DWARF HAKE OFF THE COAST OF BAJA CALIFORNIA, MEXICO

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ABSTRACT

Dwarf hake found in southern California is compared to *Merluccius productus,* the common hake found along the western coast of the United States, through morphometric measurements, meristic counts, and the electrophoresis of tissue proteins from the eye lens, vitreous humor, and muscle myogens.

Dwarf hake differs significantly from *M. productus* to suggest it may be a separate species and does not interbreed with either *M. productus* or the rarer *M. angustimanus*.

INTRODUCTION

This study was initiated to investigate the possibility of more than one stock of hake living off the coast of California and Baja California, Mexico. *Merluccius productus* is the common hake which spawns from off northern California to the tip of Baja California (Ahlstrom and Counts, 1955; Kramer and Smith, 1970). Ginsburg (1954) indicated the range of *M. angustimanus* extended northward along the west coast of Baja California to Del Mar, California, but Ahlstrom and Counts (1955) found no evidence of eggs or larvae of any species other than *M. productus.*

MacGregor (1971) collected a number of small hake off southern Baja California in January 1970, for fecundity studies. The smallest maturing male he found was 119 mm standard length (SL) and the smallest maturing female was 125 mm SL. All males 129 mm SL and longer and all females 140 mm SL and longer were sexually mature. The size at which these hake were mature was less than half that reported by Best (1963) who found only one mature fish shorter than 400 mm total length (TL). This fish was a female 380 mm TL (about 336 mm SL) with small ovaries filled with maturing eggs.

We obtained 51 frozen specimens from the same sample taken by MacGregor on January 11, 1970, at 26°07' N, 113°07' W. After thawing, all the fish in this sample had a rather red skin color. The red color is not consistent however, and has not been observed in subsequent samples. Perhaps the red color was caused by abrasion during capture as the fish had virtually no scales left because they had to be picked out of over 3,000 lbs (1,360 kg) of pelagic red crabs, *Pleuroncodes planipes,* that were caught in the same trawl. The red color faded to grey-brown when the fish were preserved in formalin.

The age of 56 hake from this and subsequent samples was determined from an examination of otoliths. The mean length at age I was similar to the mean length Best (1963) found for *M. productus,* but age groups II through V were remarkably smaller (Table 1, Figure 1). Of the 393 individual fish which we have identified and measured, the largest was only 305 mm SL and 97% of them were 250 mm SL or less.

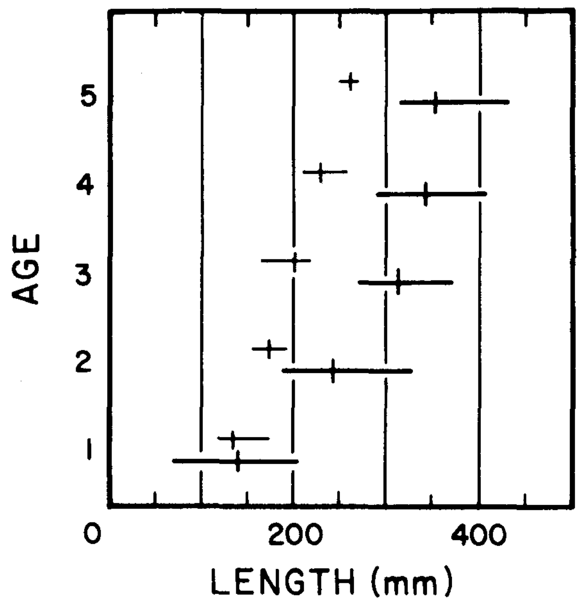

FIGURE 1. Length and age of *M. productus* (heavy bars) from Best (1963) and from dwarf hake (light bars).

From these data it appears that most of these fish are mature at age I and all are mature at age II. According to Best (1963), most *M. productus* are mature at 354 mm SL or age IV with perhaps a few of the larger age III maturing. The extremely small size at first maturity and the very slow growth rate has prompted us to refer to these small hake off southern Baja California as "dwarf hake."

TABLE 1

Mean Standard Lengths of *Merluccius productus* and Dwarf Hake by Age

AGE	Merluccius productus* Number	Mean SL (mm)	Range SL (mm)	Dwarf hake Number	Mean SL (mm)	Range SL (mm)
I	186	137.0	71–203	23	135.9	118–173
II	93	243.3	186–327	11	173.6	156–195
III	91	313.0	274–371	13	203.2	168–220
IV	9	342.2	292–407	7	231.0	214–260
V	10	351.9	318–433	2	261.5	253–270

* From Best (1963).

PROTEIN ELECTROPHORESIS

Electrophoresis of tissue proteins is an important tool for taxonomic studies. The form and structure of protein molecules are relevant sources of phylogenetic information (Sibley, 1962). Species differences in the electrophoretic patterns of muscle myogens of salmonoids were demonstrated by Tsuyuki and Roberts (1963). Tsuyuki et al. (1965) presented evidence for the virtual constancy and species specific nature of muscle myogens.

Electrophoresis of muscle myogens as well as eye lens and vitreous humor proteins was carried out in polyacrylamide gel columns according to the method described by Broome (1963). Muscle myogens of individuals of approximately 50 *M. productus* tested produced patterns similar to each other but different from the patterns observed from 30 dwarf hake (Figure 2). Proteins from these and other tissues were also electrophoresed in starch gel and in polyacrylamide gel slabs, and in all cases *M. productus* differed from the dwarf hake.

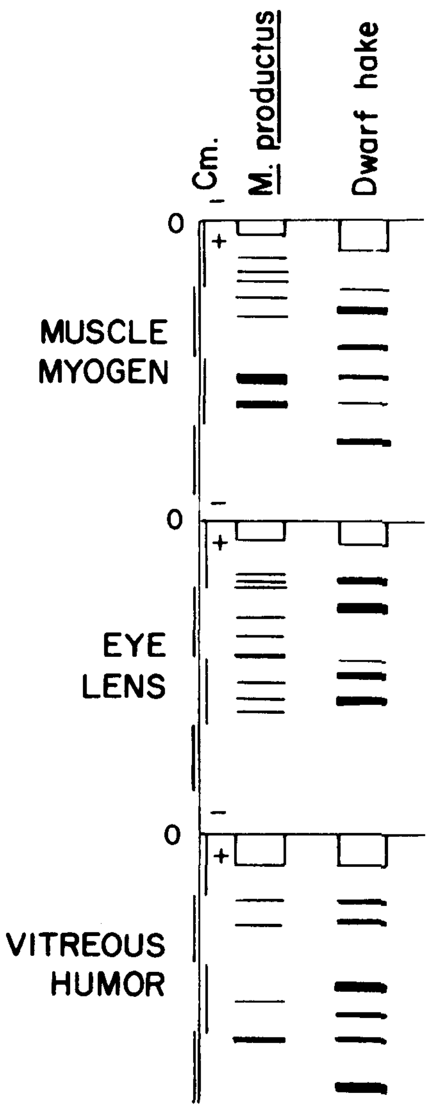

FIGURE 2. Protein patterns produced by electrophoresis in polyacrylamide-gel columns of tissues from *M. productus* and dwarf hake.

MORPHOMETRICS

We chose meristic and morphometric characters for this study according to those indicated by Ginsburg (1954) to be diagnostic for *M. productus* and *M. angustimanus*. All counts and measurements were made as he described.

Ginsburg (1954) indicated allometric growth for head length and pectoral length. Our data indicated essentially isometric growth for all the morphometric characters we examined except there did appear to be slight allometry in the snout to tip of pectoral fin for dwarf hake less than 100 mm SL (Figure 3). However, the calculated mean length of snout to tip of pectoral fin for all dwarf hake less than 100 mm SL was 52.59% SL and 52.56% SL for all those over 100 mm SL; the two are not significantly different (df = 230, F = 0.0095 ns).

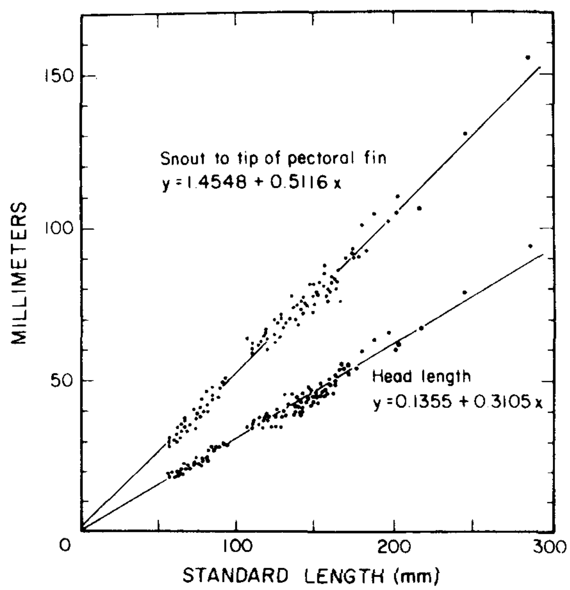

FIGURE 3. Snout to tip of pectoral fin and head length in relation to standard length for dwarf hake.

The morphometric measurements are expressed as percent of standard length (Table 2, Figure 4) and are graphically compared, as detailed by Hubbs and Hubbs (1953). The differences in the means between dwarf hake and *M. productus* are highly significant at the 0.01 level for all seven characters measured (Table 3), with dwarf hake having the largest percent of standard length for all characters.

TABLE 2

Morphometric Measurements of Dwarf Hake and *Merluccius productus* Expressed as Percent of Standard Length

Merluccius productus	N	Mean % SL	Range % SL	Standard deviation	Standard error
Snout to tip of pectoral fin..	76	48.58	43.86–52.44	2.2945	0.2646
Pectoral fin length............	76	19.67	11.59–23.08	2.0715	0.2376
Head length........	76	28.76	25.64–33.33	1.3361	0.1498
Snout length........	76	9.90	7.41–12.37	0.9761	0.1073
Maxillary length	76	13.54	10.77–17.46	1.2542	0.1438
Snout to anal fin insertion	76	45.01	37.70–50.77	1.8791	0.2243
Eye diameter......	76	5.92	4.24–8.82	0.7395	0.0848
Dwarf hake					
Snout to tip of pectoral fin..	231	52.57	45.78–59.26	2.3228	0.1466
Pectoral fin length............	231	21.46	15.71–25.93	1.7453	0.1148
Head length........	231	31.25	26.57–35.48	1.8356	0.1207
Snout length........	231	10.41	8.55–13.16	0.9379	0.0617
Maxillary length	231	14.92	11.46–19.35	1.4898	0.0980
Snout to anal fin insertion	231	48.09	44.37–54.39	1.7690	0.1163
Eye diameter......	231	6.58	5.33–7.94	0.5461	0.0359

fin ray counts were made from x-ray plates, gill raker counts were made directly from the fish. In nearly all cases the raker count was made from the first gill arch on the left side, in a few the left side was damaged so the right side was used. Only well formed rakers were counted, tubercles were not.

Ginsburg suggested that in some hake there might be a slight growth change in gill raker count. Since the mean standard length of our *M. productus* (218.5 mm SL) was almost twice that of dwarf hake (114.3

TABLE 3

Comparison of the Means of the Morphometric Characters for Dwarf Hake and *Merluccius productus*

	M. productus % SL	Dwarf hake % SL	Difference % SL	df	F
Snout to tip of pectoral fin	48.58	52.57	3.99	306	169.03
Pectoral fin length	19.67	21.46	1.79	306	53.80
Head length	28.76	31.25	2.49	306	126.76
Snout length..........	9.90	10.41	0.51	306	19.63
Maxillary length ..	13.54	14.92	1.38	306	55.69
Snout to anal fin insertion..........	45.01	48.09	3.08	306	155.66
Eye diameter	5.92	6.58	0.66	306	69.33

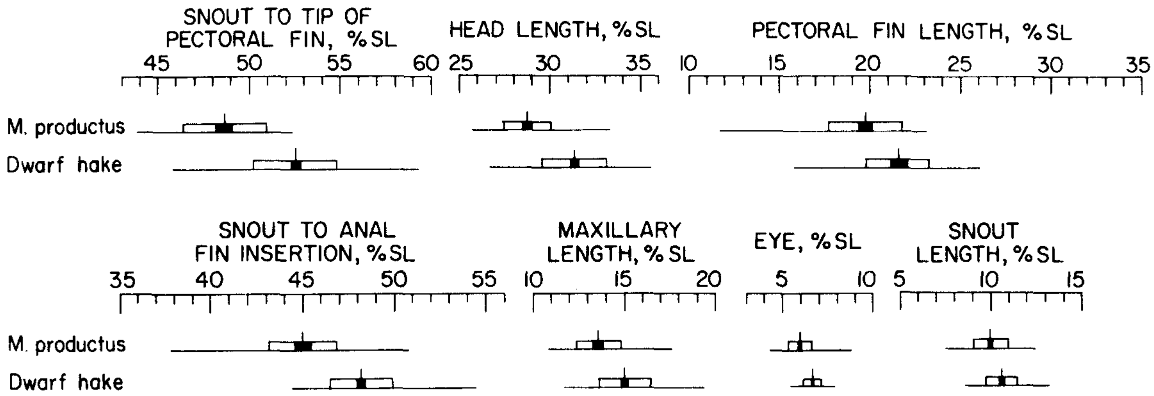

FIGURE 4. Graphic comparisons of morphometric data for *M. productus* and dwarf hake (see Table 1). The range is shown by the horizontal line and the mean by the vertical line. The solid bar represents two standard errors of the mean on either side of the mean. The open bar plus one-half of the solid bar represents one standard deviation on either side of the mean. Graphic method from Hubbs and Hubbs (1953).

Although these differences are all significant, the degree of overlap of each is so great (Figure 4) that none of the characters is very useful for field identification of individual fish; however, the combination of longer head and fin lengths and greater distance from snout to anal fin insertion gives the dwarf hake a more slender appearance than *M. productus*. In all the specimens we examined, both dwarf hake and *M. productus* had truncate or slightly emarginate caudals.

MERISTICS

In addition to the number of anal fin rays, second dorsal fin rays, and gill rakers on the first gill arch which Ginsburg (1954) indicated as the chief characters which separate *M. productus* from *M. angustimanus*, we counted vertebrae. Vertebral and

TABLE 4

Mean Numbers of Gill Rakers on the First Gill Arch of *Merluccius productus* and Dwarf Hake Segregated into 100 mm Size Groups

	Standard length 0–99 mm		Standard length 100–199 mm		Standard length over 200 mm	
	N	Mean	N	Mean	N	Mean
M. productus..........	0	—	37	19.54	62	19.37
Dwarf hake	95	17.26	131	17.36	5	17.20

mm SL) we tested for growth changes. The mean number of gill rakers on the first gill arch was calculated for both species segregated into 100 mm SL size groups (Table 4). The differences in the means between size groups within either species were tested and found to be not significant at the 0.5 level.

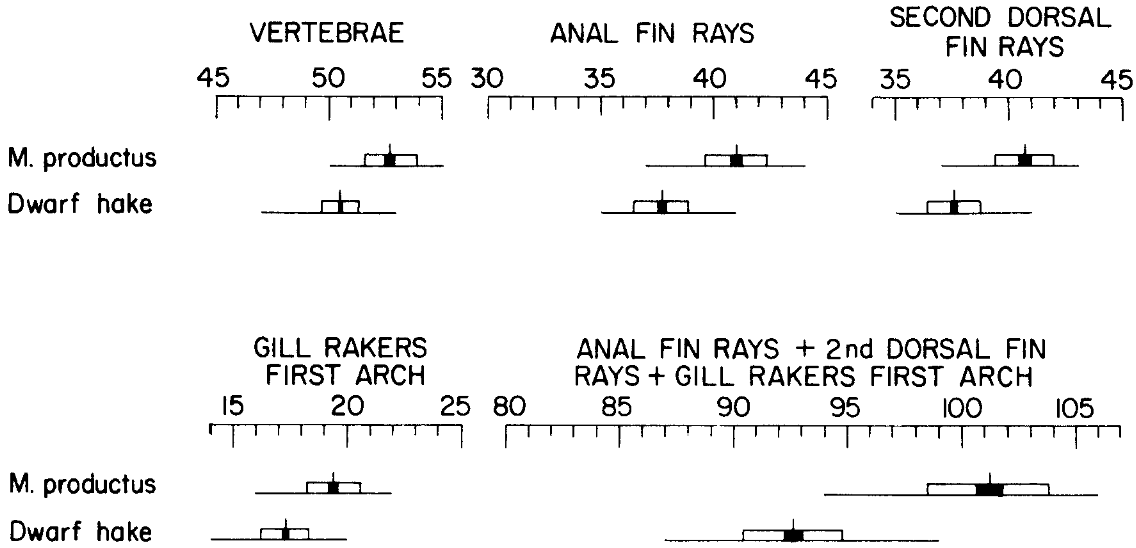

FIGURE 5. Graphic comparisons of meristic data for *M. productus* and dwarf hake (see Table 4). The range is shown by the horizontal line and the mean by the vertical line. The solid bar represents two standard errors of the mean on either side of the mean. The open bar plus one-half of the solid bar represents one standard deviation on either side of the mean. Graphic method from Hubbs and Hubbs (1953).

TABLE 5
Meristic Counts for *Merluccius productus* and Dwarf Hake

	N	Mean	Range	Standard deviation	Standard error
Merluccius productus					
Number of vertebrae	94	52.73	50–55	1.1563	0.1193
Anal fin rays	91	41.02	37–44	1.3497	0.1415
Second dorsal fin rays	93	40.69	37–43	1.3265	0.1376
Gill rakers upper limb	105	4.30	3–5	0.5904	0.0576
Gill rakers lower limb	105	15.10	13–18	0.9085	0.0887
Total gill rakers first arch	105	19.41	16–22	1.1985	0.1170
Anal + 2nd dorsal + total rakers	91	101.20	94–106	2.6759	0.2805
Dwarf hake					
Number of vertebrae	210	50.52	47–53	0.7959	0.0549
Anal fin rays	192	37.71	35–41	1.1794	0.0851
Second dorsal fin rays	175	37.58	35–41	1.2004	0.0907
Gill rakers upper limb	231	3.90	3–5	0.4913	0.0323
Gill rakers lower limb	231	13.43	11–16	0.8145	0.0536
Total gill rakers first arch	231	17.32	14–20	1.0767	0.0708
Anal + 2nd dorsal + total rakers	171	92.67	87–99	2.2566	0.1726

Dwarf hake have fewer vertebrae, anal fin rays, second dorsal fin rays, and gill rakers than *M. productus* (Table 5, Figure 5). The differences in the means for all of these characters are highly significant at the 0.01 level (Table 6). There is considerable overlap in the counts so no single character is very useful for field identification of individual fish; however, the sum of three meristic characters which are readily counted in the field, anal rays, second dorsal rays, and gill rakers on the

TABLE 6
Comparison of the Means of the Meristic Characters for *Merluccius productus* and Dwarf Hake

	M. productus	Dwarf red hake	Difference	df	F
Number of vertebrae	52.73	50.52	2.21	302	373.07
Anal fin rays	41.02	37.71	3.31	281	441.84
Second dorsal fin rays	40.69	37.58	3.11	266	381.08
Gill rakers upper limb	4.30	3.90	0.40	334	41.50
Gill rakers lower limb	15.10	13.43	1.67	334	287.23
Total gill rakers first arch	19.41	17.32	2.09	334	246.81
Anal + 2nd dorsal + total rakers	101.20	92.67	8.53	260	727.82

TABLE 7

Meristic Data From Samples Arranged From North to South

Sample number*	Latitude	Vertebrae		Anal rays		Second dorsal rays		Gill rakers		Anal + second dorsal + rakers	
		N	Mean	N	Mean	N	Mean	N	Mean	N	Mean
1	38–34°N	25	53.04	23	41.35	25	41.24	25	19.64	23	102.04
2	33–30°N	25	53.08	23	41.17	25	40.92	25	19.80	23	102.00
3	29°N	25	52.52	23	40.78	25	40.20	25	19.60	23	100.96
4	27°N	25	50.76	23	38.22	25	37.52	25	17.24	23	92.43
5	26°N	25	50.72	23	37.00	25	37.24	25	17.64	23	91.83
6	25°N	25	50.56	23	37.74	25	37.80	25	17.12	23	92.65

* Samples 1, 2, and 3 are *Merluccius productus*; samples 4, 5, and 6 are dwarf hake.

first arch, is a good tool. If we had arbitrarily separated all the hake in our samples into two groups with this combination character, those with a sum of 96 or less as dwarf hake and those with 97 or more as *M. productus*, we would have misclassified only 6 *M. productus* out of 91 and only 8 dwarf hake out of 171, for a total identification error of 5.34%.

Frederick H. Berry,[1] a National Marine Fisheries Service (NMFS) Fishery Biologist formerly at this laboratory, proposed in an unpublished manuscript that all the eastern Pacific hake from Alaska to southern Chile were represented by two species. He concluded that *M. polylepis* from southern Chile was a valid species and the other four forms, *M. productus, M. angustimanus, M. gayi gayi*, and *M. gayi peruanus*, were a single species, *M. gayi*. He postulated that the meristic and morphometric characters which had been used to separate the last four merely reflected environmentally induced differences which varied clinally over the geographic range.

Our data did not indicate such a cline; instead, we found a distinct break in both morphometric and meristic characters in the area off Punta Eugenio, Baja California, or about 28° N. We can demonstrate this by using the method described by Rothschild (1963) for graphic comparisons of meristic data.

The procedure requires samples of equal size for comparison of any single character; therefore, after we arranged our samples in geographic order from north to south, we selected randomly from the larger number of fish to produce sample sizes equal to the smallest. We counted the mean number of vertebrae, anal fin rays, second dorsal fin rays, gill rakers on the first gill arch, and the combination of anal rays plus second dorsal rays plus gill rakers for each sample arranged from north to south (Table 7).

An analysis of variance was performed for each of these characters and in all cases F was found to be highly significant at the 0.01 level (Table 8).

The ranges, means, and one ω interval on each side of the means were plotted (Figure 6). ω is a single valued parameter for judging the significance of multiple comparisons of the observed differences using Tukey's procedure (Steele and Torrie, 1960)

[1] Berry, Frederick H. (MS) Taxonomy of the eastern Pacific hake *Merluccius*.

TABLE 8

Analysis of Variance for Meristic Data From Samples*

	df among samples	df within samples	F
Number of vertebrae	5	144	48.60
Anal fin rays	5	132	65.95
Second dorsal fin rays	5	144	63.67
Total gill rakers first gill arch	5	144	35.15
Anal + 2nd dorsal + total rakers	5	132	145.81

* See Table 7.

for $\alpha = 0.01$. A mean beyond one ω interval on either side of the mean of another sample is significantly different from that sample at the 1% level. For all 5 meristic characters tested, there is a sharp break between samples 3 and 4 or at about 28° N, which does not fit Berry's clinal theory.

The morphometric and meristic data, the size at first maturity, and the differences in tissue proteins

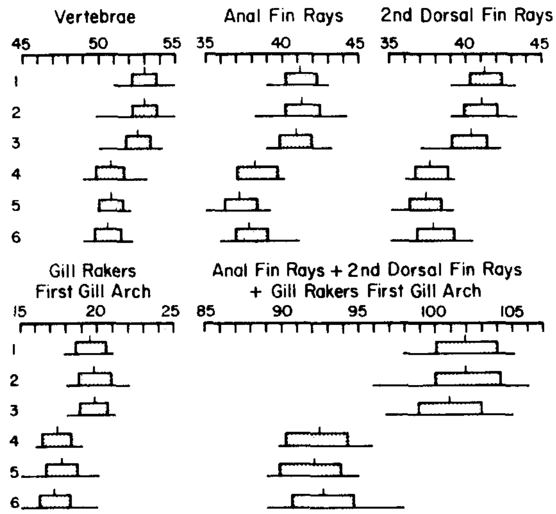

FIGURE 6. Graphic comparisons of meristic data of samples arranged from north to south. Samples 1, 2, and 3 are *M. productus*, samples 4, 5, and 6 are dwarf hake. The horizontal line represents the range, the vertical line the mean, and the solid bar represents one on either side of the mean. Graphic method from Rothschild (1963).

are convincing evidence that the dwarf hake is a species distinct from *M. productus*. However, we are not convinced that the dwarf hake is *M. angustimanus*. We have examined the specimens from off Del Mar, California, and Santo Domingo, Baja California, that Ginsburg (1954) used in his description of *M. angustimanus* and find that they fit our description of dwarf hake. Dwarf hake do not quite fit the original description of *M. angustimanus* by Garman (1899). He found 110 lateral line scales, and although we find it very difficult to get an accurate count on our specimens, the range is much higher, 125 to 150, with an average around 135. Garman's illustration and description indicates extremely long pectoral fins reaching to the fifth anal ray or beyond. Dwarf hake have relatively long pectorals but they seldom reach to the fifth anal ray and frequently do not even reach to the anal fin insertion. Garman did not count vertebrae, but C. Mathews [2] (MS) found from 45 to 49 vertebrae with a mean of only 47.02 for *M. angustimanus* from the Gulf of California; dwarf hake have from 47 to 53 vertebrae with a mean of 50.52. Out of the 83 *M. angustimanus* Mathews examined, only 2 had more than 48 vertebrae, and out of 210 dwarf hake, we found only 3 with less than 49. To adequately compare dwarf hake and *M. angustimanus* we would need to obtain fresh *M. angustimanus* from Panama suitable for electrophoresis; a series of specimens from which to take counts and measurements, and we would also need to examine Garman's type specimen, which is beyond the original scope of this paper.

CONCLUSIONS

1. There are two stocks of hake off the coast of Baja California, Mexico; *M. productus* to the north and dwarf hake to the south. The primary division between the two stocks is in the area of Sebastian Viscaino Bay or about 28° N, with some overlap in the range of the two. One dwarf hake was taken off Del Mar, California, 33° N, and one sample of 4 *M. productus* was taken off San Hipolito Bay, 27° N

2. Dwarf hake and *M. productus* are approximately the same size at age I but subsequent growth of dwarf hake is much slower than in *M. productus*. The maximum observed size of dwarf hake is 305 mm SL. The maximum reported size of *M. productus* (Best, 1963) is 800 mm TL (707 mm SL).

3. Most dwarf hake are mature at age I, and all are mature at age II. Most *M. productus* mature at age IV with perhaps a few of the larger age III mature.

4. Dwarf hake are distinctly different from *M. productus* in electrophoretic patterns produced from proteins of the eye lens, vitreous humor, and muscle.

5. Morphometrically, dwarf hake differ from *M. productus* by having longer heads, longer pectoral fins, larger eyes, longer snouts, greater distance from snout to tip of pectoral fin, and greater distance from snout to anal fin insertion.

6. Meristically, dwarf hake have fewer vertebrae, anal fin rays, second dorsal fin rays, and gill rakers than *M. productus*.

[2] Mathews, C. (MS) Meristic studies of the Gulf of California hake, with description of a new species.

ACKNOWLEDGMENTS

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