Aspects of the Life History of Hornyhead Turbot, *Pleuronichthys verticalis*, off Southern California

The hornyhead turbot *(Pleuronichthys verticalis)* is a common resident flatfish on the mainland shelf from Magdalena Bay, Baja California, Mexico to Point Reyes, California (Miller and Lea 1972). They are randomly distributed over the bottom at a density of about one fish per 130 m^2 and lie partially buried in the sediment (Luckinbill 1969). Hornyhead turbot feed primarily on sedentary, tube-dwelling polychaetes (Luckinbill 1969, Allen 1982, Cross *et al.* 1985). They pull the tubes from the sediment, extract the polychaete, and then eject the tube (Luckinbill 1969). Hornyhead turbot are batch spawners and may spawn year round (Goldberg 1982). Their planktonic eggs are 1.00-1.16 mm diameter (Sumida *et al.* 1979). Their larvae occur in the nearshore plankton throughout the year (Gruber *et al.* 1982, Barnett *et al.* 1984, Moser *et al.* 1993).

Histological section of a fish ovary.

Several agencies in Southern California measure the bioaccumulation of trace metals and chlorinated hydrocarbons in muscle tissue of hornyhead turbot as part of their receiving water monitoring programs. In 1991 off Orange County, *p,p'*-DDE averaged 362 µg/kg wet weight in hornyhead turbot liver and 5 µg/kg dry weight in the sediments (CSDOC 1992). In the same year in Santa Monica Bay, *p,p'*-DDE averaged 7.8 mg/kg wet weight in liver and 81 µg/kg dry weight in the sediments (City of Los Angeles 1992). The highest tissue levels of chlorinated hydrocarbons in hornyhead turbot occur on the Palos Verdes Shelf; concentrations decline to the north and south (Mearns *et al.* 1991).

Despite the importance of the hornyhead turbot in local monitoring programs, its life history has received little attention. The long-term goal of our work is to determine how a relatively low trophic level fish like the hornyhead turbot accumulates tissue levels of chlorinated hydrocarbons several orders of magnitude greater than levels in sediments. The objectives of this study were to describe the reproductive cycle and diet of *Pleuronichthys verticalis* on the mainland shelf off Orange County.

Materials and Methods

Hornyhead turbot were collected off Huntington Beach in 30-35 m of water approximately every six weeks in 1992 (Figure 1). Fish were collected with a 7.6 m headrope otter trawl in the morning and transported live to the laboratory. The fish were euthanized with MS-222, measured to the nearest mm standard length, and weighed to the nearest 0.1g. The stomachs were removed, placed in Davidson's fixative for 30 days, and then transferred to 70% ethanol. The gonads were removed, weighed, and a 1-2 mm section was removed from the center and placed in Davidson's fixative for 30 days.

Fish weight-length relationships were calculated separately for males and females from:

$$W = aL^b,$$

where:
W = body weight in gm and
L = standard length in cm.
The constants a and b were determined by nonlinear regression technique (Marquardt 1963) in Sigmaplot™ for Windows Version 1.00.

The gonadosomatic index (GSI) was calculated for individual fish from:

$$GSI\ (\%) = (W_G / W_B) \times 100,$$

where:
W_G = gonad weight in gm and
W_B = body weight in gm.

Sections of gonads were cut at 6 µm and stained in hematoxylin and eosin. The histological preparations of the gonads were evaluated for reproductive status. Male gonads were rated based on the system of Grier (1981) and female gonads were rated based on the system of Ross and Merriner (1983) (Table 1). The diameters of a minimum of 50 randomly selected oocytes were measured for each female in a subset of females from each collection. Only oocytes sectioned through the nucleus were measured.

The stomach contents and major taxa were weighed to the nearest 0.01 g. Prey items were identified to the lowest possible taxon. The Index of Relative Importance (IRI) modified from Pinkas *et al.* (1971) was calculated from :

$$IRI = \%O\ (\%N + \%W),$$

where
%O = percent occurrence,
%N = percent numbers, and
%W = percent weight.
The sample size of stomachs that was sufficient to describe the diet of hornyhead turbot was determined from a plot of cumulative taxa versus number of stomachs. The asymptote of the curve was the minimum sample size.

The diel feeding pattern was determined from fish collected throughout a 24 h period in November 1992. Fish were collected by trawling before and after sunrise and sunset, and around midday and midnight. The fish were measured, sexed, and dissected on the ship. The stomachs were placed in

Figure 1.
Map of the study area off Orange County.

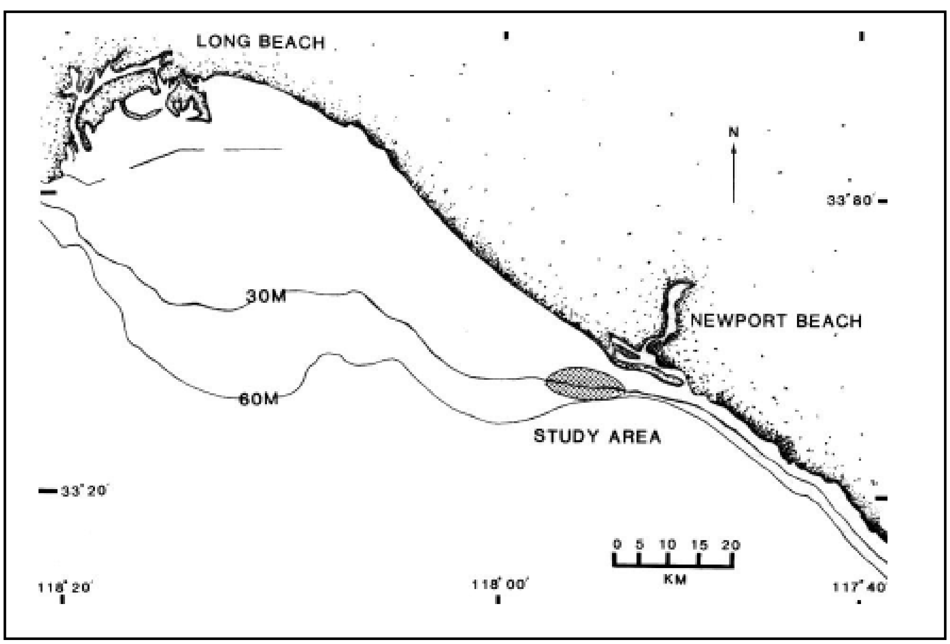


Table 1.
Rating system for female and male *Plueronichthys verticalis* gonads.

STAGE	FEMALES	MALES
I	Immature: Ovigerous lamellae composed of dense aggregations of undifferentiated oogonia and primary oocytes.	Immature: Spermatogonial proliferation.
II	Resting: Primarily early and previtellogenic oocytes with <1% early vitellogenic oocytes.	Early recrudescence: Spermatogonia and spermocytes present.
III	Developing: Previtellogenic oocytes numberically dominant with some early and active vitellogenic oocytes.	Mid-recrudenscence: All stages of sperm development present.
IV	Well developed: Vitellogenic oocytes predominant and evenly distributed over a large range	Late recrudescence: Tubules filled with sperm and number of developing cysts are declining.
V	Ripe: Broad distribution of vitellogenic oocyte, with a mode of very large vitellogenic oocytes with some atresia.	Functional maturity: Tubules filled with sperm, very little, if any spermatogenisis is occurring.
VI	Spent: No evidence of vitellogenisis, stage IV and V oocytes are atretic, a few stage III oocytes occur.	Post spawn

Davidson's fixative and treated as before. Individual fish weight was estimated from a weight-length regression for males and females previously collected. The stomach contents weight was normalized to fish weight from:

$W_{NS} = (W_S / W_B) \times 100$,

where:

W_{NS} = normalized stomach contents weight,

W_S = stomach contents weight, and

W_B = fish body weight predicted from regression.

Results

Size

The relationship between length and weight was different for females and males (Figure 2). Females weighed more than males at the same length and also grew to a larger size than males. The weight-length relationships were:

females $W = 0.3027\ L^{2.145}$

and

males $W = 0.8915\ L^{1.767}$.

Reproduction

Females reached sexual maturity at 150-160 mm SL (Figure 3). The GSI for mature females was high (>3%) from January to September (Figure 4). More females with stage four and five oocytes were collected between January and March (Figure 5) and the largest oocytes occurred in March. Ripe and running females (stage 6) were not collected during the study.

Males reached sexual maturity at 90-100 mm SL (Figure 6). The GSI for mature males was highest between July and September (Figure 7). Males with sperm (stage 5) were collected between October and January (Figure 8).

Food Habits

The plots of cumulative taxa became asymptotic at about 40 stomachs in the annual study and in the 24 h study (Figure 9). Hornyhead turbot fed on bivalves and polychaetes almost exclusively (Table 2). Bivalves composed 44% of the total IRI in the annual study and 57% in the 24 h study. Polychaetes composed 56% of the total IRI in the annual study and 40% in the 24 h study. Turbots ate only the tip of the bivalve siphon and not the whole bivalve. *Solen roseaceous* was the most common bivalve in the diet. Polychaetes were generally consumed whole. *Diopatra ornata*, *Pista alata*, and *Paraprionospio pinnata* were the most frequently occurring polychaetes. Echinoderms, nemerteans, nematodes, and cnidarians were also consumed, but made up less than 3% of the total IRI.

Hornyhead turbots had diel and annual feeding patterns. In the 24 h study, fish collected around sunrise had the highest stomach contents weight, which declined to a low in the evening (Figure 10). In the annual study, the median stomach contents weight of fish collected in the summer (2.64 g) was more than double the weight of fish collected in the winter (0.98 g).

Discussion

Males and females grew at the same rate up to about 150 mm, about the size of sexual maturity. After 150 mm, females grew proportionately more than males. Hornyhead turbot appeared to spawn mainly from late winter to spring, but Goldberg (1982) suggested that they spawn through the year. Their larvae occur in the plankton all year, but abundance is highest between June and August with a smaller peak between February and April (Moser *et al.* 1993). The larvae occur predominately inshore (Gruber *et al.* 1982, Moser *et al.* 1993) in depths between 5-70 m (Barnett *et al.* 1984). We found the largest concentrations of hornyhead adults

Figure 2.
Weight-length regression for female and male *Pleuronichthys verticalis* off Orange County.

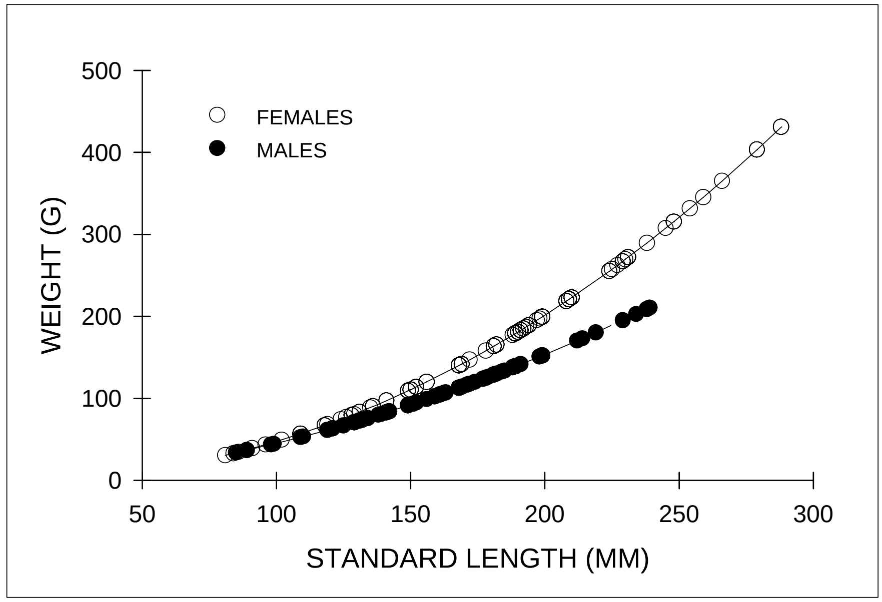


Figure 3.
Stage of development of female *Pleuronichthys verticalis* by size class.

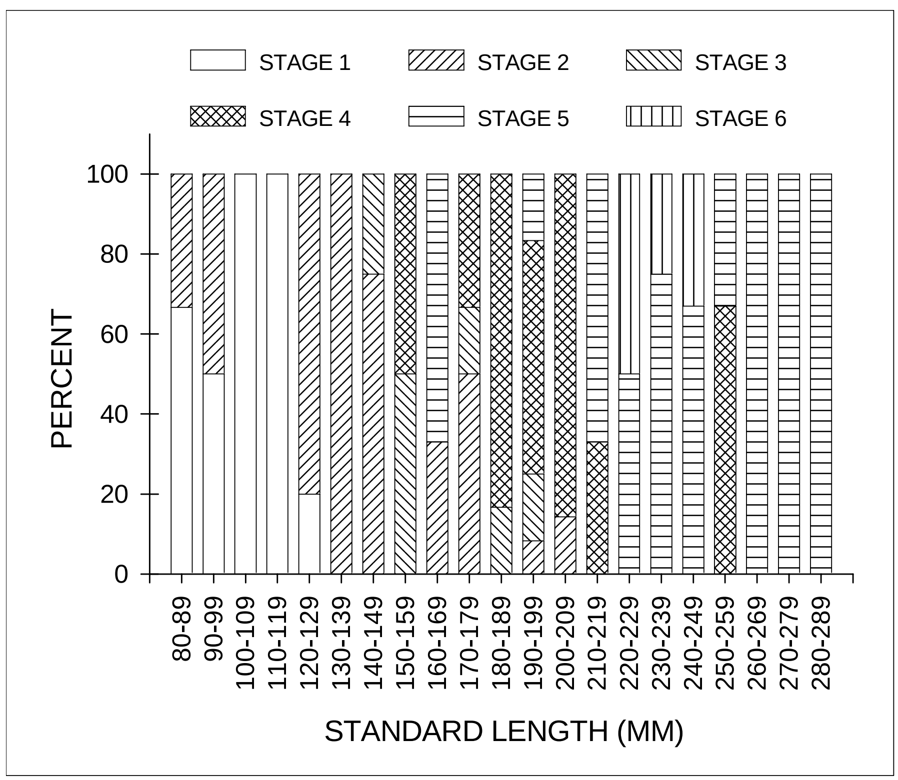


Figure 4.
Stage of development of male *Pleuronichthys verticalis* size class.

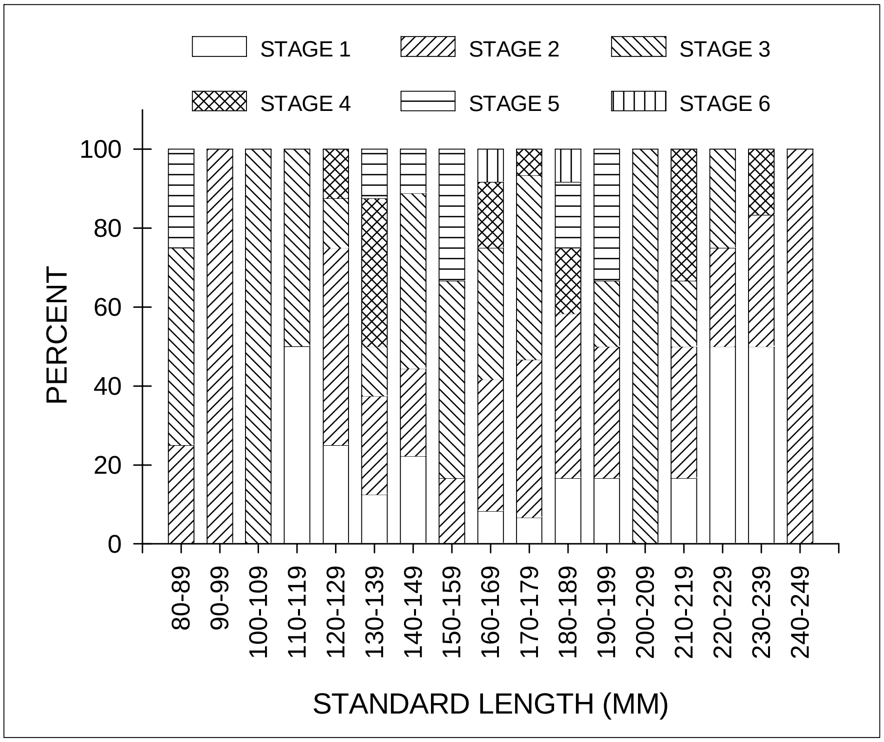
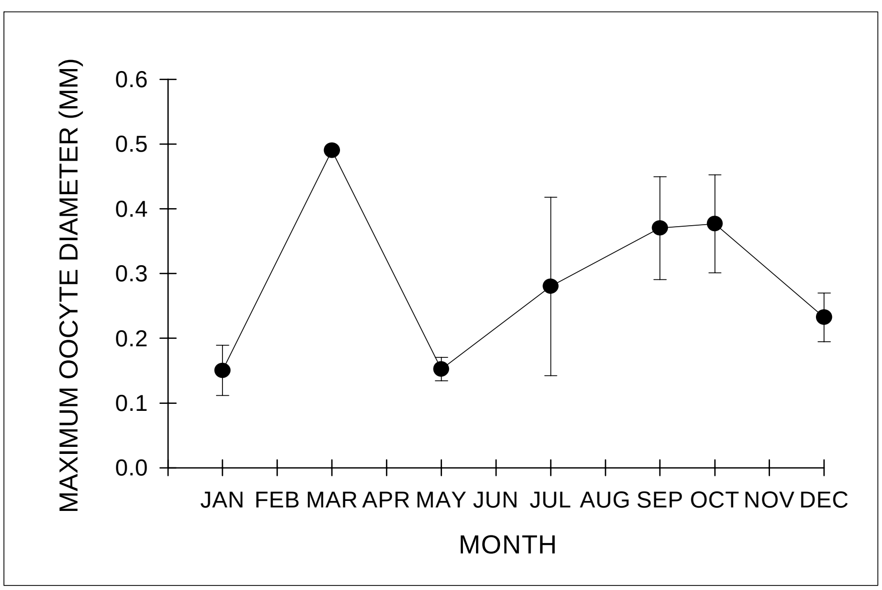


Figure 5.
Mean maximum oocyte diameter (± S.E.) for female *Pleuronichthys verticales* by month.



and juveniles off Huntington Beach in 30-35 m of water.

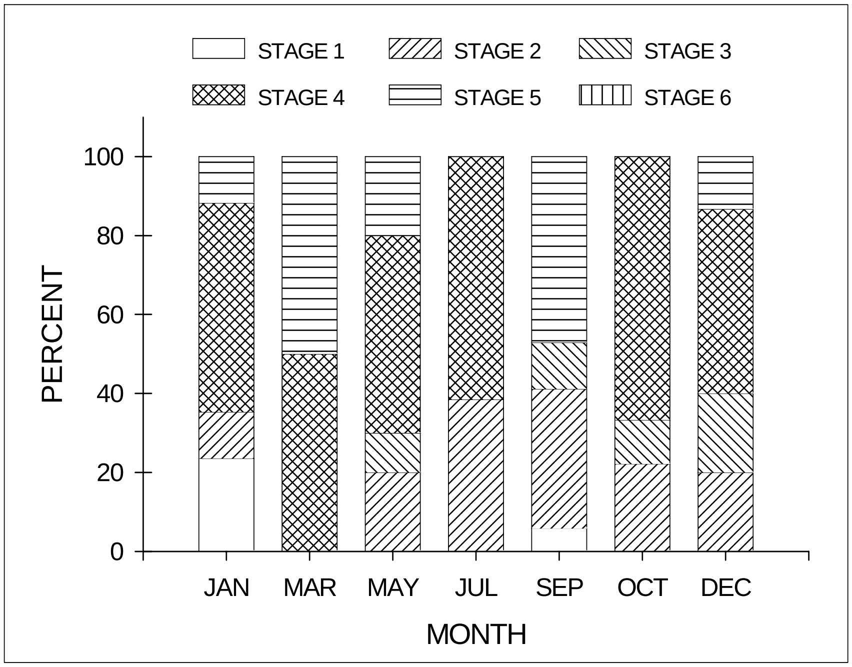
Spent males were collected in January, but spent females were not encountered during the study. These results were similar to Goldberg (1982) who found that 93% of the females he examined (n=140) had mature oocytes, but only 3% had postovulatory follicles (evidence of recent spawning). It is also possible that the El Niño that occurred in 1992 with the accompanying elevated water temperatures (CSDOC 1992) affected the reproductive ability of hornyhead turbot.

Hornyhead turbot had a diet restricted primarily to bivalves and tube-dwelling polychaetes; other taxa were probably eaten incidentally. Interestingly, the cnidarian, *Ceriantheria* sp., occurred in 7% of the fish collected during the 24-h study. It is a tube-dwelling anemone that probably resembles tube-dwelling polychaetes (Morris *et al*. 1980). Hornyhead turbot examined by Luckinbill (1969), Allen (1982), and Cross *et al.* (1985) also ate relatively few species of tube-dwelling polychaetes; bivalves were not an important prey item in these studies.

Hornyhead turbot fed predominately at sunrise. Food availability was probably higher in the summer when fish contained about three times the mass of prey as fish collected in the winter. The diets of fish caught in the

Figure 6.

Stage of development of female *Pleuronichthys verticalis* by month.



annual and 24 h studies were nearly identical. Because of the narrow dietary range, 40 stomachs were sufficient to describe the food habits.

Conclusions

The hornyhead turbot is a common resident of the mainland shelf off Southern California. It is a small mouth flatfish that preys on bivalves and polychaetes, which in turn are primarily deposit and suspension feeders. If bioaccumulation is primarily through the food, the foodweb leading to hornyhead turbot is relatively simple. Future studies will focus on how contaminants are transferred from particles to bivalves and polychaetes and then to turbots.

Figure 7.

Mean gonadosomatic index (GSI) for Pleuromichthys verticalis A) males >120 mm and B) females >150 mm (± S.E.) by month.

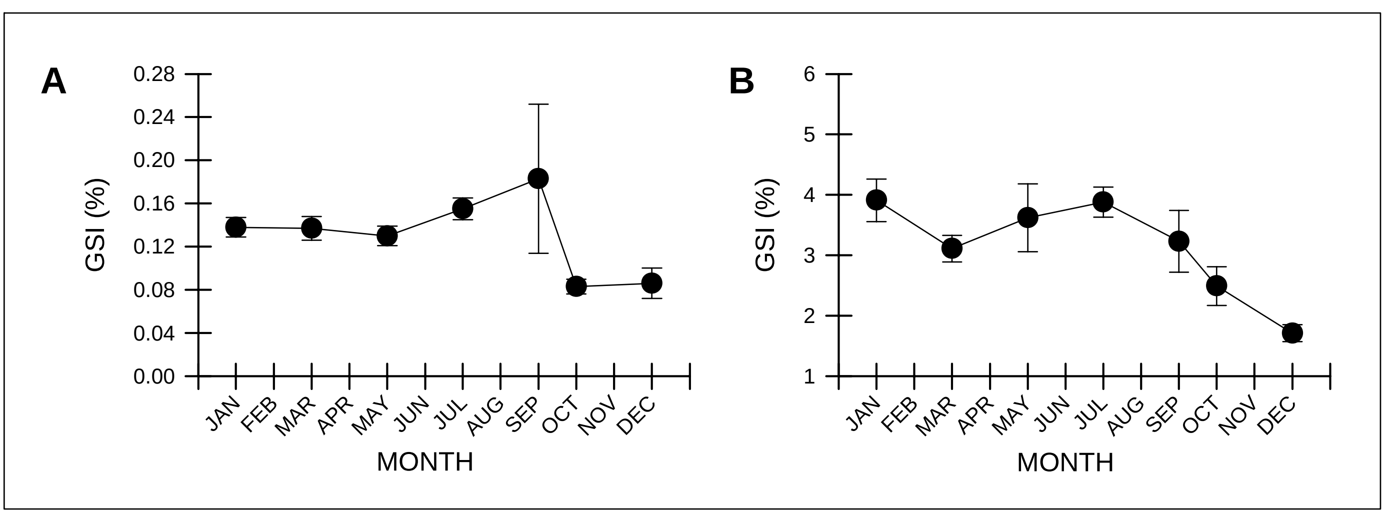


Figure 8.

Stage of development of male *Pleuromichthys verticalis* by month.

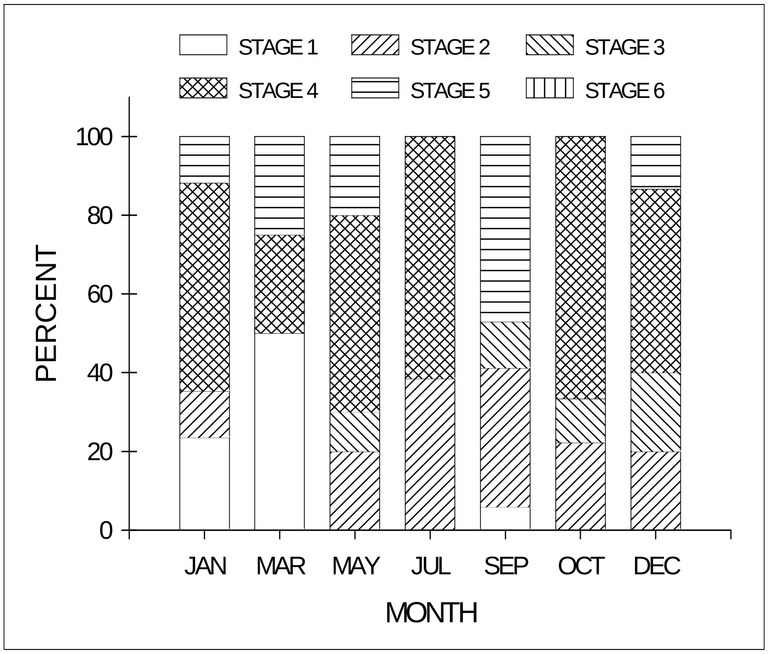
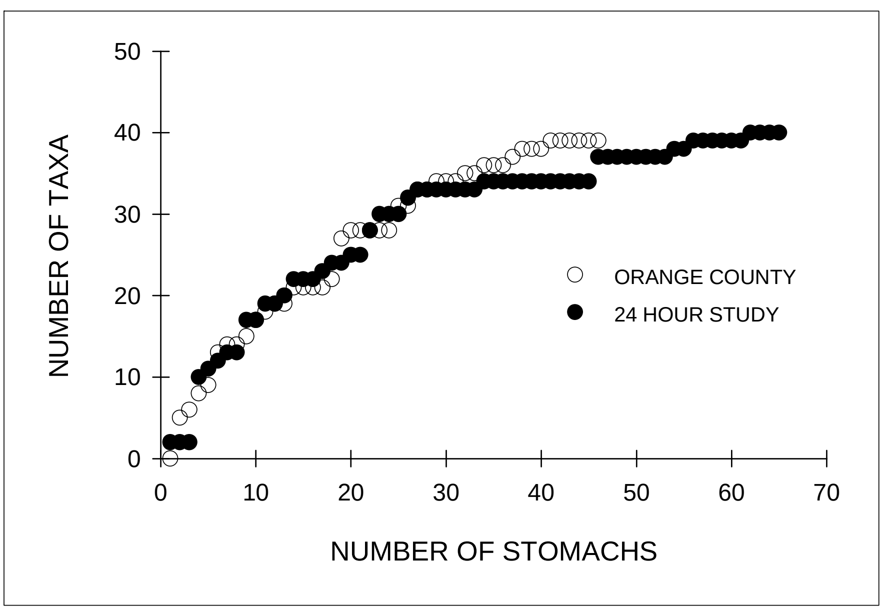


Figure 9.

Plots of the cumulative number of taxa consumed by *Pleuromichthys verticalis* in the annual and 24 h studies off Orange County.



References

•Allen, M.J. 1982. Functional structure of soft-bottom fish communities of the Southern California Shelf. Ph.D. Diss., University of California, Scripps Institution of Oceanography. 577 pp.

•Barnett, A.M., A.E. Jahn, P.D. Sertic, and W. Watson. 1984. Distribution of ichthyoplankton of San Onofre, California, and methods for sampling very shallow coastal waters. *Fish. Bull.* 82:97-109.

•City of Los Angeles. 1992. Marine monitoring in Santa Monica Bay: Annual assessment report for the period July 1990 through June 1991. Environmental Monitoring Division, Bureau of Sanitation, City of Los Angeles. 225 pp.

•County Sanitation Districts of Orange County. 1992. Marine monitoring. Annual report 1992. County Sanitation Districts of Orange County, Fountain Valley, California.

•Cross, J.N., J. Roney, and G.S. Kleppel. 1985. Fish food habits along a pollution gradient. *Calif. Fish Game* 71:28-39.

•CSDOC see *County Sanitation Districts of Orange County.*

•Goldberg, S.R. 1982. Seasonal spawning cycles of two California flatfishes, *Pleuronichthys verticalis* (Pleuronectidae) and *Hippoglossina stomata* (Bothidae). *Bull. Mar. Sci.* 32:347-350.

•Grier, H.J. 1981. Cellular organization of the testis and spermatogenesis in fishes. *Amer. Zool.* 21:345-357

•Gruber, D., E.M. Ahlstrom, and M.M. Mullin. 1982. Distribution of ichthyoplankton in the Southern California Bight. *Calif. Coop. Ocean. Fish. Investig. Rep.* 23:172-179

Table 2.

Stomach contents of *Pleuronichthys verticalis* collected off Orange County in 1992. O=occurrence of prey in stomachs, N=number of prey, W=weight of prey, IRI=index of relative importance (modified from Pinkas *et al.* 1971).

PREY ITEMS	% 0	% N	% W	IRI
Bivalvia	29	64	46	3,190
Veneroida	23	57	41	2,229
Solenidae	23	57	41	2,229
Solen roseaceous	23	57	41	2,229
Gastropods	3	1	0	2
Polychaeta	148	88	160	36,694
Capitellida	1	0	4	6
Maldanidae	1	0	4	6
Asychis disparidentata	1	0	4	6
Eunicida	13	7	4	118
Onuphidae	13	7	4	118
Diopatra ornata	11	7	3	117
Diopatra sp.	1	0	0	1
Phyullodocida	1	0	1	1
Sigalionidae	1	0	1	1
Sthenelanella uniformis	1	0	1	1
Sabellida	16	8	7	164
Sabellidae	16	8	7	164
Chone veleronis	6	5	7	76
Spionida	11	6	6	114
Spionidae	11	6	6	114
Paraprionospio pinnata	9	6	4	87
Terebellida	13	9	32	521
Ampheritidae	3	3	1	10
Melinna oculata	3	3	1	10
Teribellidae	10	6	31	376
Amaeana occidentalis	1	0	4	5
Pista alata	8	5	27	246
Pista sp.	1	0	0	1

•Luckinbill, L.S. 1969. Distribution and feeding relationships of the flatfishes *Pleuronichthys verticalis* and *Pleuronichthys ritteri*. M.S. Thesis, San Diego State University. 81 pp.

•Marquardt, D.W. 1963. An algorithm for least squares estimation of nonlinear parameters. *J. Soc. Indus. Appl. Math*. 11:431-441.

•Mearns, A.J., M. Matta, G. Shigenaka, D. MacDonald, M. Buchman, H. Harris, J. Golas, and G. Lauenstein. 1991. Contaminant trends in the Southern California Bight: Inventory and assessment. NOAA Tech. Mem. NOS ORCA 62. Office of Ocean Resources Conservation and Assessment, Rockville, MD. 404 pp.

•Miller, D.J. and R.N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Dept. Fish Game, *Fish Bull*. 157. 249 pp.

•Morris, R.H., D.P. Abbot, and E.C. Haderlie. 1980. Intertidal Invertebrates of California. Stanford University Press, Stanford, California. 65 pp.

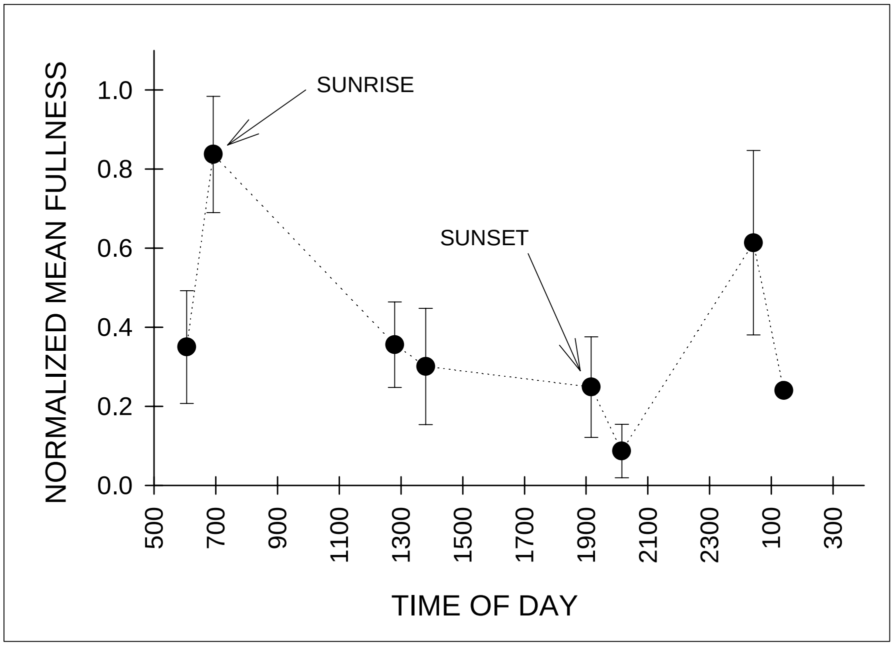
•Moser, H.G., R.L. Charter, P.E. Smith, D.A. Ambrose, S.R. Charter, C.A. Meyer, E.M. Sandknop, and W. Watson. 1993. Distributional atlas of fish larvae and eggs in the California Current region: Taxa with 1000 or more total larvae, 1951-1984. *Calif. Coop. Ocean. Fish. Investig. Atlas* No. 31. 233 pp.

•Pinkas, L., M.S. Oliphant, and I.L.K. Iverson. 1971. Food habits of the albacore, bluefin, tuna and bonito in California waters. *Calif. Fish Game* 152:1-105.

•Ross, J.L. and J.V. Merriner. 1983. Reproductive biology of the blueline tilefish, *Caulolatilus microps* off North Carolina and South Carolina. *Fish. Bull. U.S.* 81:553-568.

Figure 10.

Normalized mean stomach fullness (± S.E.) for *Pleuronichthys verticalis* collected off Orange County.



•Sumida, B.Y., E.H. Ahlstrom, and H.G. Moser. 1979. Early development of seven flatfishes of the eastern North Pacific with heavily pigmented larvae (Pisces, Pleuronectiformes). *Fish. Bull. U.S.* 77:105-154.

Acknowledgements

Author Larry Cooper thanks J. Cross for support and guidance during the project; H. Stubbs and D. Diehl for help in the lab and in the field; and D. Tsukada and F. Cummings for identifying the stomach contents.