Monitoring High-Seas Fisheries With Long-Range Passive Acoustic Sensors

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Abstract – The decline of the world's major fisheries has spurred international conservation efforts. Toward this goal, various technological means of monitoring fishing have been implemented. Here we report on experiments with passive acoustic listening, using the US Navy's Sound Surveillance System (SOSUS). We describe some of the results obtained in a series of experiments over the 1992–1995 period on driftnet fishing (now banned by international treaty), salmon poaching in the North Pacific, and trawlers in the Bering Sea "Donut Hole."

I. INTRODUCTION

The US Navy's Sound Surveillance System (SOSUS) is a network of underwater hydrophone arrays deployed throughout the oceans of the northern hemisphere. Cables connect the arrays to processing centers where directional beamforming and sophisticated spectral processing displays give SOSUS analysts sensitive "ears" to all sorts of natural and man-made underwater sounds. The system was built to detect and track submarines. However, in recent years the Navy has encouraged research in new applications—for example, using SOSUS to track whales is described in another paper in this conference [1]. This report deals specifically with research directed at detecting and classifying fishing vessels on the high seas.

The principal motivation behind this work was to establish a new technological means of monitoring compliance with agreements on high-seas fishing. A satellite-based transponder system is already in use by several nations, but it is widely recognized that the system can be circumvented. SOSUS is one of the leading technologies for non-cooperative surveillance. In the 1992–1995 period SRI International, under US Navy sponsorship, conducted three experiments to evaluate just how effective SOSUS is for surveillance of fisheries.

Prior to the initial SRI experiments in 1992, it was well-known that SOSUS had the capability to detect surface vessels. Over 30 years of prior research enabled SOSUS operators to recognize the distinctive acoustic signatures of engines, electrical generators, propellers, pumps, and winches. It was also well-known within the SOSUS community that fishing vessels could be detected and can be a source of background interference for submarine surveillance. Our experiments used controlled targets and targets-of-opportunity to address the following questions: what is the detection range of the system; how well can the vessels be localized, and; can the acoustic signatures be used to discriminate illegal from legal fishing.

All the data analyzed for this study were the output of high gain directional beamformers. The most common post-beamformer processing was a spectrogram display with various noise-equalization and resolution options. The spectrograms were visually inspected by experienced analysts. When interesting spectral signals were detected on one array we looked for simultaneous detections on other arrays that then provided a location fix. There are two techniques for location fixing. First and easiest is plotting the intersection of the two bearing lines. The second method uses advanced signal processing techniques to find the relative time delay and Doppler shift that gives the greatest correlation between the two signals.

II. DRIFTNEX'92

Driftnet fishing is undertaken by laying out a net up to 30 km long. The net is left to drift in the water on the order of 10 hrs. The limited effort needed to deploy, monitor, and retrieve a driftnet makes driftnet fishing very efficient compared to other fishing techniques. Unfortunately, driftnets have gained notoriety as "curtains of death" and their wide spread use generated an ecological disaster. Driftnets indiscriminately kill sea birds, dolphins, and whales, and will literally turn a patch of ocean into a biological desert. In 1991 the UN General Assembly passed a resolution declaring a worldwide moratorium on the use of driftnets on the high seas after 31 December 1992. Following the UN action, the US passed the High Seas Driftnet Fishing Act, which imposed economic sanctions on vessels, companies, and nations continuing to engage in driftnet fishing on the High Seas.

The problem now shifted to monitoring compliance with the ban. Driftnet fishing in the North Pacific was of special interest and concern to the US and Canada. The US and Canada cooperated on extending aircraft surveillance beyond their 200 nmi Exclusive Economic Zones (EEZs). However, the North Pacific is too large an area to cover economically with aircraft. At the suggestion of SRI, the US Navy lent its support to experiments designed to asses whether, and how well, SOSUS cold detect driftnet fishing vessels, and driftnet fishing patterns. The experiment was conducted at the Naval Facility on Whidbey Island, Washington, in September–October 1992, when the last legal driftnet season was still in progress in the North Pacific, just months before the UN ban would take effect. Thus this was an opportunity to collect signature characteristics while a great number of driftnet vessels were operating openly.

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Driftnet operations follow a rigid diurnal cycle. In the first phase the vessel runs at 10 kt and deploys the net. In the second phase the vessel loiters overnight while the nets are drifting and filling with fish. In the third phase the nets are retrieved. Each phase has a distinct acoustic signature.

The loiter phase is a particularly distinctive characteristic of driftnet fishing and also the most easily recognized phase in SOSUS spectrograms. Driftnet vessels use variable-pitched propellers. Their engines run at a governor-controlled constant speed and the vessel's speed is controlled by the pitch of the propeller blades. In the loiter phase the engines continue running steadily with zero-pitch so their acoustic signature is very stable and of long duration. Fig. 1 is a spectrogram of the typical pattern of narrow, steady engine line harmonics associated with loitering. (In all the spectrograms shown here time increases from top to bottom and frequency increases from left to right.) In this example the harmonics are multiples of 10 Hz. Most driftnet vessels have harmonics that are multiples of about 10 or 15 Hz.

Experience shows that those steady engine line harmonics are the easiest feature to detect for the following reasons. First, the strongest harmonics are fortuitously at higher frequencies (typically around 100 Hz), well above the general shipping noise background (generally between 10 and 60 Hz). That is because the driftnet vessels are small relative to most of the transoceanic traffic. Second, the signals can be "eye integrated" over the long duration (typically 10 hrs) of the loiter phase. Those two features make the engine lines distinctly recognizable in spectrograms.

The 17-hr spectrogram in Fig. 2 shows acoustic characteristics of all three phases of driftnet fishing. The period begins with the narrow and steady lines of the loiter phase. In the early morning there is a perceptible downshift and widening of the engine lines when the engine load increases for net retrieval. Retrieval takes 11 hrs. In the late afternoon strong propeller lines appear as the vessel speeds up to re-deploy the nets. Expert reading of this spectrogram shows that there are actually two very similar vessels going through the operational phases in unison.

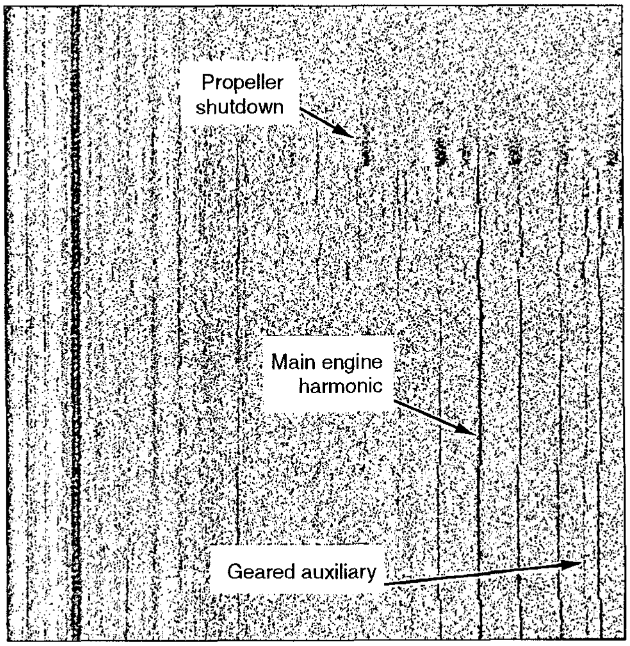

Fig. 1. 10 Hz harmonics of engine line of loitering driftnet vessel (predominately on right side of spectrogram)

Although there were hundreds of vessels with 10/15 Hz engine harmonics operating in the North Pacific during the summer of 1992, individual vessels could be identified and tracked for several days and even weeks by the uniqueness of their harmonic amplitudes. For example, the strongest harmonics in one vessel might be 120 Hz, and 100 Hz on another vessel. One vessel is strongest in the 7-10th harmonics, another in the 9-13th. The relative amplitudes thus provide an identifiable vessel-specific signature. It was on the basis of this uniqueness that we establish that two fishing vessels operated continuously and illegally for several weeks, at lat 48° N, long. 165° E, 80 nmi north of the legal fishing area. The location was determined from the relative time delay measured for the signals received simultaneously by two hydrophone arrays (Fig. 3). An aircraft patrol also sighted and documented the violation. Salmon poaching with driftnets is one of the major enforcement concerns in this area.

III. DRIFTNEX'94

SRI returned to the Whidbey Island facility in the summer of 1994 to look for changes in North Pacific fishing since the UN ban took effect. Our *modus operandi* was to search for the "loitering" signature, that is, 10/15 Hz

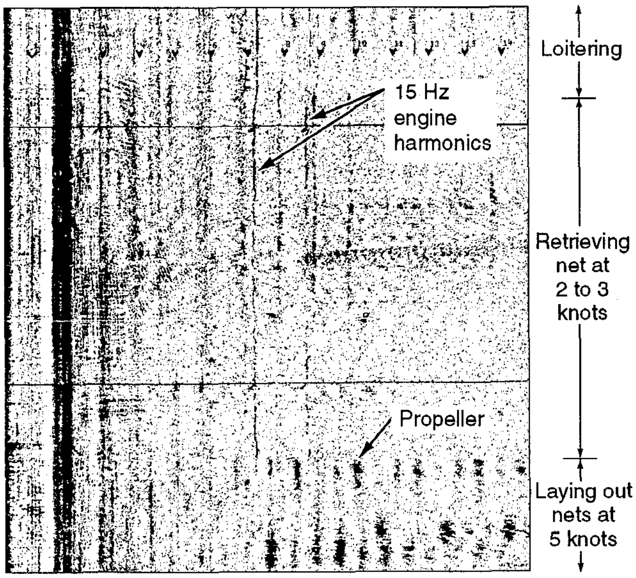

Fig. 2. Three phases of driftnet fishing: loitering, net retrieval, and net deployment.

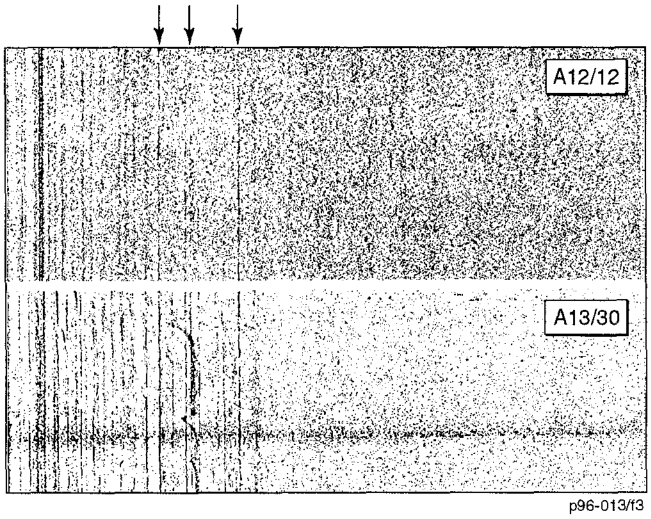

Fig. 3. Simultaneous detection of driftnet vessel on two arrays. Arrows point to some common spectral lines.

engine lines that persist all night, since that was the most notable and unique characteristic we saw in 1992 driftnet operations. Overall, the number of vessels matching this characteristic was much reduced in 1994, but there were a few candidates. Fig. 4 shows an example of a 1994 detection, with a comparative 1992 vessel. As noted earlier, the similarity in harmonic spacing in the upper spectrum are common characteristics, but relative amplitudes vary considerably from one vessel to another.

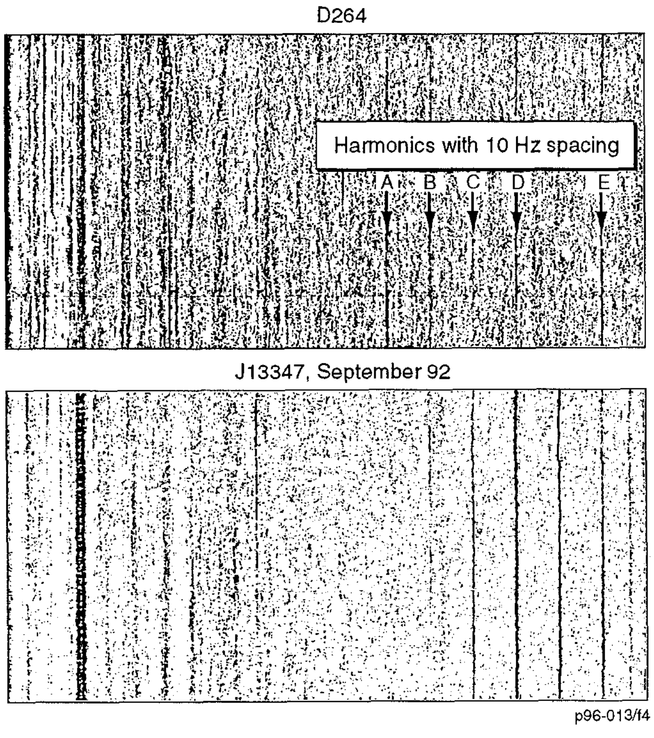

Fig. 4. Comparison of signatures of a 1994 target (upper) and 1992 target (lower).

IV. Bering'95

Pollock, which is a member of the cod family, constitutes about 70 percent of the biomass in the Bering Sea and is an important and managed resource within the EEZ of the US and Russia. Unfortunately, the specie was seriously depleted by international fleets fishing in the Donut Hole, the central section of the Bering Sea that lies outside the EEZs. The US in concert with other fishing nations reacted to the collapse of the pollock fishery by organizing a closure period.

An experiment was conducted in October–December 1995 to assess SOSUS capability to monitor fishing vessels and discriminate between illegal and legal vessels in the Bering Sea.

Most of the SOSUS detections were Russian trawlers operating on the western rim of the Bering Sea. Like driftnet and many other types of fishing vessels, the Russian trawlers can be recognized by their distinct and persistent engine lines and loitering in one place for many hours or days. But the trawlers have a harmonic structure different from that of the driftnet vessels. Figs. 5, 6, and 7 are examples of the variety of Russian trawler signatures. As was the case with the North Pacific driftnet vessels, the vessels in this class have similarities and individual characteristics.

When trawlers speed up, their predominant signature is the harmonics and sub-harmonics of their propeller. Fig. 8

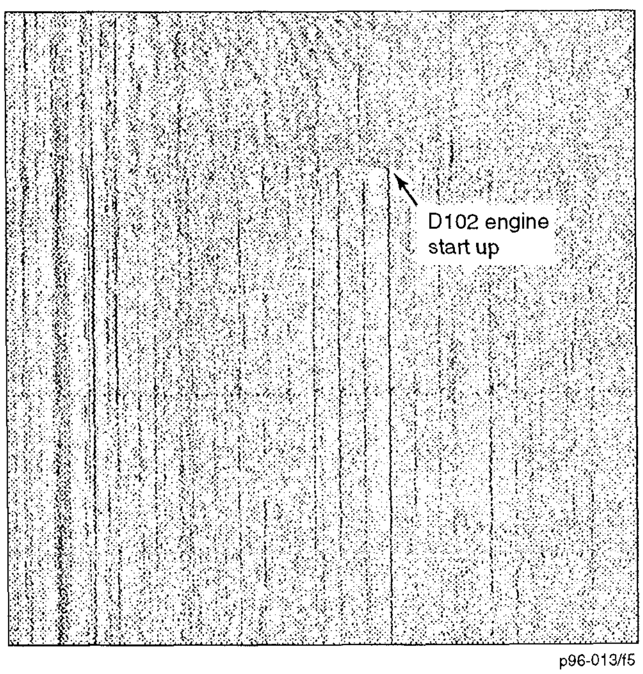

Fig. 5. Signature D102 (1 Nov 95).

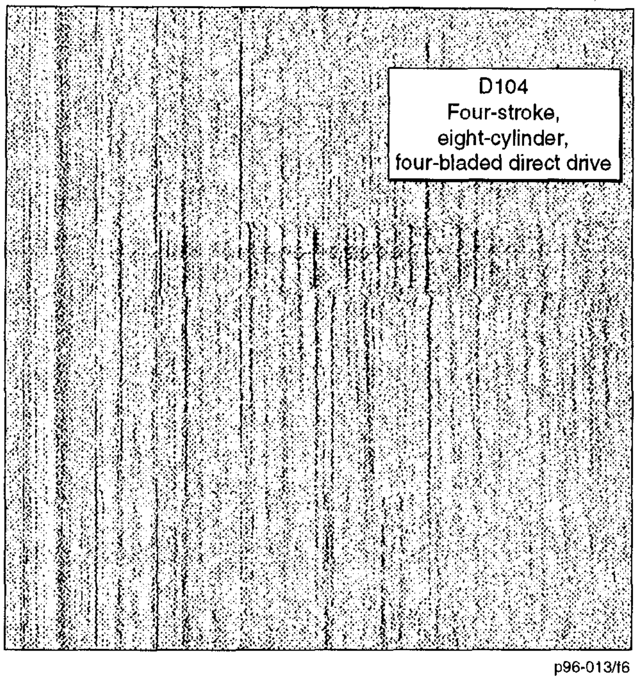

Fig. 6. Signature D104 (1 Nov 95).

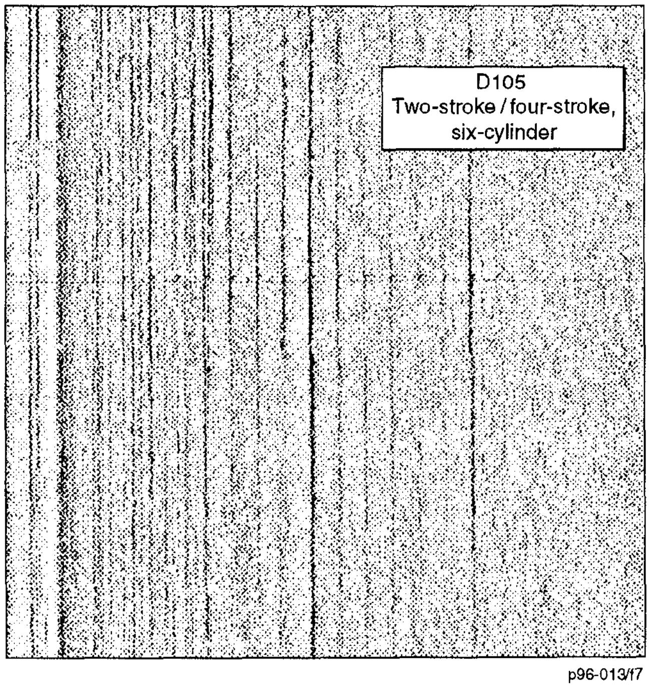

Fig. 7. Signature D105 (4 Nov 95).

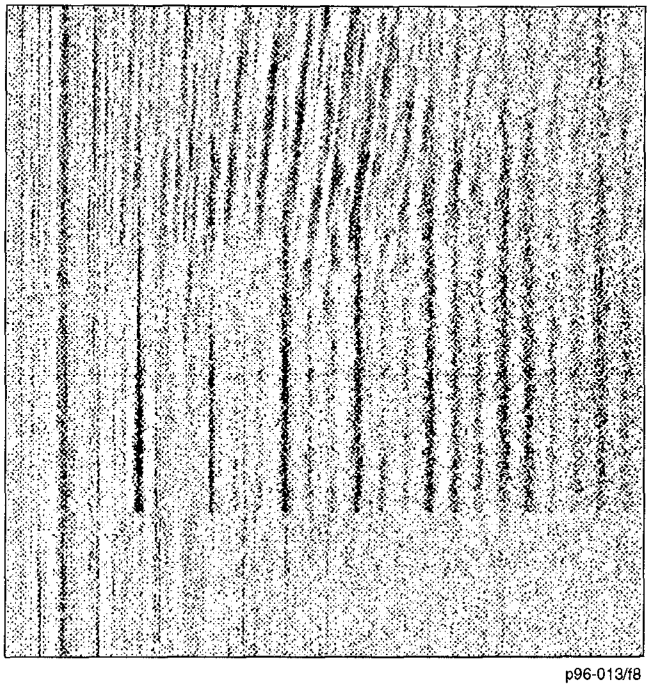

Fig. 8. Propeller signature of target D103.

shows an example of a blade signal (until it abruptly turns off near the end of the record). The presence of two weak lines between consecutive strong harmonics implies a three-bladed propeller.

Propeller signals are distinctive for different types of vessels. Fig. 9, for example, is the propeller signal of the USCG cutter *Storis,* which we used as a surrogate fishing vessel to evaluate SOSUS tracking. Fig. 10 shows the actual track and SOSUS-determined track of the *Storis*, demonstrating that we can detect vessels in the Donut Hole making incursions into the US EEZ. At one point SOSUS observed the merging of the *Storis* signal with the signal of the Polish trawler, *Homar*, just inside the Donut Hole boundary.

V. Summary

Results of three experiments show that the US Navy's SOSUS can monitor and discriminate fishing vessels in the North Pacific and Bering Sea by taking advantage of the vessels' unique acoustic signatures. A 1992 experiment established the signatures of driftnet fishing vessels. The number of such signatures were considerably diminished in a 1994 survey, which followed the UN ban on driftnets. Our 1995 experiment focused on the Bering Sea and demonstrated that trawlers can be detected and tracked throughout the region, both in the EEZs of Russia and the US, and in the international Donut Hole.

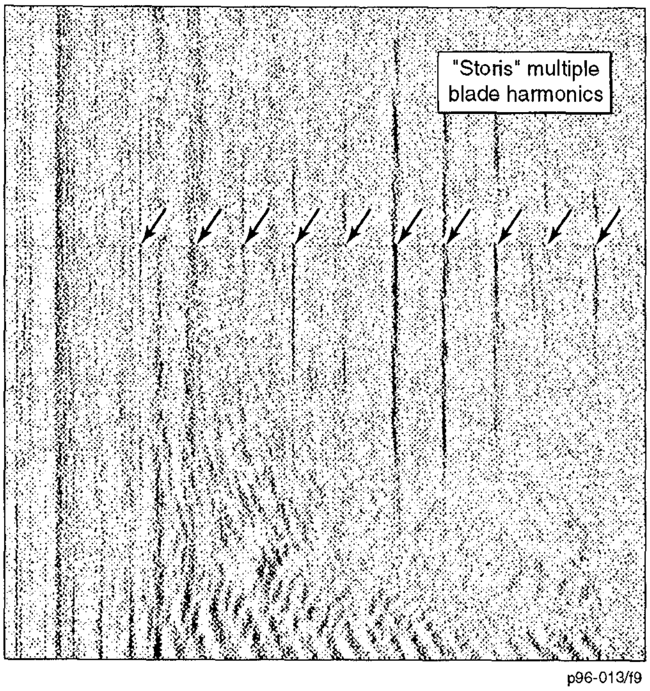

Fig. 9. USCG cutter *Storis* multiple harmonics.

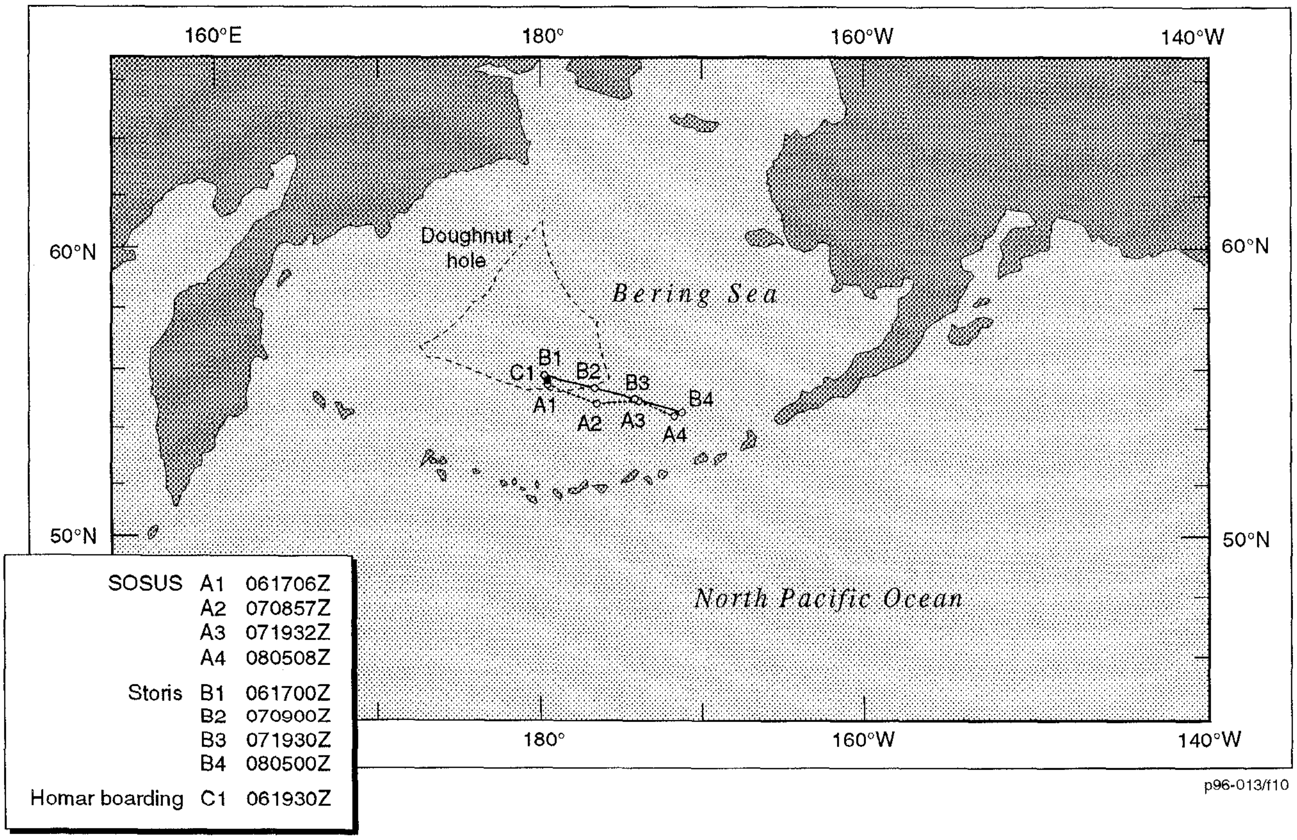

Fig. 10. Vessel track of USCG cutter *Storis*.
Date-time stamps are in the format ddhhmm.

ACKNOWLEDGMENTS

The work reported herein was substantially aided by the active support of the National Marine Fisheries Office of Enforcement and the US Navy's Naval Oceanographic Processing Facility at Whidbey Island, Washington. The sponsor of the work was the US Navy Space and Naval Warfare Command (SPAWAR).

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[1] Ronald Abileah, Darel Martin, Steve Lewis, and Bob Gisiner. Long Range Acoustic Detection and Tracking of the Humpback Hawaii-Alaska Migration. In this conference.