assays containing 5% DMF and 50 ppm DDT, it was 0.23 + 0.03 (-38%; PL0.01). Accordingly the disruptive of Na^+ transport by DDT in intact gills may be related to Na^+,K^+,Mg^{2+}-ATPase inhibition.

Summarizing these data and our previous reports, marine adapted eels lose the capacity to maintain plasma osmolarity after being exposed to DDT. The primary osmoregulatory organs in marine teleosts are the intestine and the gill. DDT disrupts sodium dependent water absorption across isolated intestines, as well as the ability of gill filaments to maintain a Na^+ gradient against sea water. The disruption of sodium transport appears to have an enzymatic basis since DDT inhibits Na^+,K^+,Mg^{2+}-ATPase in the intestinal mucosa and gill filaments.

Finally, the osmotic gradient between the body fluids of teleosts and the bathing medium is greater in sea water than in fresh water. It can be reasoned, therefore, that teleosts should be more sensitive to DDT in sea water than in fresh water. To test this we studied the percent mortality versus time of marine adapted killifish *(Fundulus heteroclitis)*in sea water containing 0.1% ethanol and 1 ppm DDT; and, fresh water containing 0.1% ethanol and 1 ppm DDT. Killifish were maintained in aluminum trays at 15° C. There were 20 killifish in each group, each fish representing 5% of the data. Mortality was linear with time in both graphs. However, whereas 50% of the killifish in sea water died within 12 hr, the time at which 50% of the fresh water killifish died was delayed to 24 hr. (There was no mortality in control fish, trays containing sea water and fresh water with 0.1% ethanol.) DDT appears therefore to be more toxic to teleosts in sea water than in fresh water environments. Moreover, the increased sensitivity in sea water is consistent with the hypothesis that osmoregulatory disruption is involved in the toxicity of DDT in teleosts. (Supported by Grant AM06479, from the U.S.P.H.S.)

1971 #26

DISTRIBUTION OF BLOOD FLOW IN *S. Acanthias:* A PRELIMINARY STUDY

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The distribution of blood flow through the gills and the parallel elements of the arterial circulation were determined in the intact circulation of the dogfish.

Eleven free-swimming and four partially restrained male dogfish (1.49 $\pm$ 0.61 Kg) were used. In the first group an injection catheter was threaded into either the dorsal aorta to the level of the fifth gill arch or into the caudal artery 3 cm caudal to the cloaca through a #15 Touhuy needle inserted into the caudal artery. The fish swam freely in an 0.3 cubic meter seawater tank. In the restrained group the heart was exposed through a midline incision and the injection catheter was inserted into the ventricle through the apex. The same protocol was used for both groups of animals. Blood samples were taken from the injection catheter at time 0 (time when the cannula was approximately positioned), 30 minutes, and one and one-half hours later, for oxygen saturation, pH, equilibrated pH (abstract #27 MDIBL 1967), and hematocrit. At 30 minutes, 1cc of 15μ diameter ^{141}Ce tagged and 1cc of 50 μ diameter ^{125}I tagged microspheres (3M Brand Tracer Microspheres) were given and washed in by 1cc of dogfish Ringers. The amount of activity in each dose was

approximately 1μCi. The fish were allowed to continue swimming for an hour after the microsphere injection. At this time they were sacrificed by section of the spinomedullary junction and autopsied. The organs isolated and weighed were as follows: gills, heart, esophagus, duodenum, ileum, liver pancreas, spleen, kidneys, gonads, gall bladder, rectal gland, and brain. The remainder of the carcass was weighed and considered as muscle, cartilage and skin. Samples of muscle were taken. All samples were weighed and analyzed for radioactivity by a Nuclear-Chicago gamma counter. The cpm for each sample for each isotope was calculated and an average activity for each organ was determined. Total cpm for areas I, II, III of the dogfish circulatory system (Figure 1) were calculated. Percent

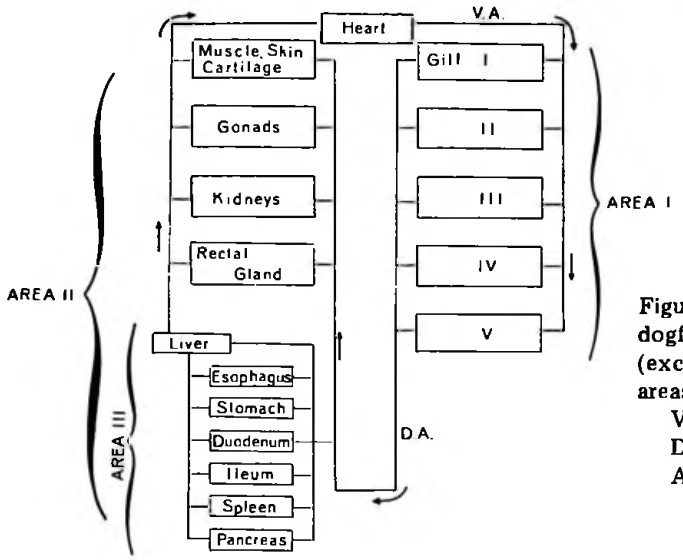


Figure 1. Block diagram of dogfish circulatory system (excluding brain) showing areas I, II, and III
V.A. = ventral aorta
D.A. = dorsal aorta
Arrows indicate direction of flow

flow through organs in parallel within each of these areas was found as: $\frac{\text{average activity/gm x organ wei}}{\text{Sum activity within area}}$ x 100. Flow in ml/gm/min was calculated using 1.4L/Kg/hr as an estimate of total cardiac output (MDIBL #29, 1967).

When microspheres were injected into the ventricle of partially restrained fish, 92.7 $\pm$ 20 SEM % of the 50μ microspheres, and 69.0 $\pm$ 10 SEM % of the 15μ microspheres were trapped in the gills. When injections were made in either the dorsal aorta or the caudal artery, however, no 50μ spheres were found in the gills, but 24.8 $\pm$ 4.16 SEM % and 30.9 $\pm$ 2.2 SEM % respectively of doses of 15μ spheres were found in the gills. The distribution patterns of small microspheres in the gills from the three injection sites were indistinguishable from each other and there was no significant difference between the distribution of 50μ and 15μ spheres in the gills. The distribution of cardiac output in per cent and ml/gm/min to the gills is shown in Figure 2.

Caudal artery injection of microspheres resulted in almost complete trapping of both sizes in the vasculature of the tail muscle. None of the large spheres and only 3.7 $\pm$ 1.4 SEM % of the small ones were recovered in the kidney which receives a portal circulation from the tail. No microspheres were found elsewhere.

There was no significant difference in distribution of large and small microspheres given into the dorsal aorta. Figure 3 summarizes distributions and flow for area II. The largest proportion of spheres were trapped in muscle, cartilage and skin, but the highest concentrations per gram of tissue were found in the kidneys and rectal gland. In two fish in which injections were made into the

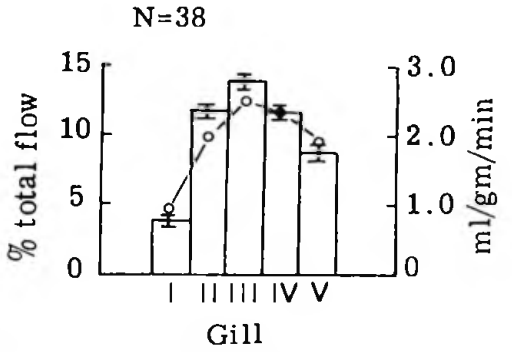
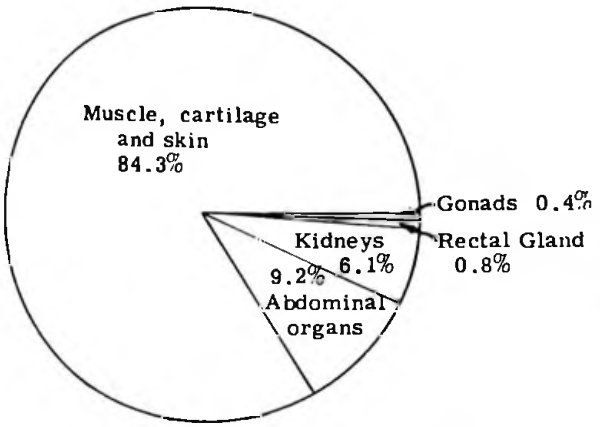
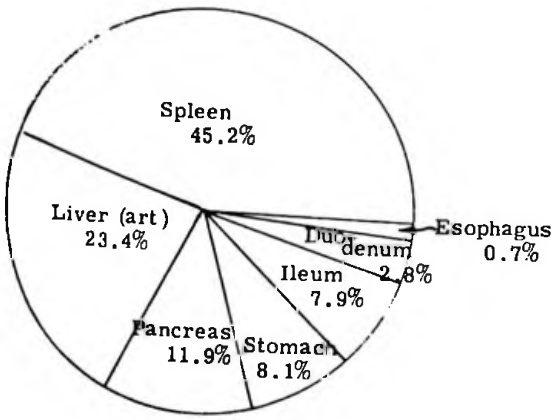


Figure 2. Blood flow pattern in the gills. Bars represent mean of % total flow ± standard error of of the mean (SEM). Open circles show ml/gm/min. I represents a half gill; II, III, IV, and V are whole gills.



N=9	% Body Weight	% Total Flow	ml/gm/min Mean	±SEM
Muscle	78.79	84.3 ±5.5	0.03	0.002
Abdominal Organs	16.37	9.2 ±5.1	0.01	0.006
Kidney	0.63	6.1 ±2.3	0.23	0.015
Rectal Gland	0.08	0.8 ±0.8	0.22	0.148
Gonads	1.58	0.4 ±0.3	0.01	0.009

Figure 3. Blood flow distribution in area II. Complete circle = 100% cardiac output. The table shows mean data ± SEM.



N=7	% Body Weight	% Total Flow	ml/gm/min	Organ Flow (ml/min) Mean	±SEM
Pancreas	0.31	11.89	0.082	0.39	0.26
Spleen	0.34	45.22	0.244	1.47	0.86
Duodenum	1.34	2.83	0.006	0.09	0.08
Stomach	1.40	8.05	0.010	0.24	0.22
Esophagus	1.51	0.69	0.001	0.02	0.01
Ileum	1.84	7.92	0.009	0.26	0.13
Liver Arterial	9.98	23.40	0.004	0.83	0.53
Liver Total		100.00	0.015	3.30	0.30

Figure 4. Blood flow distribution in area III. Complete circle represents 9.2% cardiac output. The table shows mean data ± SEM.

caudal artery, samples were taken of red muscle along the lateral line and of white muscle immediately adjacent to it. There was four times the amount of radioactivity in the red muscle per gram of tissue as in the white.

Of the microspheres in area II (Total dose minus amount in gills) 9.2 $\pm$ 5.1 SEM % were distributed to the organs in the abdominal cavity designated as area III. The spleen received the largest portion of arterial flow and was the organ with the highest flow per gram (Figure 4). Since most of the venous return from the organs in this part of the circulation perfuses the liver via the hepatic portal system, the total hepatic flow includes arterial flow to the liver and the sum of flow to each organ.

Hematocrit, pH, calculated pCO_2, and O_2 saturations changed very little over the time course of the experiment.

The similarity of the pattern of blood flow through the gills of all fish tested is striking. Since flow through the rostral gill per gram of tissue is less than half the flow through the other gills, distribution is not merely a function of gill size. If tissue other than gill lamella were included in the sample this difference might be expected. Care was taken, however, to dissect the gills from underlying gill arches and other supporting tissue. The geometry and position of departure from the ventral aorta of the afferent branchial arteries may contribute to the uneven perfusion of the gills. Since distribution patterns of both sizes of spheres are the same, either the proportion of large to small vessels in each gill is the same, or the sinusoidal path of capillaries in gill lamellae causes sequestration of both sizes of spheres.

There are several probable reasons for the variance in distribution and flow values for organs in areas II and III. If vascular beds of differing sizes occur in the same organ, then random samples would yield different total organ flows (e.g., mammalian kidney). Dispersion values of data, then, would correlate with homogeneity of vasculature within an organ. There may also be large variations in perfusion patterns from one fish to another or in one fish from time to time, depending on conditions such as pH and activity. Blood distribution to the abdominal organs may be controlled by local factors such as recent ingestion of food. In any event, the variance of values for area III is very large.

The value for blood flow through the liver found in this study, 0.015 ml/gm/min, agrees well with the flow rate obtained by BSP methods, 0.019 ml/gm/min *(Sharks, Skates and Rays*, 1967, p. 298). The arterial portion of blood flow in the liver may be lower than estimated by the microsphere technique. If microspheres are not completely trapped in the abdominal organs, they appear in the hepatic portal supply and may then become trapped in the liver. They would then be falsely considered as deposits from the arterial supply.

From an anatomic consideration of the efferent branchial arteries it can be assumed that the brain receives its blood supply from the first and second gills. The rostral continuation of the aorta is the internal carotid artery (The Vertebrate Body, 1970, p. 432). This carries blood not only to the brain but to the mandibular muscles and other parts of the skull and jaws. With the injection sites used in this study, it is not possible to determine the fraction of blood flow to the brain.

The high flow rates to the kidneys and rectal gland are to be expected since these organs play such a large role in osmoregulation and metabolism in the dogfish *(Sharks, Skates and Rays*, 1967, p. 177). In this preliminary study with microspheres the overall pattern of blood flow is shown.

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