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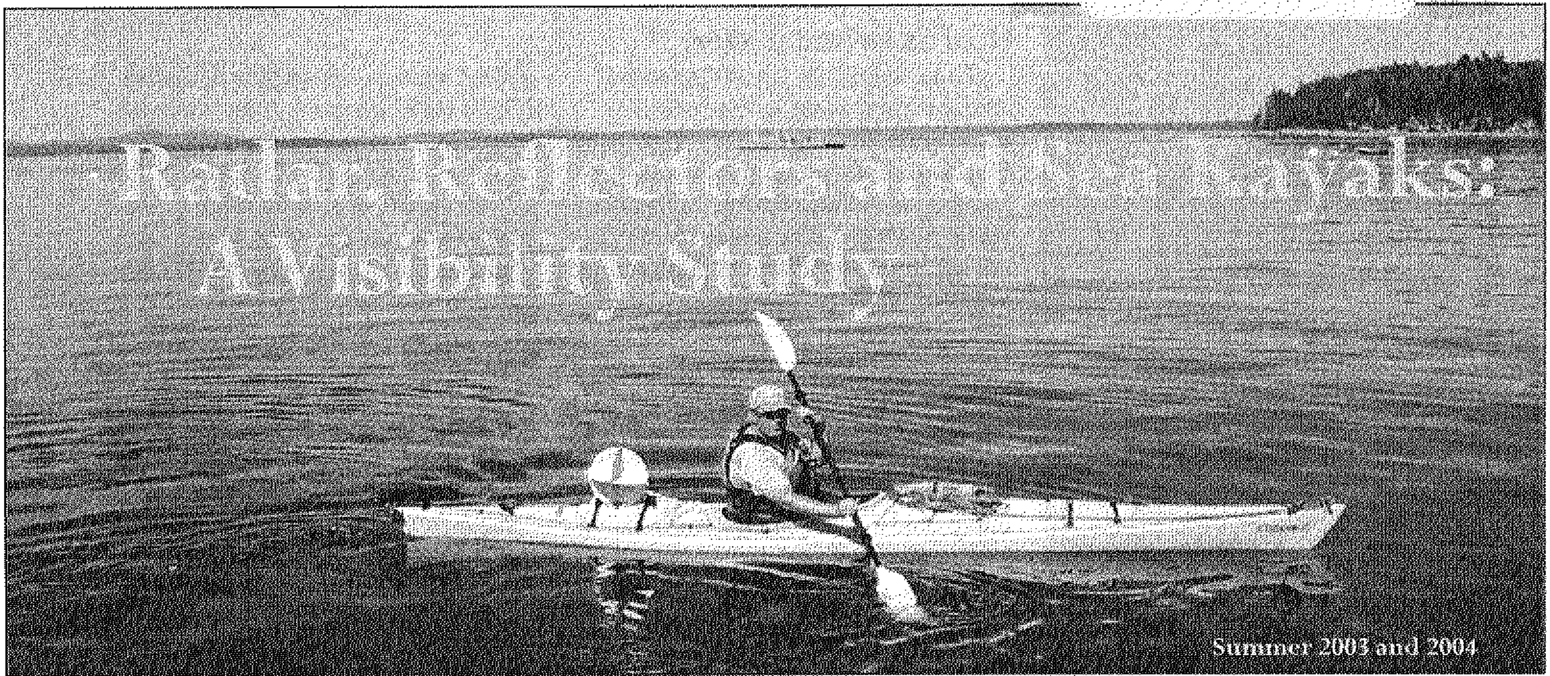


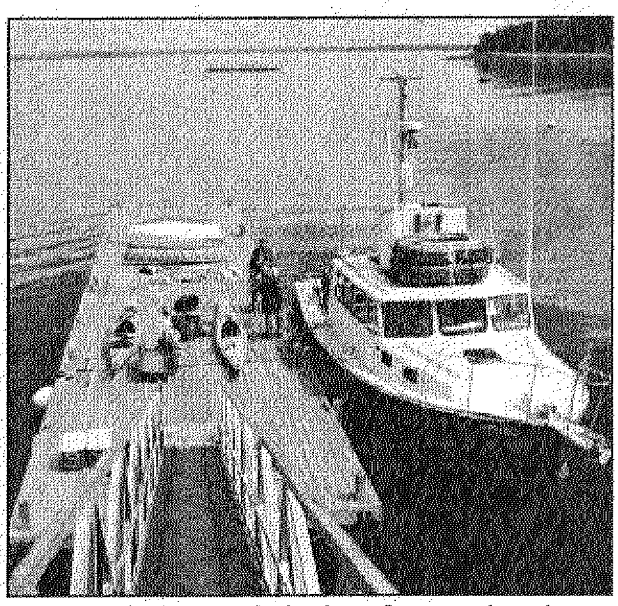
Introduction

In recent years, sea kayaking has been growing in popularity throughout North America and especially in Maine. Sea kayakers are regularly observed along our coastal shores; and sea kayak guides and outfitters are becoming a significant part of the working waterfront, with commercial operations spanning from Kittery to Calais. With such popularity, the potential for kayak collisions with larger vessels increases dramatically.

Radar reflectors are used by sailboats, motorized recreational craft, and working boats of all sizes to increase their potential appearance on the radar of other vessels; the more obvious the "return" on a radar screen, the more likely an attendant boat captain is to avoid collision. On the coast of Maine, sea kayakers are increasingly using radar reflectors to increase their visibility, both in an effort to avoid collision and to facilitate search and rescue operations in the event of trouble. However, concrete information is lacking on just how effective radar reflectors are in helping kayaks appear on radar. Conventional wisdom is that the higher a reflector is mounted aloft (such as on a sailboat's mast), the better radar signal it will return. The intentional low-profile design of sea kayaks that makes them comparatively sea worthy in the hands of a capable paddler also makes sea kayaks difficult to see, both with the naked eye and on a radar screen.

The purpose of this study is to review the effectiveness of a variety of commercial and homemade radar reflectors in increasing the visibility of sea kayaks on radar. It is intended that the results of this study will 1) raise awareness about the efficacy of radar reflectors on sea kayaks; 2) provide all users of our coastal waters with knowledge to reduce the risk of radar-equipped vessels colliding with sea kayaks; and 3) begin a dialog between motor-/sail- vessel operators and sea kayakers along the coast of Maine.

This report summarizes the results of radar reflector tests conducted on the coast of Maine during the summers of 2003 and 2004.



Preparing the first round of radar reflector trials at the College of the Atlantic dock, summer 2003.

Project History

During the spring of 2003, two rounds of preliminary visibility tests were conducted with the Maine Association of Sea Kayak Guides and Instructors (MASKGI): one with the U.S. Coast Guard, the other with a lobsterman. Two conflicting sets of results emerged. Using a range of radar settings, the Coast Guard radar was consistently able to detect sea kayaks at various levels of intensity, depending on the model of radar reflector. The lobsterman's radar, similar in caliber to the Coast Guard's, was NOT able to "see" any of the paddlers, despite use of the same radar reflectors and similar sea conditions. The conflicting results of these preliminary tests pointed to a need for further systematic testing following a repeatable study design.

Maine Sea Grant, MASKGI, U.S. Coast Guard, Gulf of Maine Expedition Institute, and College of the Atlantic partnered to develop testing methodologies, run field tests, and provide results to sea kayakers and operators of radar-equipped vessels. For a complete list of project participants, see back page.

Top picture: Field tester with Davis #153 radar reflector on stern deck.

Glossary of radar terms

Blind spot: Any area outside the field of view of the radar. This is generally meant to cover the area below the radar's line-of-sight, generally closer to the radar platform.

Clutter: Term applied to the unwanted returns that appear on the radar screen. These are often returns from waves or precipitation.

Gain: A variable control that adjusts the radar's sensitivity; it amplifies signals received. Typically adjustable from 0-100%. Tuning gain down toward zero reduces overall sensitivity; tuning gain up toward 100% amplifies noise or clutter, creating false signals or registering features of little or no concern (such as lobster buoys or waves).

Noise: Unwanted energy generated internal to the radar that can appear as a false signal on the radar screen.

Radar Horizon: The line of sight of the radar. Radar arrays mounted higher can see further than those mounted lower. In rough seas, the target might be obscured by a swell at distances well short of the radar horizon.

Radar reflector: Any device specifically manufactured to reflect radar waves back to a radar platform. The return, or signal, from a radar reflector generally shows up on the radar screen as an amorphous blob.

Radar scope: Another name for radar screen.

Radar screen: The monitor on which radar signals are displayed for viewing.

Rain clutter: Random dots on the radar screen generated from radar waves hitting raindrops or other precipitation. On the radar screen, this can create an effect that looks like it is "snowing." Rain clutter does not represent "real" returns, and thus, the rain clutter control is generally used to filter out these features.

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How does Radar Work?

Radar stands for RAdio Detection And Ranging. In the marine environment, radar refers to a system that broadcasts radio waves (electromagnetic energy) toward the horizon. When radar waves hit an object or target, the waves bounce or reflect. Some of that reflected energy returns toward its point of origin where it is electronically rendered into a spatial image on a radar screen (a **return**). The monitor also shows the location of the radar-equipped vessel, or radar platform. With experience and training, this image can be readily interpreted to represent the surrounding landscape and seascape. Landforms, navigational aids, and other vessels will be displayed as returns of varied size and strength in their correct position. When used in conjunction with nautical charts or local knowledge, it is possible to identify these images and avoid collision with objects on the water.

In principle, radar operation is straightforward. However, vessel operators should never assume that a lack of returns means that there are no other vessels or objects on the water. A variety of factors affect the ability of targets to reflect wave energy back to its source. There are **blind spots**, areas where an object is completely out of the path of a radar wave. Objects too close to a radar platform fall beneath the angle of the radar wave, and therefore would not show up on the radar screen; objects outside the range of the radar also will not show up. The choppiness of the water's surface creates **clutter** or random pixilated forms on the radar screen. To the untrained, this clutter can appear to be the return of an object. Raindrops can also reflect radar waves and create a "snow-falling" pattern on the radar screen. How the radar antenna (sometimes referred to as the "radar array") is mounted on a vessel can affect how the radar signal is sent and whether it will hit a target at all. On radar-equipped vessels, the radar array tends to be mounted either on a mast or above the pilothouse. In choppy conditions, radar arrays mounted higher are better able to see down into the troughs of waves; hence, kayaks are more likely to show up if the radar settings are properly set. Proximity of other objects on the radar-equipped

> *"Every radar installation is different."*
> —Andrew Peterson, Marine Superintendent, College of the Atlantic

The group gathers for the third set of radar reflector trials, this one at the Boothbay Harbor Coast Guard Station with the help of the Coast Guard Auxiliary. Front row from left to right: Rich MacDonald, John Roscoe, Natalie Springuel, Gerry Vaillancourt, David Lenz and Deb Swanton. Second row: Paul Travis, Gordon Nash, Mark Potter, LT Kevin King, Bob Loney, Jim Powers, Al Johnson and Dave Power. Bob Arledge is in the kayak at far left.

vessel, such as life rafts, can affect the performance of the radar.

Modern radar units have adjustments for **sea clutter** and **rain clutter**. Adjusting the radar controls for sea clutter or rain clutter affect the sensitivity of the radar signal; thus, it is possible to eliminate the clutter created by choppy seas or rain. **Gain** is another radar adjustment. This affects overall sensitivity, so adjusting gain can also reduce clutter.

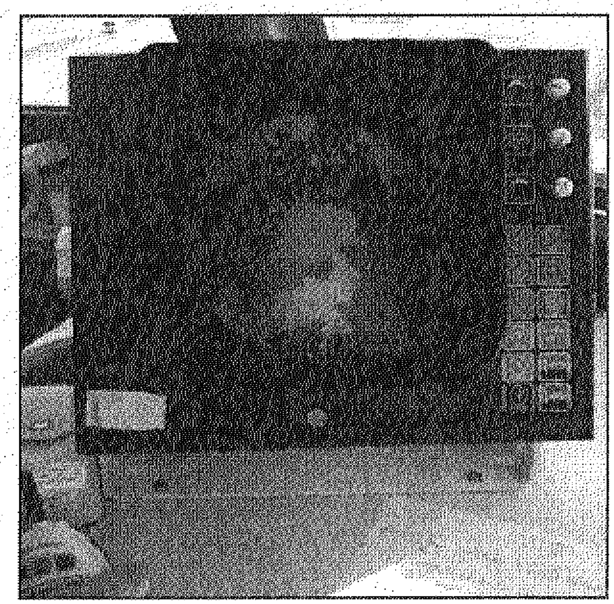
Adjusting the sensitivity of a radar unit is a balance between filtering out unwanted clutter or noise and accepting some level so that more objects can be observed. Many radar operators adjust sea clutter, rain clutter, and gain so as to filter out the maximum amount of clutter. However, this is sometimes done at the expense of other real targets.

The construction material and design of the target object affects how well it shows up on a radar screen. Landmasses, particularly with built-up vertical surfaces such as cliffs or houses, reflect radar well. In contrast, low-lying, horizontal, or rounded and undeveloped landmasses (such as rocks, ledges, and bars) tend to disperse energy such that they do not show up on radar, or, if they do show up, not consistently. Similar rules apply to boats. Larger vessels made out of steel more readily reflect radar wave energy than smaller, lower profile vessels made out of wood, fiberglass, or plastic.

Radar reflectors are designed to reflect some of the radar waves back toward radar platforms, increasing the strength of the return as a target on the radar screen. An increased radar return increases the probability of a boat being seen by radar-equipped vessels. Sailboats, typically made of wood or fiberglass, often generate poor radar returns. To help alleviate this problem, they have long used radar reflectors: to make the best use of radar reflectors, they are most often affixed to the top of the mast. This increased height of the radar reflector is much more likely to intercept radar waves and reflect a signal back to radar-equipped vessels for definition on the radar screen.

Sea kayakers have a greater challenge when trying to increase their visibility to radar-equipped vessels. A sea kayak's stability comes, in part, from its low profile. Affixing a mast of any height, even a couple of feet, with a radar reflector at its apex increases windage and thus decreases stability. In the event of capsize, a mast-mounted radar reflector hampers the ability of a sea kayaker to perform an Eskimo roll or attempt other rescue techniques. This creates a potentially significant hazard for a sea kayaker. Out of necessity, many sea kayakers have experimented with alternative methods of either affixing a radar reflector or developing new strategies with the intent of increasing visibility to radar-equipped vessels.

Until this study, the effectiveness of radar reflectors for increasing the visibility of sea kayaks, traditionally low-lying vessels, had not been tested.



This radar screen shows one way that "noise" or "clutter" can appear on screen (pattern left of center). Picture taken on board U.S. Coast Guard Auxiliary vessel on November 6, 2004, Boothbay Harbor, Maine.

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Range: The field of view of the radar screen, typically a circle (the center of the screen is the location of the radar antenna). For example, if the range is set to one mile, then from the center of the radar screen to the outer edge of the screen is 1 mile (*i.e.*, this is the radius of the radar screen—typical ranges include ¼, ½, 1, and 2 miles).

Return: Any signal that appears on the radar screen indicating an object within the range of the radar platform.

Ring: These are electronic markers, in the form of concentric circles radiating out from the center, placed on the radar screen to aid in judging distances. Scale units for the circle or circles between the center of the radar screen and the outer edge, or range, are fractions of the range (typical rings include 1/8, ¼, ½, and 1 mile).

Scope: Another name for radar screen.

Sea clutter: Term applied to the random dots on the radar screen which appear as a result of radar waves reflecting off the sea surface; heavier seas create more clutter on the radar screen. Sea clutter represents real but unwanted returns, and thus, the sea clutter control is generally used to filter out these features.

Sensitivity: The degree to which the radar picks up undesired returns, whether from artifacts such as sea or rain clutter and other natural phenomena or from lobster buoys and other man-made features that do not pose a significant hazard to navigation.

Signal: Any signal that appears on the radar screen indicating an object within the range of the radar platform.

Methodology

The goal of this study was to assess methods for increasing sea kayak visibility on radar. A variety of commercial and homemade radar reflectors were tested against different radar settings to assess each variable. Volunteers paddled radar reflector-equipped sea kayaks along an established course to determine how well they showed up on the radar. These studies were repeated at three locations over two paddling seasons:

- 18-19 August 2003. College of the Atlantic, Bar Harbor. The college's research vessel, *Indigo*, was the radar platform.
- 06 July 2004. U.S. Coast Guard Group Southwest Harbor. U.S. Coast Guard vessel CG 55120 was the radar platform.
- 06 November 2004. U.S. Coast Guard Station, Boothbay Harbor. U.S. Coast Guard Auxiliary vessel *Equinox* was the radar platform.

The experimental design for each location was the same. Local nautical charts were used to establish a course for the volunteer kayakers to paddle. Courses were generally perpendicular to the bow of the radar platform. At the same time, mooring locations for the radar platform were determined. A data form was created to ensure the same information was collected for each run. Radar settings—tuning, gain, range, and rings—were recorded.

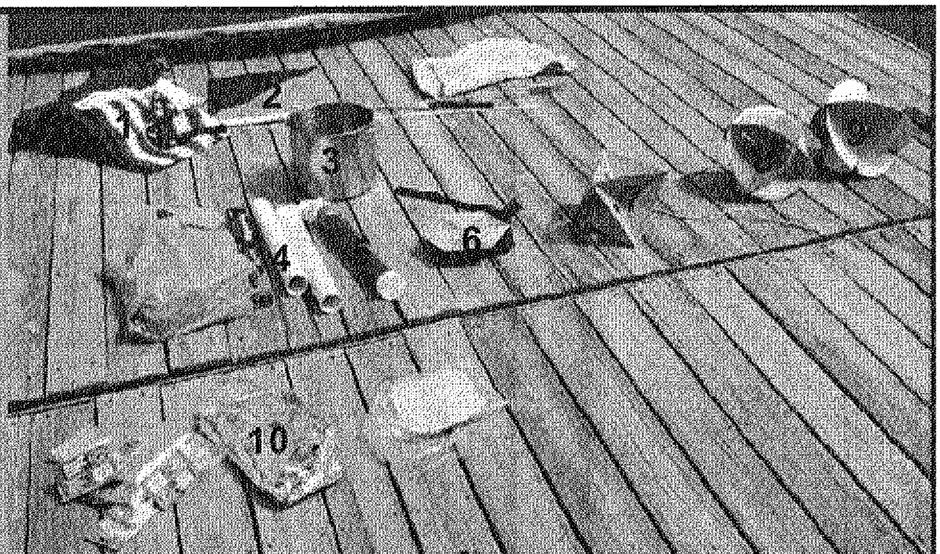
Each kayak was paddled, one at a time, along the course without any radar reflector to determine its "baseline" radar signature. This represented a "run." Optimal radar settings were used. Aboard the radar platform, a qualitative sliding scale was used to rank the strength of the radar signal (or return). The captain and one volunteer monitored the radar scope and called out "zero," "one," or "two" with each sweep of the radar. "Zero" indicated no signal; "one" indicated a weak to moderate signal; and "two" indicated a strong signal. Another volunteer recorded this data on the dataform. Initially, up to 100 sweeps of the radar were recorded. After reviewing the first day's data, it was clear that 30-50 sweeps of the radar would be adequate. Each run was at a predetermined distance from the radar platform: typically 1/8, ¼, and ½ mile. At the ½-mile point, the range and rings were adjusted. The kayaks always ran the same course; so, to change distances, the radar platform vessel would move and re-anchor.

Once baseline data was established, the experimental portion of the study began. Each kayak was rigged with a radar reflector (see the picture and caption below for a list of commercial and homemade radar reflectors used). The procedure was similar to that used for gathering baseline data: radar settings were recorded and kayaks were paddled one at a time along the course, 1/8 mile from the radar platform. However, the experimental portion varied in that each kayak ran the course again, but with the radar platform adjusting gain. Gain was adjusted to get the best return from the kayak while allowing for some minimal amount of clutter deemed acceptable by the captain.

The radar platform was moved and the whole sequence repeated for each distance (¼ and ½ mile). As with the baseline runs, range and rings were adjusted at ½ mile. Subsequently, all data were entered into a relational database to facilitate analyses.

Radar Reflector Models Tested

1 RadarFlag 24" x 36" U.S. ensign;
2 RadarFlag standard kayak flag;
3 10-quart aluminum "chili pot";
4 19" PVC tube filled with crushed aluminum foil (homemade);
5 Kayak Watchdog;
6 Stalker Radar Super Reflector;
7 Hamilton Marine collapsible radar reflector;
8 Davis # 151 gold foil radar reflector;
9 Davis # 153 aluminum radar reflector;
10 space blanket worn as a cape (Academy Broadway Camper's Emergency Blanket (item no. 50330; 84" x 52" aluminum laminated polyethylene).



Reflectors tested but not pictured here: **A** North Water Paddle Sports Equipment 30SK-25R Radar Reflective Paddlefloat; **B** North Water Paddle Sports Equipment 30SK-51R Radar Reflective Expedition Deck Bag; **C** Homemade: broad-brimmed hat covered in aluminum foil; **D** Homemade: PFD with vertical bands of TrimBrite Products Metal Mend Tape; **E** Homemade: vest lined with space blanket, vest lined with other reflective material; **F** aluminum foil crunched up and worn over a hat.

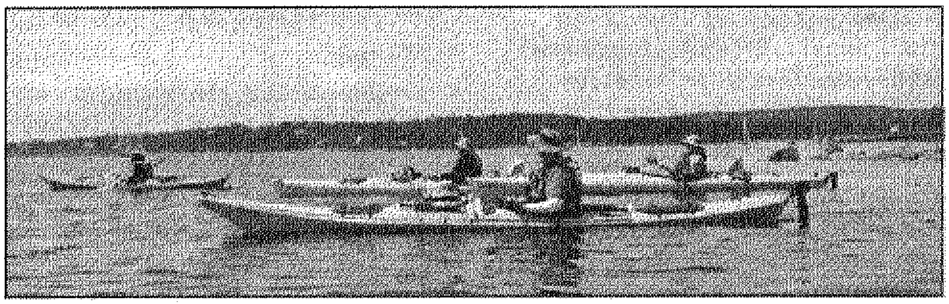
Discussion & Results

This study investigated the effectiveness of a variety of commercial and homemade radar reflectors for increasing kayak visibility on radar. There are two major variables: the kayak and the radar platform. The following discussion explores the data collected and the lessons learned during this study.

To illustrate the importance of providing a good radar return, consider that a boat traveling at 15 knots covers ¼ nautical mile (nm) in 60 seconds. When correlated with our results—that kayaks are generally only visible at less than ½ nm—the window of radar visibility for the boat operator to detect a kayak is one to two minutes. Boat operators, especially commercial fishermen, tend to be focused on multiple tasks when in motion. In reduced visibility, this provides little opportunity for the boat operator to define and discriminate objects on radar. In addition, in order to detect potential collisions with other large vessels, boat operators tend to set their radars at longer ranges than those used in these field tests. Furthermore, they typically adjust their radar settings to exclude clutter in order to reduce the number of objects that need to be defined. This often eliminates sea kayaks from showing up on their radar screen.

For fishermen, adjusting to the dramatic growth in the numbers of sea kayakers can be a challenge. However, the fact remains that more and more kayakers are taking to the coasts, and increasing numbers of guides and outfitters are joining the ranks of the working waterfront by making their living from the sea.

Our first radar reflector field test (in Bar Harbor) was designed to generate baseline data. As defined by the boat operator, "optimal" radar settings were used so as to filter out unwanted clutter. The area where we conducted this first study contained numerous obstacles—islands, floats, moorings, and other marine traffic, including a large locally-guided group of kayakers—that obstructed or confused returns, exemplifying the challenges a radar operator has for maintaining orientation to all potential obstacles. Regardless of which commercial or homemade radar reflector was used, the kayaks generally did not show up on the radar except at the closest distance (1/8 nautical mile).



Kayaks traveling in a tight pod, like this group during our Southwest Harbor trials, are more likely to be seen on radar than kayaks spread apart.

We identified the need to vary radar settings, particularly gain. Gain adjusts the sensitivity of the radar; it may be the most important adjustment for increasing detectability of sea kayaks. Varying gain adjusts the amount of unwanted signals showing up on the radar screen. Tuning gain down reduces the number of false signals or signals from small objects, such as lobster buoys…or kayaks. When gain is turned up, the number of returns is greatly increased. This can pose a challenge to the radar operator in deciphering what is just "clutter" and what is a target of interest.

During our second field tests in Southwest Harbor with the U.S. Coast Guard, we assessed the effectiveness of radar reflectors to return hits at various radar settings. In addition to gain, we experimented with range. Range is the scaled distance from the center point of the radar screen (which is the location of the radar platform) to the edge of the screen. Increasing range increases the area displayed on the radar screen. One additional experimental design introduced in Southwest Harbor was having all kayaks paddle together in a tight pod: the radar return was significant.

Our third round of field tests in Boothbay Harbor had several goals: 1) Given a different radar platform and operator, could we repeat our Southwest Harbor results? 2) Which, if any, combination of radar reflector and radar settings are most effective at generating a return from a sea kayak? 3) Does the construction material of a sea kayak affect radar visibility?

Upon completion of the Boothbay Harbor tests, data from all three sets of field tests were entered into a relational database. To facilitate comparison among field tests, we developed a "visibility factor." During testing, as described in the methodology section, each radar return was ranked on a three-point scale. The visibility factor for each individual kayak/reflector combination, is an average of these scores and can range from 0 to 2; the higher the number, the more visible that particular radar reflector was on radar.

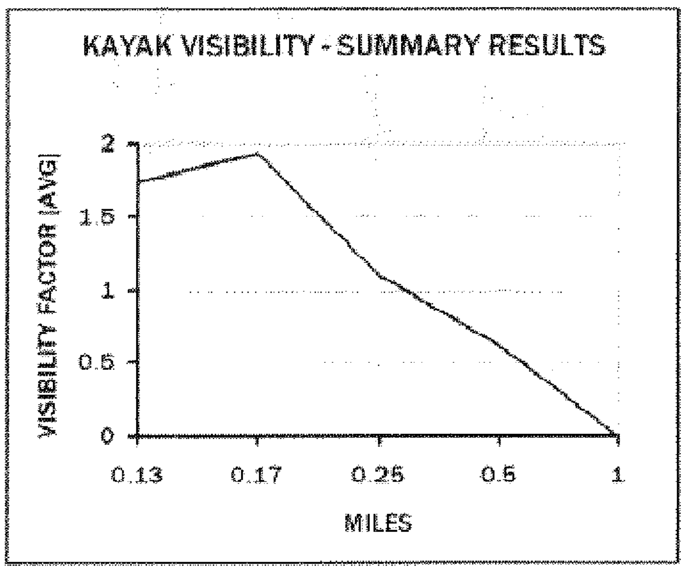


Figure 1. Visibility Factor SummaryResults: *Visibility factor is an average of the radar return for each radar sweep, on a three point scale (0, 1 and 2, with 2 being the strongest signal). This graphic represents a general average of the visibility factor in all the testing for all the kayaks. This is to highlight the relationship between kayak visibility on radar and distance from the radar platforms.*

Based on the three sets of field tests, we made the following findings concerning the effectiveness of commercial and homemade radar reflectors for increasing kayak visibility on radar.

1. **Choose and mount your reflector wisely.** Commercial and homemade radar reflectors provide increasingly better visibility as height above waterline is maximized (*e.g.*, a radar-reflective hat provides better visibility on radar than a deck bag made of radar reflective materials).

2. **The greater the "angularity" of a radar reflector, the greater its visibility factor** (*e.g.*, the Davis 153 and the homemade tin foil hat, both with sharp angles, generated stronger radar returns than smooth radar-reflective surfaces such as deck bags, flags, or vests).

3. **The larger the kayak, the greater its visibility factor.** The tandem sea kayak turned up much better than the solo sea kayaks, regardless of radar reflector. The material a sea kayak is made of had little effect on visibility factor: Kevlar sea kayaks were equally visible as those made of polyethylene (figure 5).

4. **Kayaks paddling closely together in a pod formation** produce a much more significant radar return than a kayak paddling singly with a radar reflector.

5. **At both 1/8 and ¼ nautical mile from the radar platform, kayaks consistently showed up on radar,** regardless of whether there was a reflector in use or not. Beginning at ½ nautical mile, kayaks produced an obvious radar signal less than 10% of the time (fig. 2).

6. **The angle of the sea kayak to the radar platform affects visibility:** a sea kayak perpendicular to the radar platform has a greater visibility factor than one whose bow or stern is facing the radar platform.

7. **Changing gain and sea clutter on the radar screen will increase the ability to detect kayaks** (figure 3). However, this comes at the cost of additional background clutter or noise. It is important to allow radar three sweeps to help identify questionable returns.

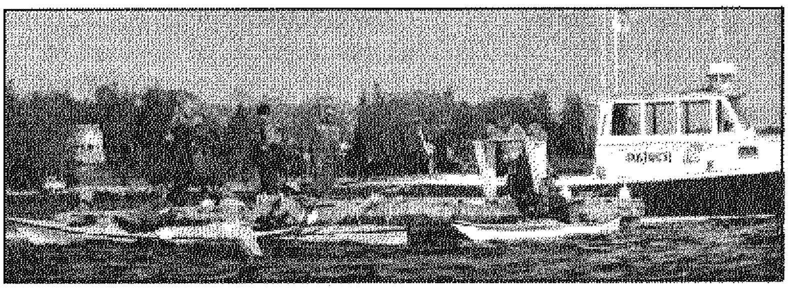
8. **The visibility factor decreases with distance away from the radar platform** (figure 1). Generally, sea kayaks 1 mile from the radar platform are not visible on radar, whether or not they have reflectors.

9. **The higher a radar antenna is mounted on a vessel, the less effect sea state has on kayak visibility** (figure 4). It is important that the radar antenna be mounted with no obstructions, such as life rafts, impeding line of sight to the horizon.

10. **Motion of the radar platform can reduce its effectiveness at picking up targets.** One Coast Guardsman said that the bows of typical Maine lobster boats tend to point upward when traveling at cruising speeds. Therefore, radar waves may completely miss an object low to the waterline, such as a kayak.

11. **The strength of the return is the dominant factor.** Even with radar reflectors, the strength of the return is more of a driving factor than the radar horizon. In other words, the strength of the return may fall short of the radar horizon.

12. **Radar is only effective when it is being watched;** if the radar is not being attended, then the quality of the radar signal produced by a sea kayak is irrelevant.



Switching out reflectors during the third radar reflector visibility trials. Boothbay Harbor, Maine.

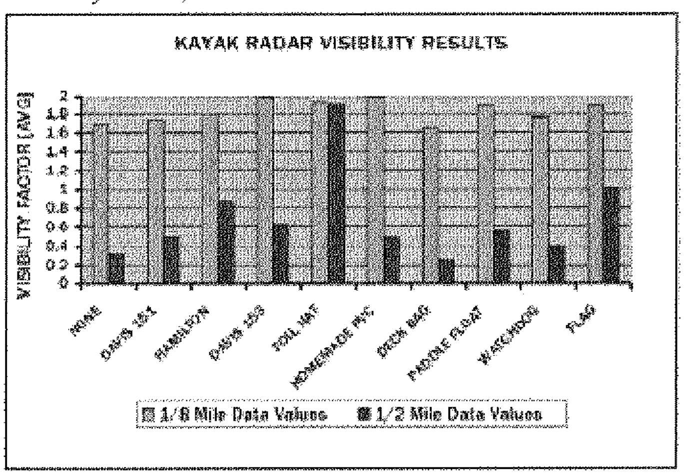


Figure 2. Kayak Radar Visibility Results: *This graphic is a comparison of 10 types of reflectors at two of the test distances. This highlights the performance of various reflectors during testing. We can also correlate reflector height above the waterline with performance. The higher reflectors, Foil Hat and Flag, demonstrated less performance degradation at the increased distance.*

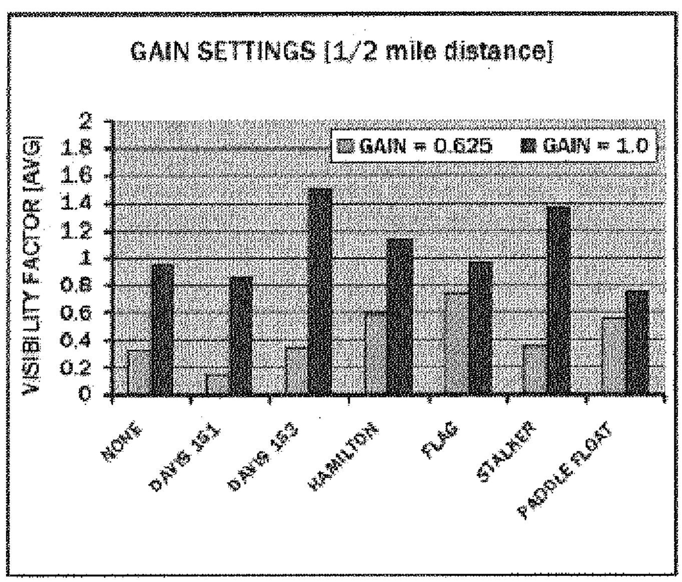


Figure 3. Gain Settings [1/2 mile distance]: *This graphic shows the impact the radar unit GAIN setting has on visibility.*

Conclusions and Recommendations

It is increasingly important for sea kayakers and boat operators to minimize variables that increase the potential of collision or reduce the effectiveness of radar reflectors and radar platforms. Some variables should be addressed by sea kayakers, some by boat operators, and some require further research and development. Applied collectively, the likelihood of kayaker/boater conflict should decrease and all boaters can ply the seas with greater peace of mind.

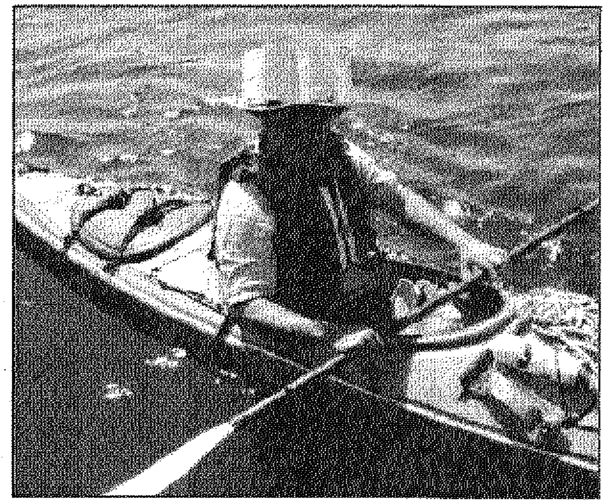
Recommendations for paddlers

Based on our field tests, we found that some form of radar reflector, be it commercially manufactured or homemade, is better than none and bigger radar reflectors produce better returns.

Radar reflector design needs to be functional for paddling. While our field tests and common sense dictate that a solo kayak equipped with a radar reflector atop a four-foot mast may be optimal for visibility, it is neither practical nor safe to do so. Such a reflector increases windage, thus decreasing kayak stability. A mast-mounted reflector can also impair rescues.

Mount radar reflectors so that they will generate the greatest return. Octahedral reflectors (those made of three intersecting, right-angle planes forming eight trihedral shapes; *e.g.*, Davis 153) are best mounted in the "catch-rain" position with one trihedral facing up, one facing down, and the remaining six optimally positioned to reflect radar waves.

Radar reflectors are one component of any paddler's safety preparations. Although they do not guarantee visibility, used in combination with other safe sea kayaking practices, they can enhance safety. When traveling with one reflector for a group—as is often the case on guided tours—paddlers should travel in a tight pod. Tight pods increase the size of the return and thus increase the chances of being identified by radar operators. Plan crossings for narrow channels and known navigation references (*i.e.*, navigation buoys). Make securité calls on VHF channel 16 to advise other boating traffic that a crossing is underway, and specify exact points of crossing. This provides a reference point to the boat operator to slow speed and change radar settings in order to find the group on the radar screen.



Due to a combination of height and angles, this homemade "hat reflector" generated among the clearest returns.

Recommendations for radar operators

Radar is only as effective as its installation. Obstructions, such as life rafts, placed in front of the radar antenna impede proper radar operations. Settings need to be optimized for a combination of clear returns without filtering out too many real targets. For radar to work at all, it must be monitored, especially in fog. And, not surprisingly, higher end radar systems mounted at the highest elevation above the waterline produce the best results.

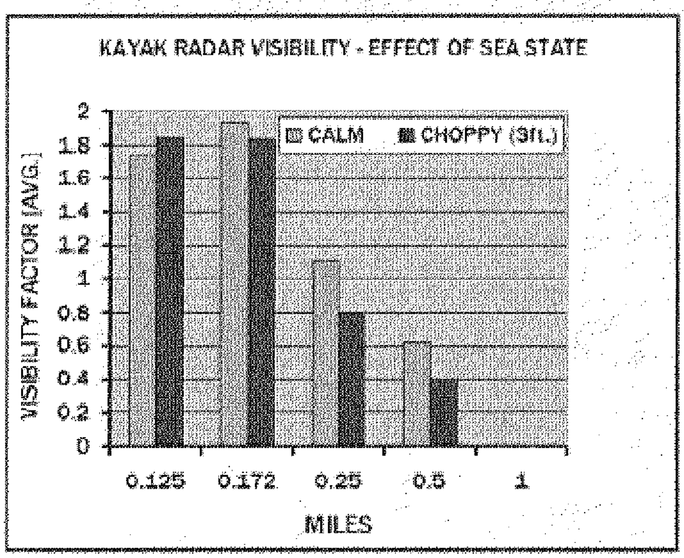


Figure 4. Kayak Radar Visibility -- Effect of Sea State
This graphic compares the SW Harbor data (calm seas) with the BB Harbor data (3 ft. chop). Differences based on sea state were not as large as expected.

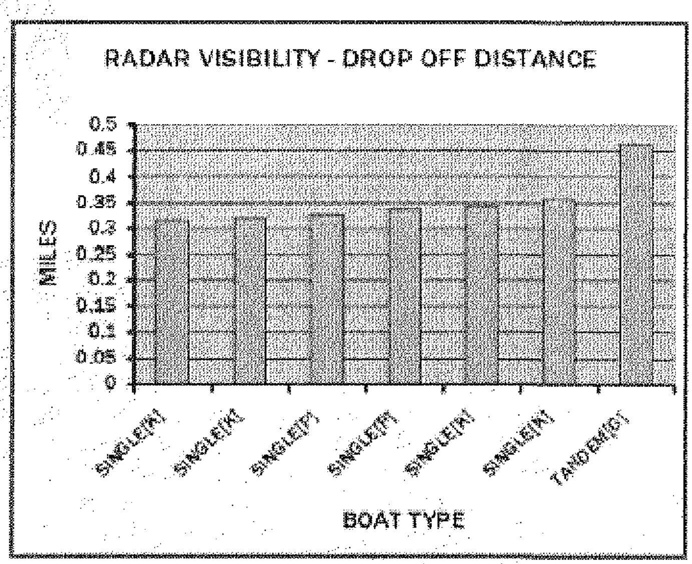


Figure 5. Radar Visibility - Drop Off Distance. *As paddlers moved away from the radar platform, the distance in miles where the radar return was lost is called the "drop off." This graphic shows the radar "drop off" point for various boats. In this test the paddlers were moving directly away from the radar vessel.*
SINGLE[K] - single person kayak, Kevlar construction
SINGLE[P] - single person kayak, Plastic construction
TANDEM[G] - tandem kayak, Fiberglass construction

Effectively setting and reading radar takes proper instruction, practice, and time. Our field tests demonstrated that it takes practice to differentiate between noise and an actual target. There is a fine line to setting the radar to minimize noise without filtering out small but legitimate targets.

Before altering settings, watch the screen through multiple radar revolutions: false returns do not repeat indefinitely the way a true echo would. If a target looks suspicious, it is a good idea to let the radar make at least three sweeps to differentiate between legitimate targets and false returns.

Navigating cautiously in known kayak territory, such as island-studded regions, harbors, and inshore waters, is a great step in decreasing chances of collision.

Recommendations for future research and development

As more and more sea kayakers—whether on guided tours or on their own—take to the seas, there is a need for innovations in safety equipment designed specifically for kayaks. Of all the commercial reflectors included in these field tests, only one was designed with kayakers in mind (the Kayak Watchdog) and even it needed modifications for mounting on a kayak. Mounting the other reflectors, which were intended for larger vessels, was awkward at best.

A radar reflector designed specifically for kayaks would need to maintain the kayak's low profile to limit windage and instability. It would need to be mounted such that it does not interfere with self- or assisted-rescues or Eskimo rolls. And it would need to be light, easy to carry and affix to the kayak, and not interfere with other deck rigging systems. Although conventional models currently do not meet these needs, the limitations are not insurmountable, as has been proven by several of the homemade reflectors included in this study.

Some options manufacturers might consider include incorporating radar reflective materials and designs within existing sea kayaking equipment and clothing. The paddle blade could be utilized to take advantage of the height it achieves. Our field tests demonstrated that crushed aluminum in a paddler's hat yielded decent results; a manufacturer could design a new hat with built-in reflective material. Life jackets and paddling jackets could be outfitted with reflective material as well. There is also a need to research the potential for incorporating reflective material within the kayak's hull design.

More research is needed on each of these possible designs. Radar-reflective cloth materials currently on the market have some limitations, not least of which are that they eliminate the angular features typical of highly visible reflectors. Alternatively, investigating active radar reflectors—reflectors that transmit a signal on the radar frequencies typically used by boats—could lead to a new, portable, affordable device. Overall, there is a tremendous opportunity for manufacturers to develop a new market by designing radar reflectors specifically with kayakers in mind.

Even on a clear day, kayaks are hard to see from the cabin of this Coast Guard Auxiliary vessel. Radar reflectors can help increase visibility.

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MSG-TR-05-01

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