ECOSYSTEM STUDIES USING PROFILING POLARIZATION LIDAR

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ABSTRACT

Airborne lidar has been demonstrated to be a useful tool to obtain horizontal distributions and vertical profiles of fish, zooplankton, and phytoplankton. Polarization filtering allows scattering from larger irregular particles like fish and plankton to be distinguished from the general background scattering. When combined with other observations, airborne lidar has been demonstrated to be a useful tool to investigate the effects of physical processes on the ecosystem and the interactions between different trophic levels.

Index Terms—Lidar, polarization, fish, plankton, thin layers

1. INTRODUCTION

Remote sensing of aquatic ecosystems is notoriously difficult. Electromagnetic radiation is strongly absorbed by water at all frequencies, so penetration into the water column is limited. The best case for electromagnetic propagation is blue light (with a wavelength around 490 nm) in very pure sea water, but even this case has an e-folding distance of less than 70 m. This is a small fraction of the ocean, which has an average depth of about 4300 m. Acoustic remote sensing is limited by the almost complete reflection of sound at the air-water interface. This means that acoustic remote sensors have to be in contact with the water, and coverage is limited by the speed of surface vessels.

Despite these limitations, two types of remote sensors have found wide application in aquatic-ecosystem studies. Passive radiometers in the visible portion of the electromagnetic spectrum have provided a wealth of information through relationships between ocean color and chlorophyll concentration [1]. Coverage from satellites is global, but no depth profile information is available. Echosounders have provided detailed vertical profiles of fish and zooplankton [2], but spatial coverage is limited to dedicated ship surveys or fixed moorings.

Polarization lidar combines the best features of ocean-color and acoustic sensors. It uses visible light, which penetrates the surface and can be deployed on aircraft and even satellites. At the same time, it provides depth information and particulate shape information that cannot be obtained from ocean-color measurements. This paper will briefly describe the characteristics of an airborne lidar and applications to ecosystem studies.

2. AIRBORNE LIDAR CHARACTERISTICS

The NOAA Oceangraphic Lidar (Fig. 1) is a dual-polarization lidar operating at a wavelength of 532 nm [3, 4]. It is similar in design to other profiling systems [5, 6], and will be briefly described here. The source is a frequency-doubled, Q-switched Nd:YAG laser, which produces 100 mJ of linearly-polarized light in a 10 ns pulse. The laser beam is diverged to a diameter of 5 m at the surface to be eyesafe for humans and marine mammals [7]. Pulse repetition frequency is 30 Hz, which provides a pulse spacing of 2-3 m along the flight track, depending on aircraft speed.

![Fig. 1. Schematic diagram of profiling polarization lidar showing laser transmitter and one of two identical receiver channels.](image-url)
50 m can be obtained. In more productive coastal waters, 20-30 m is more typical. In very turbid inland waters and river plumes, the penetration can be less than 10 m.

3. ECOSYSTEM STUDIES

The clearest signature in the lidar data is from dense schools of fish near the surface (Fig. 2). Comparisons of the distributions of fish measured by airborne lidar and by other techniques have shown high levels of correlation as long as the measurements are made within a couple of days of each other. The other techniques in these studies include echosounders [8, 9], trawls [8, 10], and video [11, 12]. When the time difference is larger than about four days, no significant correlation was generally observed, suggesting that the fish have moved during this time.

When combined with other information, lidar profiles can be used to investigate the effects of physical processes on the ecosystem and the interactions between different trophic levels. Anchovies and sardines have been shown to associate with temperature fronts in the NE Pacific Ocean [18]. Specifically, the distance between fish schools and fronts was found to be less than one would expect from a random distribution. Moreover, that distance was correlated with the level of upwelling, so that fish tended to be closer to fronts when there was less upwelling.

Jellyfish of the genus Aurelia (moon jellies) have been shown to form swarms whose bottom remains just above the thermocline. Often, the thermocline is a region of high current shear, and it seems likely that these fragile animals are actively avoiding the high shear region.

Fish have been observed avoiding research vessels, in direct confirmation of a behavior that has been inferred using less straightforward techniques [19]. In one study of sardines just outside of the harbor in Long Beach, California, the average depth of schools measured by lidar was compared with that measured by a ship-borne echosounder. There was no significant difference between the two measured depths during the day. There was no difference between the depths measured by the lidar during the day and at night. The depths measured by the echosounder at night were significantly greater than the daytime echosounder measurements or the lidar measurements. Ship traffic into the harbor is greatly reduced at night, and the conjecture is that the fish are unable to hear the research vessel during the day because of the high level of background shipping noise. At night, this noise is reduced and the fish are able to hear the approaching vessel and dive before it reaches them.

Massive predation of a euphausiid layer by whales, seabirds, and herring has been observed at a biological hot spot in the SE Bering Sea [20]. Figure 4 shows the depolarized
lidar signature of one pass over a section of the region. The returns from above the surface are sea birds, mostly shearwaters. Right at the surface is a thin layer of euphausiids. Below these is a school of herring at a depth of about 30 m for the top of the school. This forage event was tracked with the aircraft, and was observed to form and then dissipate over the course of several days.

Fig. 4. Depolarized lidar return from a biological hot spot in the Bering Sea. Darker gray represents a greater return as a function of depth and distance along the flight track.

4. CONCLUSIONS

Airborne lidar has been demonstrated as a useful tool to obtain distributions of fish, zooplankton, and phytoplankton. When combined with other observations, airborne lidar has been demonstrated to be a useful tool to investigate the effects of physical processes on the ecosystem and the interactions between different trophic levels.

The successes of airborne lidar suggest that an orbiting lidar, which would provide global coverage, might be a valuable adjunct to ocean-color sensors in orbit. Preliminary investigations have begun [21-23], using a lidar that was launched for atmospheric studies but has many of the characteristics of the airborne oceanographic systems [24, 25].

5. REFERENCES

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