic salmon (*Salmo salar*), speckled trout (*Salvelinus fontinalis*), coho salmon (*Oncorhynchus kisutch*) and chum salmon (*O. keta*) have been studied. These data have not been published and are described here in more detail.

Two series of Atlantic salmon were studied. The first experiments, involving 18 parr with controls ran from July 11 to August 15, 1939. The second series, involving 45 parr with controls, ran from June 7 to August 18, 1940. Parr varied in length from 9 cm. to 21 cm. and in age from 1 to 4 years. The following tests were made: (*a*) feeding compressed thyroid, (*b*) injection of mammalian anterior pituitary extracts—Parke Davis Antuitrin T or a preparation obtained from Dr. J. B. Collip, McGill University, (*c*) injection of 0.75% aqueous potassium iodide, and (*d*) treatments (*b*) and (*c*) combined. Control animals were either injected with 0.75% aqueous sodium chloride or not treated. Histological examination of the thyroid shows that all of the experimental treatments modified the thyroid activity. Mammalian pituitary thyrotrophins induced prompt release of colloid from the thyroid and a marked hypertrophy of the gland. In animals treated with Parke Davis Antuitrin this reaction is so extreme that the follicular lumina are obliterated with the development of a massive compact epithelial body. Both iodides and thyroid feeding result in an increase in the size of the follicles and distinct storage of secretion. There is, thus, evidence that the concentration of thyroid hormone was increased in the body of the fish. Increased silvering was evident but, with one exception, the silvering was not pronounced and the animals, after periods ranging up to 9 weeks, were not classed as "salmon smolts" when examined by experienced observers who did not know the history of the fish. The exceptional individual, classed as a "smolt" by the "judges," was a 15.0 cm. individual which had been injected with 0.5 ml. of isotonic potassium iodide daily for 34 days.

Only four brook trout were studied. Two were fed compressed thyroid and two were injected with iodides for two months. No silvering occurred.

Two series of coho salmon have been studied. In the first series (January, 1949) four groups, each containing 15 coho salmon fingerlings (6.0 cm. to 7.5 cm.), were treated with thyroid substances every other day, for a period of 18 days. Group (1) was fed des-

siccated thyroid gland; group (2) was immersed in sodium iodide (1:2,500); group (3) was immersed in synthetic thyroxine sodium (1:1,125,000); and group (4) was used as a control. Increased silvering was not pronounced but eleven independent observers picked out the three experimental groups as being more silvery than the controls after 58 days. In line with Robertson's (180) observations, the pigmentation was definitely less in the experimental animals. No differences could be detected among the three groups of experimental animals (197). In the second series (June, 1950) 25 coho fry (3.5 cm. to 4.5 cm.) were immersed continuously for 15 days in synthetic thyroxine sodium (1:2,000,000). Silvering in this case was pronounced. Parr marks had, in most of the experimental animals, completely disappeared.

Three groups, each containing 25 chum salmon alevins were studied. Group 1 was immersed continuously for 3 weeks in synthetic thyroxine sodium (1:1,000,000); Group 2 was immersed similarly in 0.36% thiourea and group 3 served as a control. At the end of the experiment yolk sacs were absorbed in the control and thyroxine treated fish but not completely so in thiourea treated individuals. Silvering was pronounced in all groups but most intense in the thyroxine treated fish. In these there was no evidence of parr marks which can be clearly seen in normally silvered fish at this stage. No difference in silvering was apparent between thiourea treated fish and the controls.

These findings substantiate the idea that thyroid hormone in some way promotes the deposition of guanine in the skin of salmonids but does not specifically control the reaction. Thyroid compounds, in high concentration, produce silvering but normal guanine deposition occurs without pronounced thyroid activity and is not interfered with by the antithyroid drug thiourea. These conclusions are in line with those of Vilter (219) for the eel. He finds that there is no clear evidence for metamorphogenic action of thyroxine but that the effects noted may be merely the pharmacological action of thyroxine on metabolism. It is tentatively suggested that the production of the typical silvery smolt is dependent upon the growth stimulation by the pituitary and the general increase in nitrogen metabolism which probably results (127). Increased thyroid function, as produced in the experimental animals, stimulates nitrogen metabolism somewhat but not sufficiently to produce intense silvering.

There are, however, some characteristic changes produced by thyroid treatment of young salmonids. In the experiments on Atlantic salmon referred to above, it was noted that, after 10 to 14 days, there was a tendency for the experimental fish to lose scales and develop a marked susceptibility to fungus. These two features are very characteristic of smolt of Atlantic (63) and coho salmon in fresh water (97). Histological studies of the Atlantic salmon show a decrease in the thickness of the epidermis which may be responsible for this condition. The decrease in thickness of the epidermis is most evident in the thyroid-fed individuals. Other histological changes are evident. Thyroid feeding brings about a utilization or withdrawal of liver fat. Stimulation of the production of the chloride-secreting cells is perhaps dependent upon the pituitary and not the thyroid since it was not apparent in fish fed thyroid or given iodides without pituitary extract. Changes observed in weight relative to length at the time of the smolt transformation (96) are probably due to thyroid activity. The condition factor of coho salmon, referred to in the above experiments, was lowered by thyroid treatment. Percentage reductions for thyroxine treatment, thyroid feeding and iodide treatment were respectively 4.38, 3.23, and 1.83. Sklower's (195) feeding experiments on a very young trout gave the same general result.

It is concluded from this experimental work that the thyrotrophic hormone of the pituitary stimulates production of the thyroid hormone and, directly or indirectly, the development of chloride-secreting cells in the salmon. The thyroid hormone in turn alters the metabolism of the fats or promotes a greater utilization of fats and induces definite changes in the epithelium of the skin. The development of the complete silver coat of the smolt requires something in addition to thyroid hormone.

Source and nature of the thyrotrophic hormone

The close parallel which exists between thyroid and pituitary activity in fishes indicates that thyroid secretion is dependent upon stimulation by the pituitary (25, 80). In the amphibia the basophils are evidently responsible for the formation of the thyrotrophic hormone (48) but for mammals, the histological picture varies considerably in different thyroid conditions (192). In fish, acidophils have been associated with the production of thyrotrophins. Von Hagen (80) observed a marked increase in these elements when the thyroid of the eel became active. Although Woodman (228) could find no cytological changes in the pituitary at the time of

smolt metamorphosis in salmon, our preparations show a marked increase in acidophils when the parr changes to a smolt (97).

There is very little evidence for a specificity of the thyrotrophic factor in vertebrates. Slight chemical variations in thyrotrophins found by Magdalena (135) and Gorbman (73) could be attributed to differences in titer of hormones. It has already been stated that mammalian extracts produce the expected histological changes in the thyroid of the salmon. Additional confirmatory literature will be found in Goldsmith's review (71).

Migration

Several workers in western Europe have recently been actively engaged in studies of the endocrine physiology of fishes and have developed some interesting theories concerning the relation of hormones to migration (60, 61, 118). According to Fontaine (61) biologists have, in general, looked to external environmental factors for explanations of fish migration. Thus, it has been suggested that fish remain in water of a certain temperature or follow a definite gradient in carbon dioxide or salinity. Fontaine believes that the internal physiological changes should be examined for explanations of migration. He feels that changes in the internal environment impose restrictions on fish and force them to move from one place to another or perish. Migration, according to this writer, occurs at the time of genital maturation or following a metamorphosis or a phase of accelerated growth. These periods are associated with profound changes in activity of the endocrine glands. These in turn modify the internal environment and may force the animal to migrate or perish.

This general concept is not new. Cahn (29), a quarter of a century ago, developed the same thesis pointing out that changes in the internal environment as well as changes in the external environment will upset the equilibrium of an animal. Cahn's article is almost entirely speculative with particular emphasis on the probable role of the reproductive organs. The idea has been developed furthest in connection with bird migration and the activity of the gonads (183). This approach, however, is new in the study of fish migrations.

Fontaine and his co-workers have devoted considerable attention to the European eel (*Anguilla anguilla*). This animal makes two extensive migrations; one, as an elver, from the ocean to fresh water and again, as a mature adult, from fresh water to the ocean. Callamand's comprehensive review (30) contains a wealth of information on the biology and physiology of this animal. Previous to the migration of the adult, Fontaine and his associates (30, 31, 61) describe the development of an excessive hydrophilia through a progressive loss of chlorides and a change in the nature of the body fats (*Coefficient lipocytique*). This hydrophilia of the tissues and loss of chlorides can only be counteracted by a return to the sea. Fontaine visualizes this return as a more or less passive phenomenon. The biochemical changes are in part dependent upon the activity of the thyroid gland. A change in activity of the thyroid is found at the time of the eel's migration to the ocean and the relationship of the thyroid to osmoregulation is emphasized. Thyroid activity has also been associated with the migration of the young elvers from the ocean to the rivers. Fontaine (61) finds that thyroid activity is responsible for the strong rheotropism which the elvers exhibit when they enter the river. Thus, in certain experiments, 90% of the individuals entering the river were positively rheotropic but after several days treatment with the thyroid inhibitor phenylthiourea (1/10,000) only 20% showed a positive response.

These workers have examined other migratory fish. In the lamprey, *Petromyzon marinus*, Fontaine (59) finds definite changes in the chloride metabolism and osmotic regulation at the time of migration. These are associated with thyroid activity. In this paper it is again suggested that the hyperthyroidism results in upset osmoregulation and a strong rheotropism. For the Atlantic salmon, this writer has confirmed Hoar's (95) findings of increased thyroid activity in spawning fish in fresh water (65). Fontaine and Callamand (63) were unable to find any change in blood chlorides at the time of seaward migration of Atlantic salmon. However, slightly injured smolts were not able to regulate as readily osmotically as parr and these writers feel that salmon migration is in some way related to thyroid activity. Fontaine (61) hastens to point out that his "explanations" are very incomplete. The hydrophilia of eels or salmon will not explain long migrations in the sea or river where osmotic properties of the environment are constant. It has been demonstrated, too, that thyroid activity occurs in *Salmo gairdnerii* migrating into lakes (179) and is not present in at least one salmon (*Oncorhynchus keta*) at the time of its seaward migration (98). Fontaine's contributions, however, form a good starting point and

the two lines of experimentation which have been followed will be reviewed briefly.

Present theories for an internal control of migratory behaviour in fishes are based on two lines of experimental investigation. These are the effects of hormones on (*a*) the osmotic regulation of anadromous and catadromous fishes and (*b*) behaviour, such as rheotaxis, associated with migration.

Hormones and osmotic regulation

The thyroid hormone has now been shown to be related to osmotic regulation in several species of teleosts. Several aspects of this subject are dealt with in Black's review (17). Whether changes in osmotic regulation, which occur prior to the migration of some fish, are dependent upon and controlled by the thyroid, or whether the hormone merely accelerates some basic chain of reactions cannot yet be decided. For Pacific salmon (*Oncorhynchus*), it is suggested that the increased thyroid activity sometimes seen at migration develops in response to excessive demands for thyroid hormone when the fish remain for a prolonged period in fresh water (98). Chum salmon, which normally migrate soon after emerging from the gravel, have quiescent thyroids before, during, and after migration. If, however, they are retained in fresh water the gland becomes hyperplastic. Changes seen in other salmonoids may be explained on the same basis.

At present, it would be unwise to conclude that the thyroid plays a specific role in chloride metabolism or osmotic regulation. It is clear, however, that the thyroid is involved in salt metabolism and osmoregulation. It has been shown that thyroid feeding alters the chloride metabolism of sticklebacks (93, 119), that transfer of several species of marine teleost to fresh water increases thyroid activity (125, 160), and that carp injected with thyroxine have a lowered resistance to salt water (59). However, the effects of thyroid feeding varied in different species of stickleback (93, 119). In addition, we have been unable to find any change in thyroid histology of goldfish transferred to sea water; nor does the immersion of coho salmon (40 mm. to 50 mm.) in synthetic thyroxine solutions for 48 to 72 hours change their ability to withstand sudden transfer to sea water of $25\ ^{0}/_{00}$ to $30\ ^{0}/_{00}$ salinity (97).

The interrenals and pituitary gland of fish have also been investigated as possible regulators of salt and water metabolism. Findings for the mammal suggest the possibility of such a relationship. For dependent on an internal state developed through the activities of the pituitary and gonads. It does not seem that the migration of salmon from the ocean to spawning grounds in the upper reaches of some river is any more complex than the nest building and spawning activities of the stickleback.

SUMMARY

The hypophysis is the master endocrine gland in fishes as in the other groups of vertebrate animals. Chromatophorotropic, thyrotrophic, glycotrophic, corticotrophic, and gonadotrophic functions have been demonstrated. The growth hormone, ketogenic and diabetogenic functions have not been adequately investigated. Pituitary activity may be modified or regulated by environmental factors, such as light, temperature and chemicals.

The thyroid gland produces a maturation hormone which stimulates growth and differentiation. It is probably involved in metabolic regulation (osmotic control, nitrogen metabolism). It has not been shown that the thyroid hormone plays any specific role in metamorphosis or migration of fish but, doubtless, influences these activities indirectly. It probably accelerates or accentuates many activities.

Parathyroid activity and the regulation of calcium metabolism have not been investigated in fish.

The Islets of Langerhans are present in all classes of fishes and carbohydrate metabolism is controlled in this group in the same way as in the higher vertebrates.

The suprarenals produce adrenalin. Variations between its action in certain fishes and in the higher vertebrates can usually be related to differences in the autonomic nervous systems of the groups.

The interrenals produce a cortical steroid which plays a part in the regulation of carbohydrate metabolism and may be related to sexual differentiation. No evidence for a function in mineral metabolism has been found.

The reproductive glands produce androgenic and estrogenic hormones which control the development of secondary sexual characters and reproductive behaviour.

In the present state of our knowledge, it seems safe to conclude that changes in the activity of the endocrine glands may sensitize the organism so as to modify or completely change its responses to environmental stimuli. Again, environmental factors may stimulate or depress the activities of the endocrine glands, and, finally, the activities of the endocrine glands may so modify the physiology of the organism as to enable it to penetrate otherwise lethal environments.

LITERATURE CITED

1. ABOIM, A. N. L'organe interrénal des cyclostomes et des poissons. Portugaliae Acta Biol., A, 1:353-383, 1946.
2. ABRAMOWITZ, A. A., HISAW, F. L., BOETTIGER, E., and PAPANDREA, D. N. The origin of the diabetogenic hormone in the dogfish. Biol. Bull., 78:189-201, 1940.
3. AZEVEDO, P. de e CANALE, L. A hypofise e sua açao nas gonadas dos peixes neotropicos. Arch. Inst. Biologico, S. Paulo, 9:165-186, 1938.
4. BABKIN, B. P. Further studies on pancreatic secretion in the skate. Contr. Can. Biol. Fish., 7:1-9, 1931.
5. BABKIN, B. P., BOWIE, D. J., and NICHOLLS, J. V. V. Structure and reactions to stimuli of arteries (and conus) in the Elasmobranch genus *Raja*. Contr. Can. Biol. Fish., 8:207-225, 1933.
6. BALDWIN, F. M. and GOLDIN, H. S. Effects of testosterone propionate on the female viviparous teleost, *Xiphophorus helleri* Heckel. Proc. Soc. Exp. Biol. Med., 42:813-819, 1939.
7. —— Effect of testosterone propionate on anal fin transformation of the female viviparous teleost, *Xiphophorus helleri* Heckel. Proc. Soc. Exp. Biol. Med., 46:283-284, 1941.
8. BARRINGTON, E. J. W. Blood sugar and the follicles of Langerhans in the ammocoete larva. J. Exp. Biol., 19:45-55, 1942.
9. BEACH, F. A. Hormones and behaviour. Paul B. Hoeber, New York, 1948.
10. BERKOWITZ, P. The effects of estrogenic substances in *Lebistes reticulatus* (Guppy). Anat. Rec., 71:161-175, 1938.
11. —— The response of fish (*Lebistes reticulatus*) to mammalian gonadotropins. J. Exp. Zool., 86:247-255, 1941.
12. BERNARDI, C. Correlazioni dell'ipofisi e della tiroide con lo stato di maturazione delle gonadi nelle anguille gialle e argentine. Riv. Biol., 40:186-228, 1948.
13. BERNHEIM, F. Action of drugs on the isolated intestine of certain teleost fish. J. Pharmacol. Exp. Therap., 50:216-222, 1934.

14. Best, C. H. and Taylor, N. B. The physiological basis of medical practice. Williams and Wilkins, Baltimore. 1945.
15. Biedl, A. Internal secretory organs: their physiology and pathology. John Bale, Sons & Danielsson, London. 1913.
16. Bissonnette, T. H. Sexual photoperiodicity. Quart. Rev. Biol., 11:371-386, 1936.
17. Black, V. S. Osmotic regulation in teleost fishes. (Below, 53.)
18. Bock, F. Kastration und sekundäre Geschlechtsmerkmale bei Teleostiern. Z. wiss. Zool., 130:455-468, 1928.
19. ——— Die Hypophyse des Stichlings (*Gasterosteus aculeatus* L.) unter besonderer Berücksichtigung der jahrescyklischen Veränderungen. Z. wiss. Zool., 131:645-710, 1928.
20. Boucher, S., Boucher, M. et Fontaine, M. Sur la maturation provoquée des organes génitaux de l'Anguille. C.R. Soc. Biol. Paris, 116:1284-1286, 1934.
21. Bowie, D. J. Cytological studies of the islets of Langerhans in a teleost, *Neomaenis griseus*. Anat. Rec., 29:57-73, 1924.
22. Bretschneider, L. H. and Duyvené de Wit, J. J. Sexual endocrinology of non-mammalian vertebrates. Elsevier, Amsterdam. 1947.
23. Brinley, F. J. Evidence for a sympathetic innervation of the teleost heart: with a note on a method of transplanting the heart of *Fundulus* embryos. Physiol. Zool., 8:360-373, 1935.
24. Brunn, A. F. and Hemmingsen, A. M. The effect of insulin on fishes (*Lebistes reticulatus* Peters). Acta Med. Scand., Supp., 90:97-104, 1938.
25. Buchmann, H. Hypophyse und Thyroidea im Individualzyklus des Herings. Zool. Jahrb. Abt. Anat. u. Ontog. Tiere, 66:191-262, 1940.
26. Burger, J. W. Some experiments on the relation of the external environment to the spermatogenetic cycle of *Fundulus heteroclitus* (L). Biol. Bull., 77:96-103, 1939.
27. ——— Some experiments on the effects of hypophysectomy and pituitary implantations on the male *Fundulus heteroclitus*. Biol. Bull., 80:31-36, 1941.
28. Burwash, F. M. The iodine content of the thyroid of two species of elasmobranchs and one species of teleost. Contr. Can. Biol. Fish., 4:117-120, 1929.
29. Cahn, A. R. The migration of animals. Amer. Nat., 59:539-556, 1925.

30. Callamand, O. L'Anguille Européenne (*Anguilla anguilla* L.). Les bases physiologiques de sa migration. Ann. Inst. océanogr., Monaco, 21:361-440, 1943.
31. Callamand, O. et Fontaine, M. Sur le déterminisme biochimique du retour à la mer de l'anguille femelle d'avalaison. C.R. Acad. Sci. Paris, 211:357-359, 1940.
32. Calvet, J. Action du lobe antérieur d'hypophyse chez divers Vertébrés (Lamproies, Oiseaux). C.R. Soc. Biol. Paris, 109:595-597, 1932.
33. Cardoso, D. -M. Relations entre l'hypophyse et les organes sexuels chez les poissons. C.R. Soc. Biol. Paris, 115:1347-1349, 1934.
34. Centi, C. Proprietà antitiroidea delle ghiandole germinali di vertebrati inferiori. Boll. Soc. Ital. Biol. Sperim., 5:340-342, 1930.
35. Chadwick, C. S. Identity of prolactin with water drive factor in *Triturus viridescens*. Proc. Soc. Exp. Biol. Med., 45:335-337, 1940.
36. ——— Further observations on the water drive in *Triturus viridescens*. II. Induction of the water drive with the lactogenic hormone. J. Exp. Zool., 86:175-187, 1941.
37. Courrier, R. Sur le conditionnement des caractères sexuels secondaires chez les poissons. C.R. Soc. Biol. Paris, 85:486-488, 1921.
38. ——— Sur l'existence d'une glande interstitielle dans le testicule des poissons. C.R. Soc. Biol. Paris, 85:939-941, 1921.
39. ——— Sur l'indépendance de la glande séminale et des caractères sexuels secondaires chez les poissons. Etude expérimentale. C.R. Acad. Sci. Paris, 174:70-72, 1922.
40. Craig-Bennett, A. The reproductive cycle of the three-spined stickleback, *Gasterosteus aculeatus*, Linn. Phil. Trans. Roy. Soc. London. B, 219:197-279, 1931.
41. Creaser, C. W. and Gorbman, A. Species specificity of the gonadotropic factors in vertebrates. Quart. Rev. Biol., 14:311-331, 1939.
42. Cummings, J. B. Quantitative studies on the induction of gonopodia in females of *Molliensia latipinna*. J. Exp. Zool., 94:351-385, 1943.
43. D'Ancona, U. Ermafroditismo e intersessualità. Med. e Biol., 3:77-101, 1943.

44. ---- Sexual differentiation of the gonad and the sexualization of the germ cells in teleosts. Nature, 156:603-604, 1945.

45. ---- Somatic influences on the sexual differentiation of germ cells. Proc. 6th internat. Congress Exp. Cytology, 571-577, 1947.

46. ---- Ermafroditismo ed intersessualità nei Teleostei. Experientia, 5:381-389, 1949.

47. ---- Corpi lutei nelle gonadi di teleostei ermafroditi. Boll. Soc. Ital. Biol. Sperim., 25:1-2, 1949.

48. D'Angelo, S. A. An analysis of the morphology of the pituitary and thyroid glands in amphibian metamorphosis. Amer. J. Anat., 69:407-437, 1941.

49. D'Angelo, S. A. and Charipper, H. A. The morphology of the thyroid gland in the metamorphosing *Rana pipiens*. J. Morph., 64:355-373, 1939.

50. Dittus, P. Experimentelle Untersuchungen am Interrenalorgan der Selachier 1. Atemfrequenz und Melanophoren bei interrenopriven und mit corticotropen Hormon behandelten Selachiern. Pubb. Staz. zool. Napoli, 16:402-435, 1937.

51. Eberhardt, K. Geschlechtsbestimmung und -Differenzierung bei *Betta splendens* Regan I. Z. indukt. Abstamm.-u. Vererblehre, 81:363-373, 1943.

52. Etkin, W., Root, R. W., and Mofshin, B. P. The effect of thyroid feeding on oxygen consumption of goldfish. Physiol. Zool., 13:415-429, 1940.

53. Evans, H. H. and Simpson, M. E. Hormones of the anterior hypophysis. Amer. J. Physiol., 98:511-546, 1931.

54. Eversole, W. J. The effects of androgens upon the fish (*Lebistes reticulatus*). Endocrinology, 25:328-330, 1939.

55. ---- The effects of pregeninolone and related steroids on sexual development in fish (*Lebistes reticulatus*). Endocrinology, 28:603-610, 1941.

56. Fancello, O. Interrene, surreni e ciclo sessuale nei Selaci ovipari. Pubb. Staz. zool. Napoli, 16:80-88, 1937.

57. Fleischmann, W. Comparative physiology of the thyroid hormone. Quart. Rev. Biol., 22:119-140, 1947.

58. Fontaine, M. Sur la maturation complète des organes génitaux de l'anguille mâle et l'émission spontanée de ses produits sexuels. C.R. Acad. Sci. Paris, 202:1312-1314, 1936.

59. ---- Des facteurs physiologiques déterminant les migrations reproductrices des cyclostomes et poissons potamotoques. Bull. Inst. océanogr., Monaco, 40 (848):1-8, 1943.

60. ---- Vues actuelles sur les migrations des poissons. Experientia, 2:233-237, 1946.

61. Du rôle joué par les facteurs internes dans certaines migrations de poissons: Etude critique de diverses méthodes d'investigation. J. Conseil, 15:284-294, 1948.

62. ---- Physiologie du saumon. Ann. Stat. Centr. Hydrobiol. appl., 2:153-183, 1948.

63. Fontaine, M., et Callamand, O. Nouvelles recherches sur le déterminisme physiologique de l'avalaison des poissons migrateurs amphibiotiques. Bull. Mus. Hist. nat. Paris, ser. 2, 20:317-320, 1948.

64. Fontaine, M., Callamand, O., et Olivereau, M. Hypophyse et euryhalinité chez l'anguille. C.R. Acad. Sci. Paris, 228: 513-514, 1949.

65. Fontaine, M., Lachiver, F., Leloup, J., et Olivereau, M. La fonction thyroidienne du saumon (*Salmo salar* L.) au cours de sa migration reproductrice. J. Physiologie, 40:182-184, 1948.

66. Fontaine, M. et Leloup, J. Action d'antithyroidiens (aminothiazol et phénylthiourée) sur la cuprémie des vertébrés poecilothermes. C.R. Soc. Biol. Paris, 141:148-149, 1947.

67. Fontaine, M. et Olivereau, M. L'hypophyse du saumon (*Salmo salar* L.) à diverses étapes de sa migration. C.R. Acad. Sci. Paris, 228:772-774, 1949.

68. Gaskell, J. F. The distribution and physiological action of the suprarenal medullary tissue in *Petromyzon fluviatilis*. J. Physiol., 44:59-67, 1912.

69. Gerbilsky, N. L. Seasonal changes of the gonadotropic potency of the pituitary glands in fishes. Doklady Akad. Nauk, URSS, N.S., 28:571-573, 1940.

70. Gerbilsky, N. L. and Saks, M. G. Postembryonic development of sturgeon (*Acipenser stellatus*) as affected by thyroxine. Doklady Akad. Nauk, URSS, N.S., 55:663-666, 1947.

71. Goldsmith, E. D. Phylogeny of the thyroid: Descriptive and experimental. Ann. N.Y. Acad. Sci., 50:283-316, 1949.

72. Goldsmith, E. D., Nigrelli, R. F., Gordon, A. S., Charipper, H. A. and Gordon, M. Effect of thiourea on fish development. Endocrinology, 35:132-134, 1944.

73. GORBMAN, A. Qualitative variation of the hypophyseal thyrotropic hormone in the vertebrates. Univ. Calif. Pub. Zool., 51:229-244, 1946.

74. GRAY, I. E. and HALL, F. G. Blood sugar and activity in fishes with notes on the action of insulin. Biol. Bull., 58:217-223, 1930.

75. GROBSTEIN, C. Endocrine and developmental studies of gonopod differentiation in certain Poeciliid fishes. I. The structure and development of the gonopod in *Platypoecilus maculatus*. Univ. Calif. Pub. Zool., 47:1-22, 1940.

76. ---- Optimum gonopodial morphogenesis in *Platypoecilus maculatus* with constant dosage of methyl testosterone. J. Exp. Zool., 109:215-238, 1948.

77. GROBSTEIN, C. and BELLAMY, A. W. Some effects of feeding thyroid to immature fishes (*Platypoecilus*). Proc. Soc. Exp. Biol. Med., 41:363-365, 1939.

78. GROLLMAN, A., FIROR, W. M. and GROLLMAN, E. The extraction of the adrenal cortical hormone from the interrenal body of fishes. Amer. J. Physiol., 108:237-240, 1934.

79. GUNTHORP, H. Results of feeding thyroid glands of various types of vertebrates to tadpoles. Physiol. Zool., 5:397-430, 1932.

80. von HAGEN, F. Die wichtigsten Endokrinen des Flussaals. Thyroidea, Thymus, und Hypophyse im Lebenszyklus des Flussaals (*Anguilla vulgaris*) nebst einigen Untersuchungen über das chromophile und chromophobe Kolloid der Thyroidea. Zool. Jahrb. Abt. Anat. u. Ont., 61:467-538, 1936.

81. HAIST, R. E. Factors affecting the insulin content of the pancreas. Physiol. Rev., 24:409-444, 1944.

82. HAMILTON, J. B. The role of testicular secretions as indicated by the effects of castration in man and by studies of pathological conditions and the short lifespan associated with maleness. Proc. Laurentian Hormone Conf., 3:257-322, 1948.

83. HAMON, M. Action de la testostérone sur la morphologie du male de *Gambusia holbrooki* Gir. C.R. Soc. Biol. Paris 139:108-109, 1945.

84. ---- Effets morphologiques du propionate de testostérone sur la femelle de *Gambusia holbrooki* Gir. C.R. Soc. Biol. Paris 139:110-111, 1945.

85. ---- Action des hormones sexuelles de synthèse sur la morphologie externe de *Gambusia holbrooki* Gir. Bull. Soc. Hist. nat. Afrique du Nord, 37:122-141, 1946.

86. HANSTROM, B. Hormones in invertebrates. Oxford, 1939.

87. HARMS, J. W. Die Realisation von Genen und die consecutive Adaption. 1. Phasen in der Differenzierung der Anlagenkomplexe und die Frage der Landtierwerdung. Z. wiss. Zool., 133:211-397, 1929.

88. HARTMAN, F. A., LEWIS, L. A., BROWNELL, K. A., ANGERER, C. A. and SHELDEN, F. F. Effect of interrenalectomy on some blood constituents in the skate. Physiol. Zool., 17:228-238, 1944.

89. HASLER, A. D. and MEYER, R. K. Respiratory responses of normal and castrated goldfish to teleost and mammalian hormones. J. Exp. Zool., 91:391-404, 1942.

90. HASLER, A. D., MEYER, R. K. and FIELD, H. M. Spawning induced prematurely in trout with the aid of pituitary glands of the carp. Endocrinology, 25:978-983, 1939.

91. HELLER, H. The distribution of the pituitary antidiuretic hormone throughout the vertebrate series. J. Physiol., 99:246-256, 1941.

92. ---- The effect of neurohypophyseal extracts on the water balance of lower vertebrates. Biol. Rev., 20:147-158, 1945.

93. HEUTS, M. -J. La régulation osmotique chez l'épinochette (*Pygosteus pungitius* L.). Ann. Soc. roy. Zool. Belgique, 74:99-105, 1943.

94. HIATT, E. P. The effect of adrenaline, acetylcholine and potassium in relation to the innervation of the isolated auricle of the spiny dogfish (*Squalus acanthias*). Amer. J. Physiol., 139:45-48, 1943.

95. HOAR, W. S. The thyroid gland of the Atlantic salmon. J. Morph., 65:257-295, 1939.

96. ---- The weight-length relationship of the Atlantic salmon. J. Fish. Res. Bd. Can., 4:441-460, 1939.

97. ---- Unpublished data.

98. HOAR, W. S. and BELL, G. M. The thyroid gland in relation to the seaward migration of Pacific salmon. Can. J. Research, D, 28:126-136, 1950.

99. HOOKER, C. W. The biology of the interstitial cells of the testis. Proc. Laurentian Hormone Conf., 3:173-195, 1948.

100. HOOVER, E. E. and HUBBARD, H. E. Modification of the sexual cycle of trout by control of light. Copeia, 1937 (4):206-210, 1937.

101. HOPPER, A. F. The effect of ethynyl testosterone on the intact and regenerating anal fins of normal and castrated females and normal males of *Lebistes reticulatus*. J. Exp. Zool., 111: 393-414, 1949.

102. HORTON, F. M. On the relation of the thyroid to metamorphosis in the lamprey. J. Exp. Biol., 11:257-261, 1934.

103. HOUSSAY, B. -A. Action sexuelle de l'hypophyse sur les poissons et les reptiles. C.R. Soc. Biol. Paris, 106:377-378, 1931.

104. HOUSSAY, B. -A. et BIASOTTI, A. Sur la substance hypophysaire augmentant le diabète pancréatique. C.R. Soc. Biol. Paris, 107:733-735, 1931.

105. HUNTSMAN, M. E. The effect of certain hormone-like substances on the isolated heart of the skate. Contr. Canad. Biol. Fish., 7:31-43, 1931.

106. VON IHERING, R. A method for inducing fish to spawn. Prog. Fish Culturist, 34:15-16, 1937.

107. JACKSON, S. The islands of Langerhans in elasmobranch and teleostean fishes. J. Metabol. Research, 2:141-147, 1922.

108. JAMPOLSKY, A. Growth-accelerating effects of alkaline extracts from the pituitary glands of spring salmon (*Oncorhynchus tschawytscha*). Thesis, Univ. British Columbia. 1949.

109. JASKI, C. J. A rapid test for pregnancy by means of the ovary of *Lebistes reticulatus* (Peters). Natuurw. Tijdschr. Ned.-Ind., 102:196-201, 1946.

110. JOHNSON, M. W. and RIDDLE, O. Tests of mammalian gonad-stimulating hormones on gonads of fish. Proc. Soc. Exp. Biol. Med., 42:260-262, 1939.

111. KAZANSKY, B. N. Zur Frage der Systematischen Spezifitat des Gonadotropen Hormons der Hypophyse bei den Fischen. Doklady Akad. Nauk, URSS, N.S., 27:180-184, 1940.

112. KAZANSKY, B. N. and PERSOV, G. M. The localization of the gonadotrophic factor in the hypophysis of bony fish. Doklady Akad. Nauk, URSS, N.S., 61:169-172, 1948.

113. KERR, T. The pituitary in normal and parasitized roach (*Leuciscus rutilus* Flem.). Quart. J. Micr. Sci., 89:129-138, 1948.

114. KEYS, A. and BATEMAN, J. B. Branchial responses to adrenaline and pitressin in the eel. Biol. Bull., 63:327-336, 1932.

115. KISCH, B. Die Funktion des Interrenalgewebes bei Torpedo. Endokrinologie, 1:31-39, 1928.

116. —— Untersuchungen über die Funktion des Interrenalorgans der Selachier. Pflugers Arch., 219:426-461, 1928.

117. KNOWLES, F. G. W. The influence of anterior pituitary and testicular hormones on the sexual maturation of lampreys. J. Exp. Biol., 16:535-547, 1939.

118. KOCH, H. J. Cause physiologique possible des migrations des animaux aquatiques. Ann. Soc. roy. Zool. Belgique, 73:57-62, 1942.

119. KOCH, H. J. et HEUTS, M. -J. Influence de l'hormone thyroidienne sur la régulation osmotique chez *Gasterosteus aculeatus* L., forme *gymnurus* Cuv. Ann. Soc. roy. Zool. Belgique, 73:165-172, 1942.

120. van KOERSVELD, E. Over de bruikbaarheid van de bittervoorn (*Rhodeus amarus* Bloch) als testobject voor steroide stoffen. (English summary). N.V. Drukkerij P. Den Boer, Utrecht, 1949.

121. LANDGREBE, F. W. The role of the pituitary and the thyroid in the development of teleosts. J. Exp. Biol., 18:162-169, 1941.

122. LEACH, W. J. The endostyle and thyroid gland of the brook lamprey, *Ichthyomyzon fossor*. J. Morph., 65:549-605, 1939.

123. —— Oxygen consumption of lampreys, with special reference to metamorphosis and phylogenetic position. Physiol. Zool., 19:365-374, 1946.

124. LELOUP, J. Action des antithyroidiens (aminothiazol et phénylthiourée) sur la cuprémie dans la série des vertébrés. Bull. Soc. Chim. biol., 29:582-595, 1947.

125. —— Influence d'un abaissement de salinité sur la cuprémie de deux Téléostéens marins: *Muraena helena* L., *Labrus bergylta* Asc. C.R. Soc. Biol. Paris, 142:178-179, 1948.

126. LEPORI, N. G. Sull'azione della follicolina e di altri ormoni sterolici nei processi di differenziamento indotto del sesso nei vertebrati inferiori. Monit. Zool. Ital., 55:104-114, 1946.

127. LI, C. H. and EVANS, H. M. The biochemistry of pituitary growth hormone. Proc. Laurentian Hormone Conf., 3:3-44, 1948.

128. LIEBER, A. Der Jahreszyklus der Schilddrüse von *Misgurnus fossilis* L. und seine experimentelle Beeinflussbarkeit. Z. wiss. Zool., 148:364-400, 1936.

129. LOVERN, J. A. Fat metabolism in fishes. V. The fat of the salmon in its young freshwater stages. Biochem. J., 28:1961-1963, 1934.

130. LUTZ, B. R. The effect of adrenalin on the auricle of elasmobranch fishes. Amer. J. Physiol., 94:135-139, 1930.

131. —— The innervation of the stomach and rectum and the action of adrenaline in elasmobranch fishes. Biol. Bull., 61:93-100, 1931.

132. LUTZ, B. R. and WYMAN, L. C. The chromaphil tissue and interrenal bodies of elasmobranchs and the occurrence of adrenin. J. Exp. Zool., 47:295-307, 1927.

133. MACKAY, M. E. The action of some hormones and hormone-like substances on the circulation in the skate. Contr. Canad. Biol. Fish., 7:17-29, 1931.

134. MACLEOD, J. J. R. The source of insulin. J. Metabol. Research, 2:149-172, 1923.

135. MAGDALENA, A. Hypophyse et thyroide. Action de l'ablation ou de l'implantation de la thyroide sur l'hypophyse du Crapaud. C.R. Soc. Biol. Paris, 112:489-492, 1933.

136. MARINE, D. The rapidity of the involution of active thyroid hyperplasias of brook trout following the use of fresh sea fish as a food. J. Exp. Med., 19:376-382, 1914.

137. MARTIN, W. R. The mechanics of environmental control of body form in fishes. Univ. Toronto Studies Biol., No. 58 Pub. Ont. Fish. Res. Lab., No. 70:1-81, 1949.

138. MATTHEWS, S. A. The pituitary gland of *Fundulus*. Anat. Rec., 65:357-367, 1936.

139. —— The relationship between the pituitary gland and the gonads in *Fundulus*. Biol. Bull., 76:241-250, 1939.

140. —— The effects of light and temperature on the male sexual cycle in *Fundulus*. Biol. Bull., 77:92-95, 1939.

141. —— The effects of implanting adult hypophyses into sexually immature *Fundulus*. Biol. Bull., 79:207-214, 1940.

142. MATTHEWS, S. A. and SMITH, D. C. The effect of thiourea on the oxygen consumption of *Fundulus*. Physiol. Zool., 20:161-164, 1947.

143. —— Concentration of radioactive iodine by the thyroid gland of the parrot fish, *Sparisoma* sp. Amer. J. Physiol., 153:222-225, 1948.

144. MCCORMICK, N. A. The distribution and structure of the islands of Langerhans in certain fresh-water and marine fishes. Trans. Roy. Can. Inst., 15:57-82, 1924.

145. —— Insulin from fish. Bull Biol. Bd. Canad., 7:1-23, 1924.

146. MCCORMICK, N. A. and MACLEOD, J. J. R. The effect on the blood sugar of fish of various conditions including removal of the principal islets (Isletectomy). Proc. Roy. Soc., London, B, 98:1-29, 1925.

147. MCCORMICK, N. A. and NOBLE, E. C. The yield of insulin from fish. Contrib. Can. Biol. Fish., 2:115-128, 1924.

148. MENDOZA, G. The reproductive cycle of the viviparous teleost, *Neotoca bilineata*, a member of the family Goodeidae I. The breeding cycle. Biol. Bull., 76:359-370, 1939.

149. MENEZES, R. S. Açao de hipófises de peixes doadores em diestro sôbre peixes reprodutores em estro. Rev. Brasil. Biol., 5:535-539, 1945.

150. MORTON, M. E., CHAIKOFF, I. L., REINHARDT, W. O. and ANDERSON, E. Radioactive iodine as an indicator of the metabolism of iodine VI the formation of thyroxine and diiodotyrosine by the completely thyroidectomized animal. J. Biol. Chem., 147:757-769, 1943.

151. MURR, E. und SKLOWER, A. Untersuchungen über die inkretorischen Organe der Fische I Das Verhalten der Schilddrüse in der Metamorphose des Aales. Z. vergl. Physiol., 7:279-288, 1928.

152. NICHOLLS, J. V. V. The effect of temperature variations and of certain drugs upon the gastric motility of elasmobranch fishes. Contr. Can. Biol. Fish., 7:447-463, 1933.

153. —— The effect of temperature variations and of certain drugs upon the intestinal motility of elasmobranch fishes. Contr. Can. Biol. Fish., 8:145-160, 1933.

154. NIGRELLI, R. F., GOLDSMITH, E. D. and CHARIPPER, H. A. Effects of mammalian thyroid powder on growth and maturation of thiourea-treated fishes. Anat. Rec., 94:79, 1946.

155. NIXO-NICOSCIO, N. V. The influence of hormones on growth in fish. Proc. Moscow Zool. Park, 1:178-184, 1940.

156. NOBLE, G. K. and BORNE, R. The effect of sex hormones on the social hierarchy of *Xiphophorus helleri*. Anat. Rec., 78 (Suppl.):147, 1940.

157. NOBLE, G. K. and KUMPF, K. F. The sexual behaviour and secondary sex characters of gonadectomized fish. Anat. Rec., 67 (suppl.):113, 1936-37.

158. NOBLE, G. K., KUMPF, K. F. and BILLINGS, V. N. The induction of brooding behaviour in the jewel fish. Endocrinology, 23:353-359, 1938.

159. Okkelberg, P. The early history of the germ cells in the brook lamprey, *Entosphenus wilderi* (Gage) up to and including the period of sex differentiation. J. Morph., 35:1-151, 1921.

160. Olivereau, M. Influence d'une diminution de salinité sur l'activité de la glande thyroide de deux Téléostéens marins, *Muraena helena* L., *Labrus bergylta* Asc. C.R. Soc. Biol. Paris, 142:176-177, 1948.

161. —— L'activité thyroidienne chez *Torpedo marmorata* Risso au cours du cycle sexuel. C.R. Soc. Biol. Paris, 143:212-214, 1949.

162. —— L'activité thyroidienne de *Scyllium canicula* L. au cours du cycle sexuel. C.R. Soc. Biol. Paris, 143:247-250, 1949.

163. Olmsted, J. M. D. The effect of insulin on cold-blooded vertebrates kept at different temperatures. Amer. J. Physiol., 69:137-141, 1924.

164. van Oordt, G. J. The relation between the development of the secondary sex characters and the structure of the testis in the teleost *Xiphophorus helleri* Heckel. J. Exp. Biol., 3:43-59, 1925.

165. van Oordt, G. J. und Bretschneider, L. H. Ueber den Einfluss gonadotroper Stoffe auf die Entwicklung der Hoden des Aales (*Anguilla anguilla* L.). Roux' Arch., 141:45-57, 1941.

166. Orias, O. Influence of hypophysectomy on the pancreatic diabetes of dogfish. Biol. Bull., 63:477-483, 1932.

167. Padoa, E. Differenziazione e inversione sessuale (femminizzazione) di avanotti di Trota (*Salmo irideus*) trattati con ormone follicolare. Monit. Zool. Ital., 48:195-203, 1937.

168. —— Observations ultérieures sur la différenciation du sexe normale et modifée par l'administration d'hormone folliculaire, chez la Truite iridée (*Salmo irideus*). Bio-Morphosis, 1:337-354, 1939.

169. Parker, G. H. Animal color changes and their neurohumors. Quart. Rev. Biol., 18:205-227, 1943.

170. —— Animal colour changes and their neurohumors. Cambridge Univ. Press. 1948.

171. Pereira, J. Jr. et Cardoso, D. -M. Hypophyse et ovulation chez les poissons. C.R. Soc. Biol. Paris, 116:1133-1134, 1934.

172. Pickford, G. E. and Thompson, E. F. The effect of purified mammalian growth hormone on the killifish (*Fundulus hereroclitus* (Linn.)). J. Exp. Zool., 109:367-384, 1948.

173. Pirotti, M. Interrene, surreni, maturità sessuale e gestazione nei Selaci. Pubb. Staz. zool. Napoli, 17:20-33, 1938.

174. Raney, E. C. The breeding behavior of the common shiner, *Notropis cornutus* (Mitchill). Zoologica, 25:1-14, 1940.

175. Ranzi, S. Ipofisi e gestazione nei Selaci. Atti. R. Accad. Naz. Lincei, Series 6, 23:365-368, 1936.

176. —— Ghiandole endocrine, maturità sessuale et gestazione nei Selaci. Atti. R. Accad. Naz. Lincei, Series 6, 24:528-530, 1936.

177. Regnier, M. -T. Contribution à l'étude de la sexualité des Cyprinodontes vivipares (*Xiphophorus helleri, Lebistes reticulatus*). Bull. biol. France-Belg., 72:385-493, 1938.

178. Rémy, P. L'iode et la métamorphose de l'*Ammocoetes branchialis* en *Petromyzon planeri* Bloch. C.R. Soc. Biol. Paris, 86:129-131, 1922.

179. Robertson, O. H. The occurrence of increased activity of the thyroid gland in rainbow trout at the time of transformation from parr to silvery smolt. Physiol. Zool., 21:282-295, 1948.

180. —— Production of silvery smolt stage in rainbow trout by intramuscular injection of mammalian thyroid extract and thyrotropic hormone. J. Exp. Zool., 110:337-355, 1949.

181. Robinson, E. J. and Rugh, R. The reproductive processes of the fish, *Oryzias latipes*. Biol. Bull., 84:115-125, 1943.

182. Root, R. W. and Etkin, W. Effect of thyroxine on oxygen consumption of the toadfish. Proc. Soc. Exp. Biol. Med., 37: 174-175, 1937.

183. Rowan, W. Light and seasonal reproduction in animals. Biol. Rev., 13:374-402, 1938.

184. Russell, E. S. Fish Migrations. Biol. Rev., 12:320-337, 1937.

185. Samuel, M. Studies on the corpus luteum in *Rhinobatus granulatus* Cuv. Proc. Indian Acad. Sci., B, 18:133-157, 1943.

186. Santa, N. Valeur endocrine des corps interrénaux des Sélaciens. Présence de l'hormone corticale, type corticostérone. C.R. Soc. Biol. Paris, 133:417-419, 1940.

187. Saphir, W. Artificial production of the "wedding dress" in *Chrosomus erythrogaster*. Proc. Soc. Exp. Biol. Med., 31: 864-866, 1934.

188. Scheresschewsky, H. Ueber den Bau des Epithelgewebes in der Pharyngeal Kiemenregion der Knochenfische. Doklady Akad. Nauk. URSS, N.S., 29:165-168, 1940.

189. SCHNEIDER, A. Effects of feeding thyroid substance. Quart. Rev. Biol., 14:289-310 and 431-450, 1939.

190. SCRUGGS, W. M. The epithelial components of the teleost pituitary gland as identified by a standardized method of selective staining. J. Morph., 65:187-213, 1939.

191. SEMBRAT, K. Influence de la glande thyroide des Sélaciens (*Scyllium canicula* Cuv. et *Sc. stellare* Gthr.) et de téléostéens (*Cyprinus carpio* L.) sur la métamorphose des têtards des Anoures (*Rana temporia* L.). C.R. Soc. Biol. Paris, 97:1508-1510, 1927.

192. SEVERINGHAUS, A. E. Cellular changes in the anterior hypophysis with special reference to its secretory activities. Physiol. Rev., 17:556-588, 1937.

193. SHEPARD, M. P. Responses of young chum salmon, *Oncorhynchus keta* (Walbaum), to changes in sea water content of the environment. Thesis, Univ. British Columbia, 1948.

194. SIMPSON, W. W. The effects of asphyxia and isletectomy on the blood sugar of *Myoxocephalus* and *Ameiurus*. Amer. J. Physiol., 77:409-418, 1926.

195. SKLOWER, A. Ueber den Einfluss von Schilddrüsen und Thymusfütterung auf die Korperlänge und das Gewicht von Forellenbrut. Z. Fischerei, 25:549-552, 1927.

196. ——— Untersuchungen über die inkretorischen Organe der Fische. II. Die Metamorphose der Plattfische und die Bedeutung der Schilddrüse für diesen Vorgang. J. Conseil, 14:81-85, 1939.

197. SMITH, S. B. The effects of thyroxine and related compounds on young salmon and trout. Thesis, Univ. British Columbia, 1949.

198. SMITH, D. C. and EVERETT, G. M. The effect of thyroid hormone on growth rate, time of sexual differentiation and oxygen consumption in the fish, *Lebistes reticulatus*. J. Exp. Zool., 94:229-240, 1943.

199. SMITH, D. C. and MATTHEWS, S. A. The effect of adrenalin on the oxygen consumption of the fish, *Girella nigricans*. Amer. J. Physiol., 137:533-538, 1942.

200. ——— Parrot fish thyroid extract and its effect upon oxygen consumption in the fish, *Bathystoma*. Amer. J. Physiol., 153:215-221, 1948.

201. STEVENSON, J. C. Preliminary survey of larval herring on the west coast of Vancouver Island, 1947. Fish. Res. Bd. Canad. Prog. Rep. Pacific, 73:65-67, 1947.

202. TAVOLGA, M. C. Differential effects of estradiol, estradiol benzoate and pregneninolone on *Platypoecilus maculatus*. Zoologica, 34:215-238, 1949.

203. TAYLOR, A. B. Experimental sex reversal in the red swordtail hybrid, *Xiphophorus-Platypoecilus*. Trans. Amer. Micr. Soc., 67:155-164, 1948.

204. TCHERNAVIN, V. Ripe salmon parr: A summary of research. Proc. Roy. Phys. Soc., 23 (part I):73-78, 1939.

205. THOMAS, T. B. Islet tissue in the pancreas of the Elasmobranchii. Anat. Rec., 76:1-18, 1940.

206. TINBERGEN, N. Social releasers and the experimental method required for their study. Wilson Bull., 60:6-51, 1948.

207. TOTH, L. A. Renal and vascular responses to epinephrine injections in glomerular and aglomerular fish. Amer. J. Physiol., 126:347-353, 1939.

208. TSCHERNISCHOW, O. B. Experimentelle Reifung der Geschlechtsprodukte beim Schlammbeisser (*Misgurnus fossilis*) im Winter. Doklady Akad. Nauk, URSS, N.S., 33: 154-157, 1941.

209. TURNER, C. D. General endocrinology. Saunders, Philadelphia. 1949.

210. TURNER, C. L. A quantitative study of the effects of different concentrations of ethynyl testosterone and methyl testosterone in the production of gonopodia in females of *Gambusia affinis*. Physiol. Zool., 15:263-280, 1942.

211. ——— Morphogenesis of the gonopodial suspensorium in *Gambusia affinis* and the induction of male suspensorial characters in the female by androgenic hormones. J. Exp. Zool., 91:167-193, 1942.

212. ——— The rate of morphogenesis and regeneration of the gonopodium in normal and castrated males of *Gambusia affinis*. J. Exp. Zool., 106:125-143, 1947.

213. UHLENHUTH, E., SCHENTHAL, J. E., THOMPSON, J. V., MECH, K. F. and ALGIRE, G. H. Colloid content and cell height as related to the secretory activity of the thyroid gland, I. In normal thyroids of *Triturus torosus*. J. Morph., 76:1-29, 1945.

214. VANDEN ECKHOUDT, J. -P. Recherches sur l'influence de la lumière sur le cycle sexuel de l'épinoche (*Gasterosteus aculeatus*). Ann. Soc. roy. Zool. Belgique, 77:83-89, 1947.

215. VANDERPLANK, F. L. Sex hormones and their effect upon conditioned responses in the rudd (*Leuciscus leuciscus*). J. Exp. Biol., 15:385-393, 1938.

216. VILTER, V. Metamorphose des larves d'anguille dans ses rapports avec l'activité hypophysaire. C.R. Soc. Biol. Paris, 137:534-535, 1943.

217. ——— Comportement de la thyroide dans la métamorphose de la civelle d'anguille. C.R. Soc. Biol. Paris, 138:615-616, 1944.

218. Rhéotropisme de la civelle et activité thyroidienne. C.R. Soc. Biol. Paris, 138:668-669, 1944.

219. ——— Action de la thyroxine sur la métamorphose larvaire de l'anguille. C.R. Soc. Biol. Paris, 140:783-785, 1946.

220. ——— Déterminisme hypophysaire du comportement "halophobe" de civelles immigrantes. C.R. Soc. Biol. Paris, 140:483-484, 1946.

221. VINCENT, S. Internal secretion and the ductless glands. 2nd ed. MacMillan, New York, 1922.

222. VINCENT, S. and THOMPSON, F. D. The Islets of Langerhans and the zymogenous tubules in the vertebrate pancreas, with special reference to the pancreas of the lower vertebrates. Trans. Roy. Soc. Can., Sect. IV, 1:275-286, 1907.

223. VIVIEN, J. -H. Sur les effets de l'hypophysectomie chez un téléostéen marin, *Gobius paganellus*. L. C.R. Acad. Sci. Paris, 207:1452-1455, 1938.

224. ——— Rôle de l'hypophyse dans le déterminisme du cycle génital femelle d'un téléostéen, *Gobius paganellus*. L. C.R. Acad. Sci. Paris, 208:948-949, 1939.

225. ——— Contribution à l'étude de la physiologie hypophysaire dans ses relations avec l'appareil génital, la thyroide et les corps suprarénaux chez les poissons sélaciens et téléostéens *Scylliorhinus canicula* et *Gobius paganellus*. Bull. biol. France-Belg., 75:257-309, 1941.

226. WARING, H. The co-ordination of vertebrate melanophore responses. Biol. Rev., 17:120-150, 1942.

227. WITSCHI, E. Hormonal regulation of development in lower vertebrates. Symp. Quant. Biol., Cold Spring Harbor, 10:145-151, 1942.

228. WOODMAN, A. S. The pituitary gland of the Atlantic salmon. J. Morph., 65:411-433, 1939.

229. WUNDER, W. Experimentelle Erzeugung des Hochzeitskleides beim Bitterling (*Rhodeus amarus*) durch Einspritzung von Hormonen. Z. vergl. Physiol., 13:696-708, 1931.

230. WYMAN, L. C. and LUTZ, B. R. The effect of adrenalin on the blood pressure of the elasmobranch, *Squalus acanthias*. Biol. Bull., 62:17-22, 1932.

231. YOUNG, J. Z. On the autonomic nervous system of the teleostean fish *Uranoscopus scaber*. Quart. J. Micr. Sci., 74:491-535, 1931.

232. ——— The autonomic nervous system of selachians. Quart. J. Micr. Sci., 75:571-624, 1932.

233. ——— Comparative studies on the physiology of the iris. I. Selachians. Proc. Roy. Soc. London, B, 112:228-241, 1933.

234. ——— Comparative studies on the physiology of the iris. II. *Uranoscopus* and *Lophius*. Proc. Roy. Soc. London, B, 112:242-249, 1933.

235. YOUNG, J. Z. and BELLERBY, C. W. The response of the lamprey to injection of anterior lobe pituitary extract. J. Exp. Biol., 12:246-253, 1935.

236. ZAHL, P. A. and DAVIS, D. D. Effects of gonadectomy on the secondary sexual characteristics in the ganoid fish, *Amia calva* Linnaeus. J. Exp. Zool., 63:291-307, 1932.

II. OSMOTIC REGULATIONS IN TELEOST FISHES

BY

VIRGINIA SAFFORD BLACK

Department of Zoology, University of British Columbia

INTRODUCTION

THE problem of regulation of the osmotic concentration of body fluids is common to both marine and fresh-water teleost fishes. Since most teleosts maintain an internal concentration equivalent to freezing point depressions (Δ) between Δ-0.5°C. and Δ-0.8°C., it follows that regulation must occur in these animals, for the osmotic concentration of fresh water is close to 0°C. while that of sea water is usually between Δ-1.5°C. and -2.3°C. For fish in fresh water, therefore, the problem is to maintain body fluids which are hypertonic to the environment; whereas marine teleosts must keep an internal fluid concentration which is hypotonic to that of the external medium. The mechanisms whereby osmotic regulation is accomplished in fish were first coherently assembled and described by Smith (128). Further advances have been discussed by Krogh (94), Baldwin (2), and Scheer (122). A short description of the basic mechanisms will be reviewed in this paper as an introduction to the discussion of some recent work in the physiology of osmotic regulation by teleost fishes. The concentrations of the external and internal media are expressed in the units used by the author to whom reference is being made. Equivalent concentrations are tabulated in table 1 for the convenience of the reader.

TABLE 1

EQUIVALENTS

Δ °C.	Salinity ‰	Chlorinity ‰
-0.4	5	2.8
-0.6	10	5.6
-0.9	15	8.3
-1.2	20	11.1
-1.5	25	13.9
-1.8	30	16.7
-2.1	35	19.4

The writer acknowledges with pleasure the assistance of Miss Anne Smith, acting Librarian, and Mrs. M. A. Wilson, in providing