DEEP SCATTERING LAYERS: PATTERNS IN THE PACIFIC

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ABSTRACT

The daytime depth of the deep scattering layers in major biotic regions of the Pacific Ocean are analyzed and found to be correlated with light levels, although at some locations a sharp temperature gradient seems to inhibit a particular layer from migrating to the surface. O_2 minimum layer seems to have no effect on the behavior of the layers. The layers have been classified as migratory, semi-migratory and stationary.

INTRODUCTION

Ever since deep scattering layers (DSL) were discovered in 1948, they have been investigated extensively. The majority of these studies may be divided into two main categories: (1) the composition of the layers, and (2) the response of the layers to various stimuli such as light and temperature.

Deep scattering layers have been observed in almost every part of the oceans except the Antarctic, and since there is not merely a single species of vertically migrating organisms or a distinct fauna which covers such a range, one can then assume that the composition of the layers may differ from location to location. Samples of the DSL organisms show differing compositions (Barham, 1957). At present, there is not enough information to group and compare the DSLs according to their biological composition; nor do sufficient data exist to ascertain whether a single stimulus, such as solar irradiance, may account for the layer movements in every region of the Pacific Ocean.

An approach for comparing the characteristics of one layer of unknown composition with those of another layer is to make use of knowledge acquired by investigations not necessarily related to DSL studies. Such an attempt was made by Beklemishev (1964) who divided the Pacific Ocean into 17 major biotic regions, the boundaries of which were determined on the basis of net tows as well as water masses and currents. Implicit in this approach is that the distinctions apply to the DSL as well.

McGowan (1974) proposed other biogeographical regions, based on the distribution of a variety of planktonic and nektonic species, which significantly differ from those proposed by Beklemishev. McGowan's classifications of major biogeographical regions are used throughout this study (Figure 1).

DSL distribution in the California Current region is also included in this study even though this region is not considered as a major biotic region by McGowan. It is believed that to compare the DSL characteristics of the California Current region, whose faunal composition is not endemic, to other regions may further aid our understanding of the DSL phenomenon.

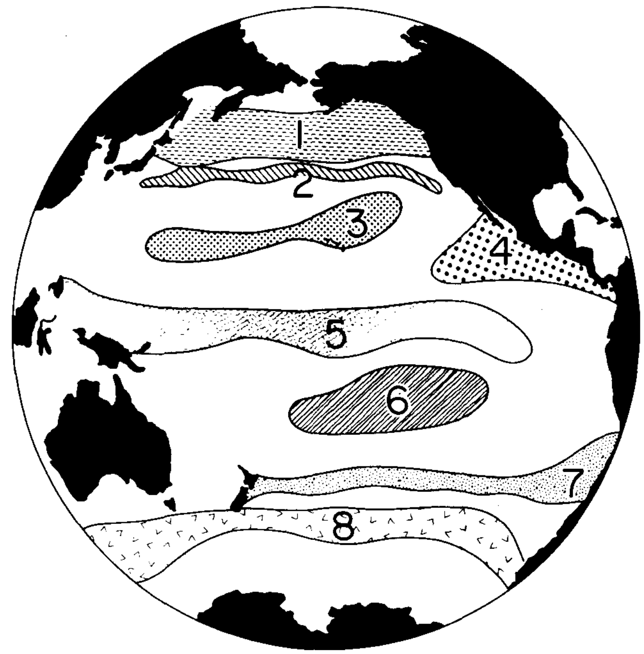

FIGURE 1. Patterns of the basic (100% "core" regions) biotic provinces of the oceanic Pacific. Redrawn from McGowan (1974).

The purpose of this study has been to investigate the characteristics of the DSL, not only as a localized parameter, but more importantly as a wide ranged oceanic phenomenon.

Materials and Methods

For the last 3 years I have been studying a massive collection of acoustical records, accumulated at Scripps Institution of Oceanography. Data collected on a number of cruises have been used in this study (Table 1). The DSL depths were obtained at a number of segments of cruise tracks (Figure 2).

On fourteen of the cruises the dominant frequency used to obtain DSL records was 12 kHz, and the data were collected using a Precision Depth Recorder (PDR). Records for the remaining cruises were taken using a Simrad Recorder at a dominant frequency of 18 kHz. No significant differences were observed between the two frequencies in ascertaining DSL depth.

The resolution of the acoustic scattering in the ocean will depend on DSL depth and transmitting

TABLE 1

Cruises from which Deep Scattering Layer Data were Obtained

Cruise	Time period
1. Downwind	22 Oct 57–28 Feb 58
2. Dolphin	27 Mar 58– 9 May 58
3. Scott	25 Apr 58–19 May 58
4. Costa Rica Dome	6 Nov 59–14 Dec 59
5. Mendocino	18 Apr 60–18 May 60
6. Step-I	15 Sep 60–14 Dec 60
7. Monsoon	28 Aug 60–18 Apr 61
8. Japonyon	27 May 61–15 Sep 61
9. Swan Song	14 Aug 61– 1 Dec 61
10. Risepac	27 Oct 61– 5 Feb 62
11. Papagayo	17 Jun 65–12 Aug 65
12. Amphitrite	3 Dec 63–29 Feb 64
13. Zetes-Broeas	4 Jan 66– 8 Aug 66
14. Albacore Oceanography Cruise 40	18 Aug 69–19 Sep 69
15. CalCOFI 6910-J (North) Cruise 41	7 Oct 69–30 Oct 69
16. CalCOFI 6912-J (South) Cruise 43	28 Nov 69–19 Dec 69
17. SCOR Discoverer Expedition	13 May 70–21 May 70
18. Albacore Oceanography Cruise 56	5 Oct 70–22 Oct 70
19. Skipjack Resource Assessment No. 1, Cruise 57	2 Nov 70–17 Dec 70
20. Skipjack Resource Assessment No. 2, Cruise 60	1 Mar 71–16 Apr 71
21. North Pacific Study-10	22 Mar 71–29 Apr 71
22. CalCOFI 7202-G	8 Feb 72–29 Feb 72
23. CalCOFI 7203-G	6 Mar 72–22 Mar 72
24. CalCOFI 7205-G	10 Apr 72–15 Jun 72
25. CalCOFI 7207-G	11 Jul 72–31 Jul 72
26. CalCOFI 7210-J	22 Sep 72–17 Nov 72

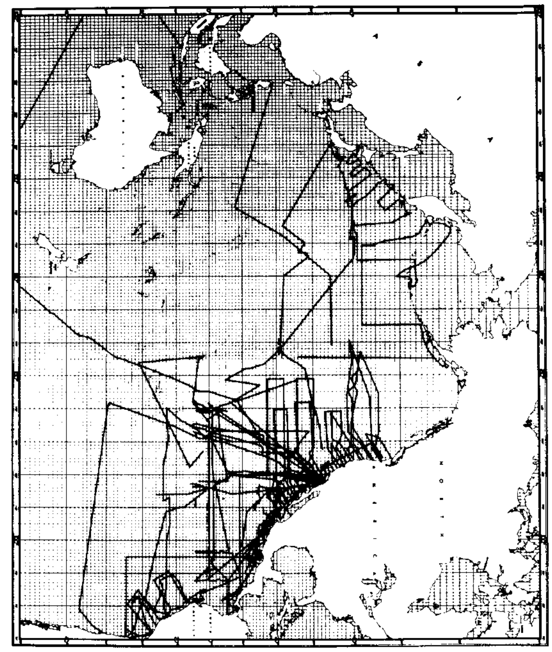

FIGURE 2. Locations of cruise tracks where the DSL depths have been obtained.

frequency. Barraclough, Le Brasseur, and Kennedy (1969), using a high-frequency echo sounder operating at 200 kHz, detected a shallow DSL around 60 m on a transpacific crossing. Johnson (1973), using an acoustic instrumental package with seven frequencies ranging from 3 to 30 kHz, reported the existence of a very deep DSL around 1,700 m off the California coast. A large majority of acoustic information about DSLs, however, has been obtained by depth recorders operating at frequencies ranging from 10 to 30 kHz, and evidence gathered by investigations using these frequencies strongly suggests that there are *principal* layers in the upper 500 m of the Pacific Ocean which can be detected by low frequency echo sounders (Dietz, 1948).

DEFINITIONS

Even though literature dealing with the deep scattering layer is massive, to the best of our knowledge, no uniform set of definitions has been established and adhered to by all the investigators in labeling as well as ascertaining layer depths. The following definitions based on the works of other researchers, and new definitions proposed by me, are used throughout this paper.

Deep Scattering Layer (DSL): a group of organisms which scatter sound and appear as a continuous layer on an echo sounder where organisms cannot be individually resolved.

DSL noontime depth: the distance between the top of the DSL to the ocean surface taken within a few minutes of local apparent noon. If data around local apparent noon were not available, a reading between 1000 and 1400 hours local time has been substituted. Only the layers which occupy a midday depth greater than 40 m are considered in this study. Forty meters is roughly the distance below the surface where the outgoing signal is often confused with the incoming signal. Thus, a true depth of a DSL cannot be ascertained with accuracy at this distance interval from the surface.

Migratory layer: a layer that migrates at least above the depth of uncertainty (above 40m).

Semi-migratory layer: the layer which migrates upward toward the surface, but the upper limit of migration is clearly below the surface.

Static layer: a layer which shows no appreciable migratory characteristics.

It should be emphasized that more than one-third of the echograms analyzed for this study have been obtained as a by-product from sea floor mapping cruises where the primary objective of the echo sounder operator has been to minimize the echo scattering from the DSL for a clear recording of the bottom.

RESULTS AND DISCUSSION

General Characteristics

The results of this survey indicate that deep scattering layers are found in every major biotic region of the Pacific Ocean. Single layers are found more frequently than multiple layers; 80% of all the echograms showed a single layer, the remaining 20% showed multiple layers.

Repeated soundings at specific locations further show that the number of layers changes year to year and single layers are more predominant than multiple layers. Barham (1957) found that in Monterey Bay the number of layers changes throughout the year.

When multiple layers occur (two is the most frequent) almost invariably their individual thickness is less than the single layer monitored at a different time. Thus it is highly conceivable that perhaps due to an external stimulus, such as a change in light intensity, the single layer may split into two components. Since a variety of organisms comprise the DSL, it is probable that only certain species respond to changes in light intensity or other stimulus. There is some evidence to support this view. First, the splitting of a single layer into two or more components during upward or downward migration is a frequently observed phenomenon. Second, Tont and Wick (1973), who monitored the DSL during a solar eclipse in the North Atlantic, found only a partial response of the DSL to the change in light intensity.

It has been further found that static layers, though not found as often as the migratory layers, do not necessarily remain static throughout the year. Evidence of this phenomenon also was found by Beklemishev (1967) in the North Pacific.

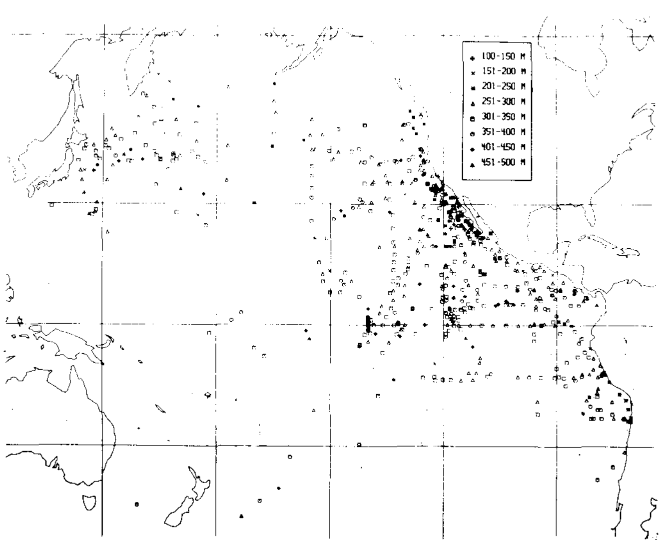

FIGURE 3. The average DSL daytime depth in the oceanic Pacific.

The average DSL daytime depths ranged between 100 and 500 m (Figure 3). The majority of the points represent a single day's sounding. When multiple soundings were available at some locations, an average value of the DSL depths has been used. Extensive data make it possible to show contours of the average DSL daytime depths in the California Current region (Figure 4).

Distributions of average DSL daytime depth in the major biotic regions, as well as several parameters pertaining to these layers, were determined (Table 2). Two very important points should be strongly emphasized. First, the parameters pertaining to the average DSL daytime depth do not necessarily reflect the typical structure of the regions, but show instead only measurements and calculated irradiance values based on these measurements at the time of monitoring of the layers. Second, the parameters reported pertain to the top of the layer and do not represent the environment of the entire community of DSL organisms. Thus, not all the organisms belonging to a layer as thick as 150 m occupy a certain isolume during the day. Generally layers are shallower in the northern regions such as the Subarctic and in the regions of the California and Peru Currents where the neretic influence is strong. As indicated by the large standard deviations, the layer depth varies significantly with time.

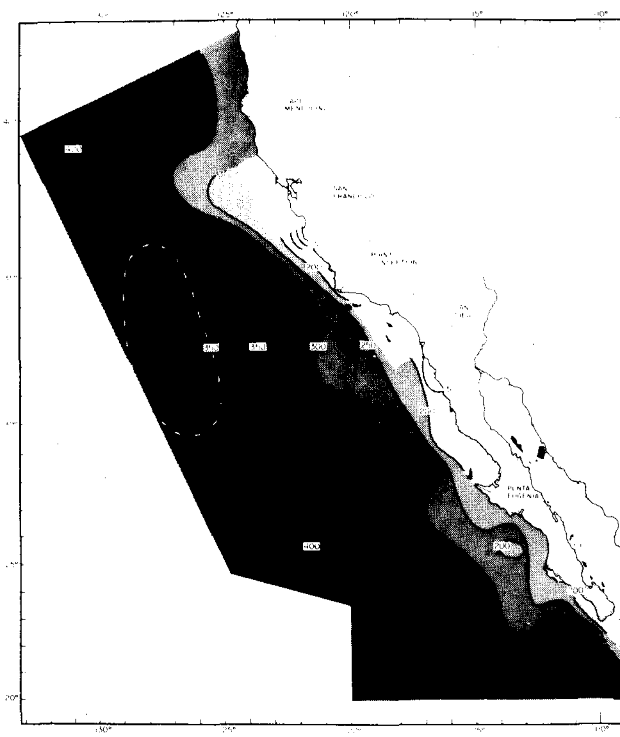

FIGURE 4. Average DSL daytime depths in the California Current System.

Virtually no quantitative information can be obtained about the number and distribution of the organisms from echograms; nevertheless, some qualitative statements could be made. Namely, layers off the coast of Peru were the thickest with clear sharp boundaries. California, Eastern Tropical, North and South Transition Zones as well as areas near the Kuroshio Current also were well formed, but were not as thick as the ones found off the Peruvian Coast.

Although two major crossings have been made in the South Central Region, only twice have scattering layers been observed, but due to the highly diffuse echo that was recorded, these two daytime depths should not be considered reliable. Nevertheless, in both cases the upward movement at sunset and

TABLE 2

Average DSL Daytime Depths and Related Parameters in the Major Biotic Regions of the Pacific Ocean

Regions	Average DSL daytime depth (m)	N (Number of days)	σ (Standard deviation)	Temperature at DSL depth	N	σ	O_2 at DSL depth (ml/l)	N	σ
1. Subarctic	295	54	--	4.0	28	1.6	7.4	15	1.6
2. Transition (North)	358	31	51	7.0	3	1.1	--	--	--
3. Central (North)	394	14	62	--	--	--	--	--	--
4. Eastern Tropical	319	130	63	10.9	36	1.0	0.2	36	0.2
5. Equatorial	350	76	53	10.4	27	1.1	0.6	25	0.2
6. Central (South)	410	2	--	--	--	--	--	--	--
7. Transition (South)	333	4	60	--	--	--	--	--	--
8. Subantarctic	415	3	48	--	--	--	--	--	--
(9. California Current)	282	110	69	9.9	6	1.8	0.6	6	0.7

downward movement at sunrise, when the layers were close to the surface, were clearly discernable.

Temperature

Moore (1958) proposed that temperature was the controlling factor for the vertically migrating organisms. Cole, Bryan, and Gordon (1970) report the absence of any scattering layer along the 50 mile transition from the Sargasso Sea to the slope waters on four crossings and attributes this absence to the Gulf Stream which marks a severe hydrological boundary.

There is a wide range of temperatures at DSL depths (Table 2). The relatively low standard deviations of temperature within each region should not be construed as an optimal temperature preferred by DSL organisms, since a change of 1°C may correspond to a depth change of 100 m in the ocean. It is not uncommon to find temperature changes as much as 5.5°C at the DSL depths from one location to another during a single transect (Figure 5). Again, if the temperature at the DSL daytime depth is the preferred optimum temperature, then one would assume that the downward migration would stop when these temperatures are first reached. No evidence to support this assumption was found (Figure 6a, b, c).

On the other hand, a sharp temperature gradient may limit the upward migration of DSLs in the subarctic region (Figure 6). DSL nighttime depth can be just below the thermocline (Figure 6a, b). In cases where no sharp thermocline exists, the DSL organisms migrate all the way to the surface (Figure 6, profile C). Unfortunately we do not have enough data to ascertain whether partial migration is temperature dependent in other regions as well.

Oxygen (O_2)

Bary (1966) found a dependency of DSL on an oxycline in Saanich Inlet. We have found no evidence of oxygen influencing DSL depth. In regions where the oxygen minimum is most pronounced, DSL organisms in no way seem to be restricted by low O_2 concentrations (Figure 7). Similar results have been obtained by Dunlop (1970) in the same region. Teal and Carey (1967) and Childress (1969) found that some DSL organisms, such as euphausiids, can survive in extremely low O_2 concentrations.

Light

The upward and downward migration of some DSLs during sunset and sunrise strongly suggest

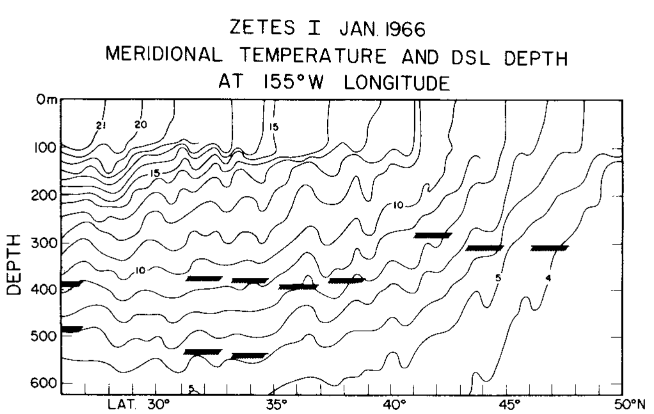

FIGURE 5. Meridional temperature and DSL depth at 155° W longitude. ZETES I Expedition January 1966.

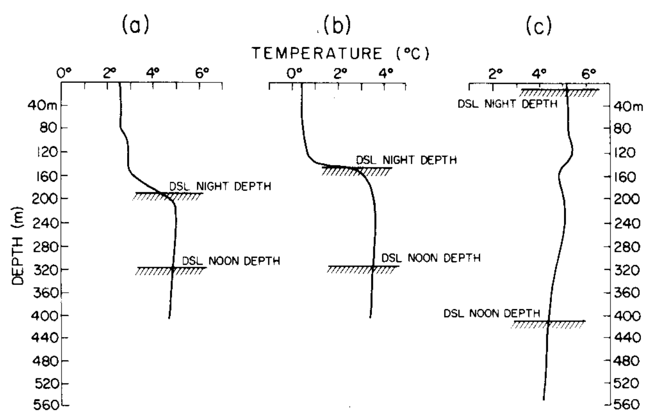

FIGURE 6. Temperature profiles and DSL daytime and nighttime depths in the Subarctic Region. (a) 49° 18′ N, 163° 12′ E; 8 March 1956. (b) 51° 09′ N, 161° 16′ E; 9 March 1966. (c) 41° 46′ N, 156° 47′ E; 19 March 1966.

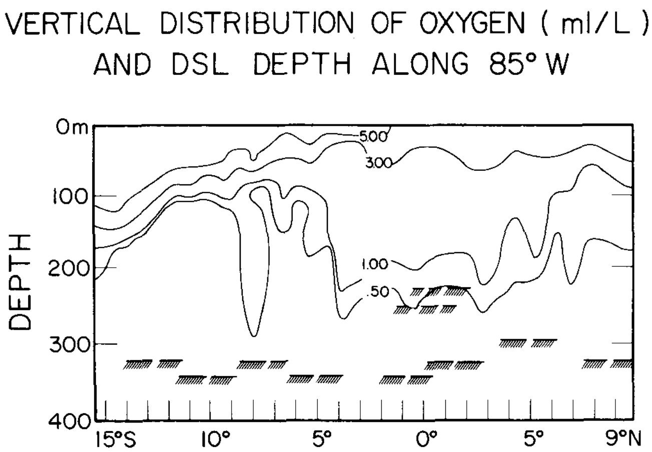

FIGURE 7. Vertical distribution of oxygen (ml/l) and DSL depth along 85° W.

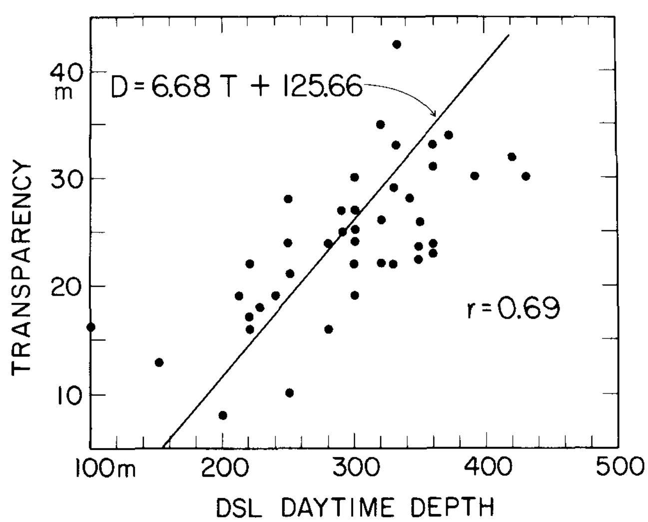

FIGURE 8. Transparency versus DSL daytime depth in the California Current region, where r is the correlation coefficient and p is the probability.

light-related behavior. Kampa (1970), investigating four layers in the eastern North Atlantic and two in the Gulf of California, reported remarkable similarities in the photo environment of the layers. Isaacs, Tont, and Wick (1974) found a strong correlation between light levels and DSL daytime depth in the Peruvian Current region.

The relationship between transparency and DSL depth in the California Current and Eastropac regions (Figure 8) is very similar to the curve obtained by Isaacs et al. (1974) in the Peru Current region.

The following considerations strongly suggest a light oriented behavior on the part of the DSLs:

1. Light penetration would be less in regions of high productivity than in other regions, due to absorption by chlorophyll and phaeopigments. According to Koblents-Mishke (1967), who conducted an extensive study of the primary productivity of the Pacific Ocean, the maximum phytoplankton concentrations are found in a narrow zone off the coast of North and South America from 60° N to 25° S, and in the Subarctic Region. Thus, it is not surprising that most of the shallow DSLs are found in these regions (Figure 3).

2. The average DSL daytime depth decreases gradually from equatorial to Subarctic regions; so does the incoming solar irradiance. In addition, Frederick (1970) reports considerably lower secchi disk values for the Subarctic than for the Equatorial Region.

CONCLUSIONS

My study indicates that light is the controlling factor in DSL daytime depth, even though the effect of temperature, which may limit the upward migration, cannot be discounted completely. It is quite possible that, depending on the type of community, organisms may seek an optimal depth regulated by light intensity, but within a specific temperature range.

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