ICES Journal of Marine Science, 63: 523–531 (2006)
doi:10.1016/j.icesjms.2005.05.023

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In situ tagging of deep-sea redfish: application of an underwater, fish-tagging system

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Sigurdsson, Th., Thorsteinsson, V., and Gustafsson, L. 2006. *In situ* tagging of deep-sea redfish: application of an underwater, fish-tagging system. – ICES Journal of Marine Science, 63: 523–531.

We describe a tagging method using underwater-tagging equipment (UTE), developed in collaboration between the Icelandic Marine Research Institute and the marine-device manufacturer STAR–ODDI. The tagging device can be attached to a pelagic or demersal trawl, immediately in front of the codend. Fish that enter the trawl are guided through the UTE, where they enter a tagging chamber to be held, tagged, and then released. The tagging equipment is electronically controlled from the vessel by a computer with a hard-wire, sonar cable link between the ship and the device. The same cable carries signals from four video cameras in the UTE, and a researcher can view images of the fish on a computer screen and control the tagging equipment simultaneously. The motivation for this project is the need to be able to tag fish, *in situ*, underwater, so avoiding the problem of swimbladder expansion that for physoclists such as redfish precludes conventional tagging. The UTE has been used to tag redfish in the size range 32–52 cm. Other species, such as saithe, have also entered the equipment and have been tagged with success. The tagging equipment could therefore be an alternative for tagging any medium-size roundfish, such as cod, haddock, and saithe, as well as many deep-sea species in their natural environment without subjecting them to the hazardous journey from deep water to the surface. In all, 752 redfish were tagged with the UTE in 2003 and 2004. Of these, 29 (3.9%) have been recaptured, most with reliable information on date, position, and condition at the time of capture. The tags used in 2003 and 2004 were dummy tags identical in size and shape to the external housings of electronic data-storage tags. In 2005, real DSTs were used of the type DST-micro from STAR–ODDI. These will in future provide time-series of ambient temperature and depth.

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Keywords: *in situ* tagging, redfish, *Sebastes mentella*, underwater-tagging equipment.

Received 7 February 2005; accepted 23 May 2005.

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Introduction

Tagging has been used in fisheries research since the late 19th century (Petersen, 1896), and is a fundamental tool for studying the behaviour of commercial fish, especially since the advent of electronic tags (Arnold and Dewar, 2001). Tagging methods have generally involved catching fish with various types of fishing gear, bringing them to the surface, and hauling them aboard, where the live fish are transferred to containers with seawater. The survivors are tagged and released back into the sea (Thorsteinsson, 2002). Some improvements have been tried in the past in the process of capturing and handling fish during tagging, e.g. the use of containers around the codend of the trawl to decrease the time the fish spend in the air, and tagging cradles to immobilize and protect them (Jones, 1979). However, the trip to the surface remains a major hazard for the survival of fish in tagging experiments (Jakobsson, 1970; Jones, 1979), especially for a physoclistous fish with a closed swimbladder (Bone *et al.*, 1996). When fish move or are hauled vertically, the volume of the swimbladder changes with pressure, according to the laws governing the behaviour of gasses in nature. For the compensation of volume change in the swimbladder of a physioclistous fish, inflation is a physiological process in the vascular countercurrent system in the *rete mirabilis*, but deflation is a physical process with the diffusion of gases through the oval gland into the vascular system and to the seawater through

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the gills (Blaxter and Tytler, 1978; Harden Jones and Scholes, 1985; Arnold and Greer Walker, 1992). Deflation is much faster than inflation, but not fast enough when the fish is hauled by fishing gear towards the surface (Tytler and Blaxter, 1973). As a result, the swimbladder may expand and rupture, and the expanded air can push the internal organs out through the oesophagus and mouth. Many attempts have been made to overcome this common obstacle to tagging experiments. Hislop (1969) described a method in which an underwater-tagging bench was used by four divers to tag fish caught by trawl or Danish seine (Jones, 1979). Fish have also been tagged in deep water with baited tags (Priede and Smith, 1986; Armstrong *et al.*, 1992), but this approach depends on the fish being studied swallowing the tag hidden in a bait. Manned submarines capable of shooting darts with acoustic transmitters have also been successful and yielded results under certain circumstances (Schauer *et al.*, 1997).

Underwater-tagging equipment (UTE) (Sigurdsson and Thorsteinsson, 2004) can be operated in conjunction with a midwater or demersal trawl. This is an important aspect of the method and makes it an attractive alternative in tagging experiments on commercial fish species such as *Sebastes* spp. The various redfish species seem to be especially vulnerable to pressure change, and suffer total mortality when hauled to the surface by conventional fishing gear. It is common knowledge that it has been impossible to tag redfish species in the North Atlantic by conventional methods. Deep-sea redfish (*Sebastes mentella*) is the most important species of redfish harvested in the North Atlantic. In addition to advising on the total allowable catch in the Barents Sea, ICES gives advice on three deep-sea redfish management units, with a total distribution extending from the Labrador Sea in the west to the Faroe Islands in the east (Figure 1). The annual catch in recent years is >150 000 t, involving at least 70−80 vessels from 15 nations (ICES, 2003).

Many questions relating to the stock structure of deep-sea redfish in this area have been raised, and extensive research has been carried out in the biochemical fields (Johansen *et al.*, 2000; Johansen, 2003; Joensen and Grahl-Nielsen, 2004; ICES, 2005a, b). Although valuable knowledge of redfish stock structure has been gained in recent years, further information is needed to quantify migration and the extent of mixing between stocks.

Redfish are crucial members of the deepwater ecosystem, so their successful tagging may substantially improve our understanding of the functioning of this ecosystem. Tagging would also give information on the growth of tagged fish and could, given sufficient recaptures, be used to estimate mortality rates. The Marine Research Institute in Reykjavík (MRI) and STAR−ODDI Ltd have therefore cooperated in the design and construction of a UTE system for tagging fish *in situ* in the sea (Schrope, 2000; Sigurdsson and Thorsteinsson, 2004). The main interest of the MRI in the UTE is to obtain more precise information on the vertical and horizontal migration patterns of various stocks of redfish. Such information can be used to answer key questions related to the stock structure of deep-sea redfish and so improve advice on how to manage the resource in future.

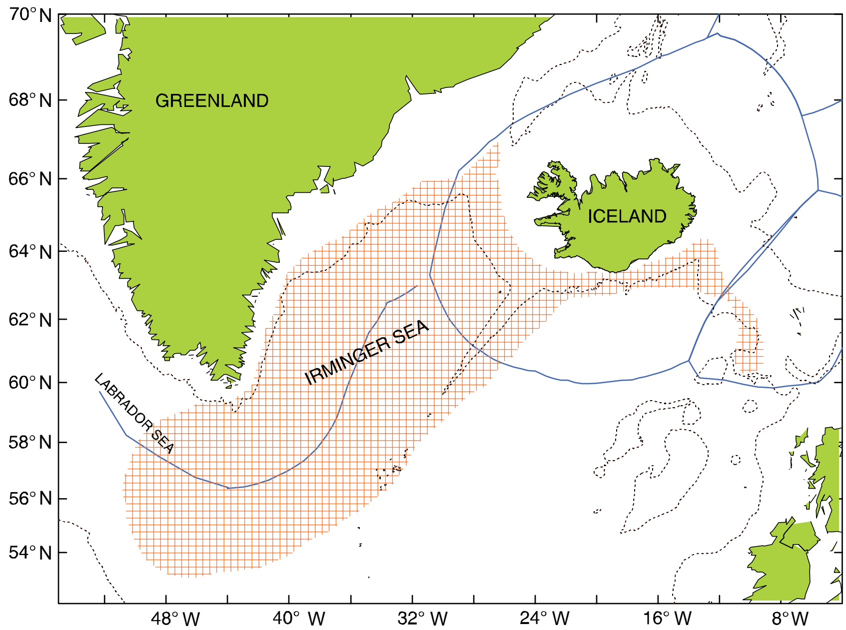

Figure 1. Schematic overview of fishing areas for deep-sea redfish from west of the Faroe Islands to the Labrador Sea.

Material and methods

Equipment

For the most efficient use of the UTE, a stern trawler is required, equipped with either or both, a pelagic or demersal fishing trawl, a standard sonar cable, and a cable winch. Both demersal and large pelagic trawls were used during the two cruises so far conducted. The sonar cable, which is used as a two-way communication link, carries control signals for the cameras and hydraulically operated moving parts of the underwater system to the UTE; video signals from the cameras are conveyed to the vessel in the opposite direction. The UTE is designed to tag fish down to 1000 m, and the fishing technique is the same as for commercial fishing operations.

The UTE is attached to the top panel of the trawl in front of the codend (Figure 2). It weighs approximately 650 kg in air, but $<$100 kg in seawater. Its length is 3 m, height 1.4 m, and width 1.5 m. The UTE can therefore be fitted to most commercial trawls. Further technical details of the device are given in Table 1.

The UTE comprises four main parts:

- an outer shell that acts both as protection for other parts of the device and as a skeleton for the attachment of other items of equipment;
- electronic−hydraulic machinery and batteries, which are placed in two tanks designed to withstand pressure down to about 1700 m and located in the lower part of the device;
- a funnel-shaped front part, designed to direct the fish into the tagging area by the flow inside the trawl; and
- a tagging chamber (Figure 3B and C).

The tagging chamber is located in the centre of the UTE, and contains a holding mechanism and a tagging unit. The holding mechanism is a grid that traps the fish and keeps it still while tagging. The tagging unit consists of a knife, a mechanism to push the tag through an incision made by the knife, a light source, two video cameras, and a magazine of tags (Figure 3C). The various parts of the tagging unit are movable and powered by a hydraulic system, so the knife can be aimed at the appropriate part of the fish before triggering the tagging mechanism by a computer onboard the ship. The UTE is equipped with four light sources, all with the option of using filters to produce red light to minimize disturbance to the fish. The holding grid has soft material (brushes) on the projections, which come into contact with the fish, to avoid damage to the skin of the fish and loss of scales.

Tagging procedure

The tagging procedure is divided into three steps.

(i) When trawling, the current inside the trawl directs the fish into the area where they can be tagged. Approaching the equipment, the fish enters through a grid and a funnel that leads into the tagging chamber. At this stage, the fish is observed alternately by two of the four video cameras of the UTE. On entering the tagging chamber (Figure 3), the fish is gently caught and immobilized by the holding grid. The tagging operator controls all adjustments of the tagging unit via the onboard computer. It may take a few minutes to position the fish correctly for tagging, but the tagging operation itself takes less than 15 s. In order to avoid damage to internal organs when tagging, it is critical that the fish be positioned correctly.

(ii) When the fish is in position and ready for tagging, the tagging unit is aimed at its most suitable part (the abdomen), and tagging is performed in the following sequence:
  - A small incision is made into the peritoneal cavity of the fish with a knife.
  - The tag is then pressed through the incision into the peritoneal cavity, but the spaghetti indicator attached to the tag is left protruding to the exterior to facilitate its detection when recaptured (Figure 4). The cut is smaller than the diameter of the tag, and after the tag has been pushed through the opening into the peritoneal cavity, the wound closes and the tag is retained.
  - At this stage in the procedure, a digital photo of the fish is taken and stored, and the length of the fish is

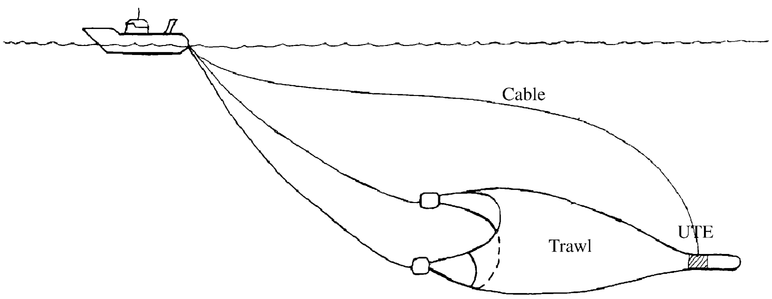

Figure 2. Placement of the UTE in the fishing gear.

estimated from the picture for comparison when it is recaptured.

(iii) After tagging, the holding grid is opened and the tagged fish released through the tail-end of the equipment.

Results

From 1999 to 2003, several cruises were carried out. During those cruises, the fish were not released, but rather diverted into the codend of the trawl and recovered with the catch for inspection of tagging success and injuries.

Table 1. Technical specifications of the UTE.

Weight in air	650 kg
Base material	Stainless steel, low corrosion
Operational pressure/depth	100 bar/1000 m
Communication	Standard sonar cable (analogue) transfers signals between ship and UTE. This includes measurements, video from four underwater cameras, and the control of all tagging functions
Video cameras	Black and white
Light	Helical bulb, 24 V and 20 W, with light filter (E-colour #164 flame red); dye-coated polyester film; 75 μm; manufactured by Rosco Laboratories, UK
Actuators	Hydraulic
Measured parameters	
Temperature	−2°C to 40°C (28−104°F)
Depth/pressure	0−1000 m/0−100 bar
UTE inclination	Roll and pitch ± 45°
Hydraulic pressure	0−250 bar
UTE control unit	PPC (Programmable Process Controller) communications unit Light- and video-switching actuators Hydraulic pump, control unit remote-controlled hydraulic pressure
PC control unit	Standard PC UTE tagging software with video card Communication unit, composite video output for VCR Power supply for charging the battery containers
Battery container lifetime	Approximately 6 h (rechargeable); two battery containers, replaceable
Tagging gun	Remote controlled, can be moved in two directions
Capacity for tags	59 tags
Tags applied	DST-micro/dummy tags DST-micro-electronic tags, measuring temperature and depth
Size of tags (diameter × length)	8.3 mm × 25.4 mm (plus the plastic tube)

The first cruise after the experimental phase took place in October 2003, when 200 redfish were tagged and released on traditional demersal redfish grounds on the continental slope about 120 nautical miles southwest of Iceland. The fish were tagged at a depth of 500−550 m, using a demersal trawl to catch them. During a second tagging cruise in June 2004, 552 redfish were tagged. Of these, 374 were caught and tagged 200 miles southwest of Iceland (tagging depth 550−800 m, bottom depth >1500 m) with a pelagic trawl, and 178 were tagged about 130 nautical miles southwest of Iceland with a demersal trawl (depth 480−550 m). The pelagic trawl was deployed where a large fleet of trawlers was fishing for "pelagic" redfish; fish caught with the demersal trawl were taken at a similar location to those caught in October 2003.

From these two releases, 29 fish have already been recaptured (Table 2; Figure 5). Of these, 12 were from the release in October 2003 and 17 from that in June 2004. All recaptured fish were recovered by stern trawlers fishing on traditional redfish fishing grounds. Information on the dates and positions at tagging and recapture are given in Table 2. The distance from the tagging location to that of recapture varies from 1 to 320 miles, and the time at liberty from one day to nearly one year. Many of the recaptured redfish have been returned to the Marine Research Institute in Reykjavík. All were examined and none of those at liberty for more than a day or so showed any visible injuries caused by the mechanical handling of the tagging gear. The cuts inflicted during tagging had healed and showed no indication of infection or swelling. Moreover, there were no indications of internal damage.

Discussion

Although only 29 fish have been recaptured from the 752 tagged in October 2003 and June 2004 (3.9%), the results show that this method of tagging fish is successful. Of the 200 fish tagged in October 2003, 12 (6%) have been recaptured already. Given the longevity of *S. mentella* (more than 30 years), and the fact that the advice given by ICES for this management unit has in most recent years been followed, one can assume that the exploitation rate is fairly low or <10% of spawning-stock biomass, lower than for many exploited fish stocks. For *S. mentella*, ICES has advised an annual exploitation rate <5% of fishable biomass (ICES, 2005a). For comparison, the cod stock around Iceland has been exploited at around 30% of its fishable stock size (Anon. 2005), and the recapture rate of tagged cod can vary between 10% and 25% within the first year, depending on where the fish is released and the type of tag used. Assuming a low exploitation rate on redfish, an even distribution of tagged fish within the population, and that the catchability of tagged and untagged fish is the same, the survival rate of tagged fish appears to be high.

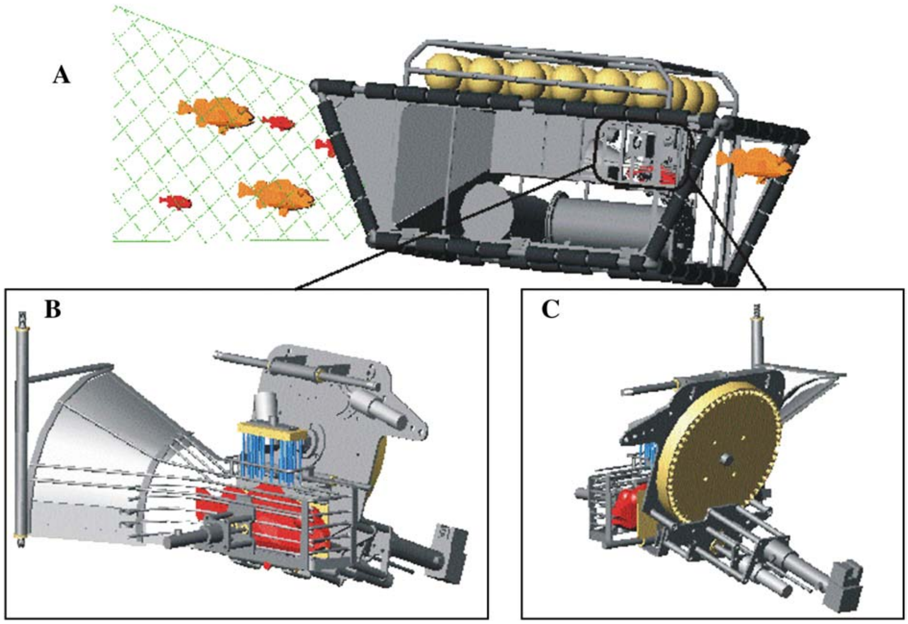

Figure 3. Schematic presentation of the tagging device. (A) The underwater-tagging equipment. The net of the trawl is attached to the left of the device and the current guides the fish through the funnel into the tagging chamber. The two tanks on the lower part of the device house the electronic−hydraulic machinery and the batteries. (B) Enlarged area indicated in (A), seen from the left. The left part of the picture shows the rear part of the funnel, which directs the fish into the tagging chamber. The fish, shown inside the tagging chamber, can be adjusted using hydraulic pumps until it is in the correct position for tagging. (C) Enlarged area indicated in (A), seen from the right. The tagging chamber and the fish can be seen on the left, together with the magazine (for 59 tags) and the mechanism that moves the knife, which makes the incision in the peritoneal cavity of the fish and pushes the tag into the cavity. For simplification, the hydraulic pumps and cameras are not shown in the illustration.

The longest time at liberty recorded so far is more than 70 weeks (Table 2), and 15 fish were recaptured after three months or more at liberty. These observations suggest that redfish tagged with this new technique will probably survive long enough to provide useful information on migration and stock mixing.

ICES assesses redfish on the continental shelves of Greenland, Iceland, and the Faroes as a single management unit. Advice is given for that unit separately from redfish caught with midwater trawls in the Irminger Sea and adjacent waters (ICES, 2005a). During the cruise in October 2003 only redfish from the continental shelf unit were

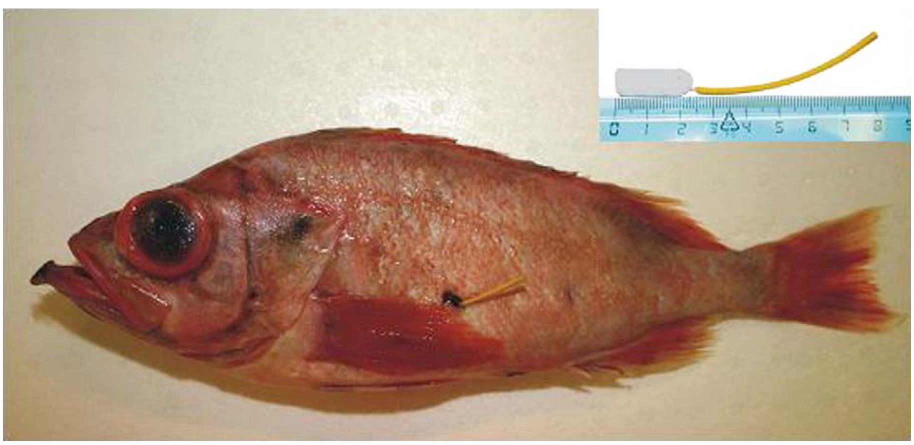

Figure 4. Recaptured redfish. The spaghetti tag indicates the position of the tag inside the fish. A dummy DST-micro (see http://www.star-oddi.com/Temperature_Recorders/Data_Storage_Tags/) tag used while tagging redfish in October 2003 and in June 2004 is also shown.

Table 2. Information on recaptured redfish. Positions of tagging and recapture, depth, date, distance between tagging and recapture locations (calculated as the minimum distance between the two positions), and the number of days at liberty.

Recapture number	Tagging					Recapture			Number of days at liberty	Distance (nautical miles)	Unit*
	Latitude	Longitude	Date	Depth (m)	Gear type	Latitude	Longitude	Date			
1	63°05′N	23°48′W	22.10.2003	500	Demersal trawl	63°05′N	23°48′W	28.10.2003	6	1	DEM
2	63°06′N	23°40′W	25.10.2003	521	Demersal trawl	63°01′N	23°57′W	21.01.2004	88	9	DEM
3	63°06′N	23°39′W	23.10.2003	531	Demersal trawl	62°56′N	24°26′W	10.02.2004	110	23	DEM
4	63°06′N	23°40′W	25.10.2003	512	Demersal trawl	63°05′N	23°50′W	19.02.2004	117	4	DEM
5	63°06′N	23°42′W	23.10.2003	503	Demersal trawl	63°00′N	24°08′W	10.04.2004	170	13	DEM
6	63°05′N	23°46′W	24.10.2003	549	Demersal trawl	63°00′N	24°00′W	11.04.2004	170	8	DEM
7	61°22′N	28°19′W	14.06.2004	741	Pelagic trawl	61°23′N	28°26′W	17.06.2004	3	3	PEL
8	61°17′N	28°13′W	14.06.2004	622	Pelagic trawl	61°21′N	28°15′W	17.06.2004	3	4	PEL
9	61°21′N	28°25′W	15.06.2004	741	Pelagic trawl	61°23′N	28°17′W	19.06.2004	4	4	PEL
10	61°22′N	28°18′W	18.06.2004	732	Pelagic trawl	61°24′N	28°18′W	19.06.2004	1	2	PEL
11	61°30′N	28°25′W	19.06.2004	622	Pelagic trawl	61°21′N	28°14′W	21.06.2004	2	11	PEL
12	61°17′N	28°13′W	14.06.2004	778	Pelagic trawl	61°30′N	28°19′W	23.06.2004	9	13	PEL
13	61°15′N	28°09′W	15.06.2004	778	Pelagic trawl	61°32′N	28°16′W	23.06.2004	8	17	PEL
14	61°18′N	28°12′W	17.06.2004	750	Pelagic trawl	61°36′N	28°19′W	26.06.2004	9	18	PEL
15	61°19′N	28°14′W	16.06.2004	778	Pelagic trawl	61°54′N	28°34′W	29.06.2004	13	36	PEL
16	61°22′N	28°12′W	20.06.2004	641	Pelagic trawl	62°05′N	28°32′W	01.07.2004	11	44	PEL
17	63°05′N	23°46′W	24.10.2003	505	Demersal trawl	63°28′N	12°20′W	16.08.2004	297	309	DEM
18	63°01′N	24°00′W	24.10.2003	503	Demersal trawl	63°18′N	12°10′W	16.08.2004	297	321	DEM
19	63°07′N	23°40′W	23.10.2003	482	Demersal trawl	63°09′N	23°25′W	26.08.2004	308	7	DEM
20	63°06′N	23°39′W	23.10.2003	458	Demersal trawl	63°00′N	24°11′W	28.09.2004	341	16	DEM
21	63°01′N	24°02′W	10.06.2004	567	Demersal trawl	65°49′N	27°21′W	07.10.2004	119	188	DEM
22	62°58′N	24°12′W	12.06.2004	458	Demersal trawl	63°10′N	23°24′W	16.10.2004	126	25	DEM
23	61°22′N	28°12′W	20.06.2004	549	Pelagic trawl	65°52′N	27°17′W	06.11.2004	139	271	PEL
24	63°01′N	24°01′W	10.06.2004	494	Demersal trawl	63°03′N	23°59′W	28.11.2004	171	2	DEM
25	63°02′N	23°59′W	08.06.2004	512	Demersal trawl	62°59′N	25°00′W	28.01.2005	234	28	DEM
26	63°03′N	23°56′W	22.10.2003	576	Demersal trawl	62°56′N	25°10′W	27.02.2005	494	34	DEM
27	63°01′N	24°01′W	10.06.2004	513	Demersal trawl	63°30′N	26°06′W	31.03.2005	294	63	DEM
28	61°27′N	28°17′W	20.06.2004	690	Pelagic trawl	61°46′N	29°04′W	28.04.2005	313	29	PEL
29	63°05′N	24°45′W	23.06.2003	507	Demersal trawl	63°59′N	11°43′W	26.06.2005	734	326	DEM

*Management unit where tagged, according to ICES (2005a). DEM = demersal management unit, PEL = pelagic management unit.

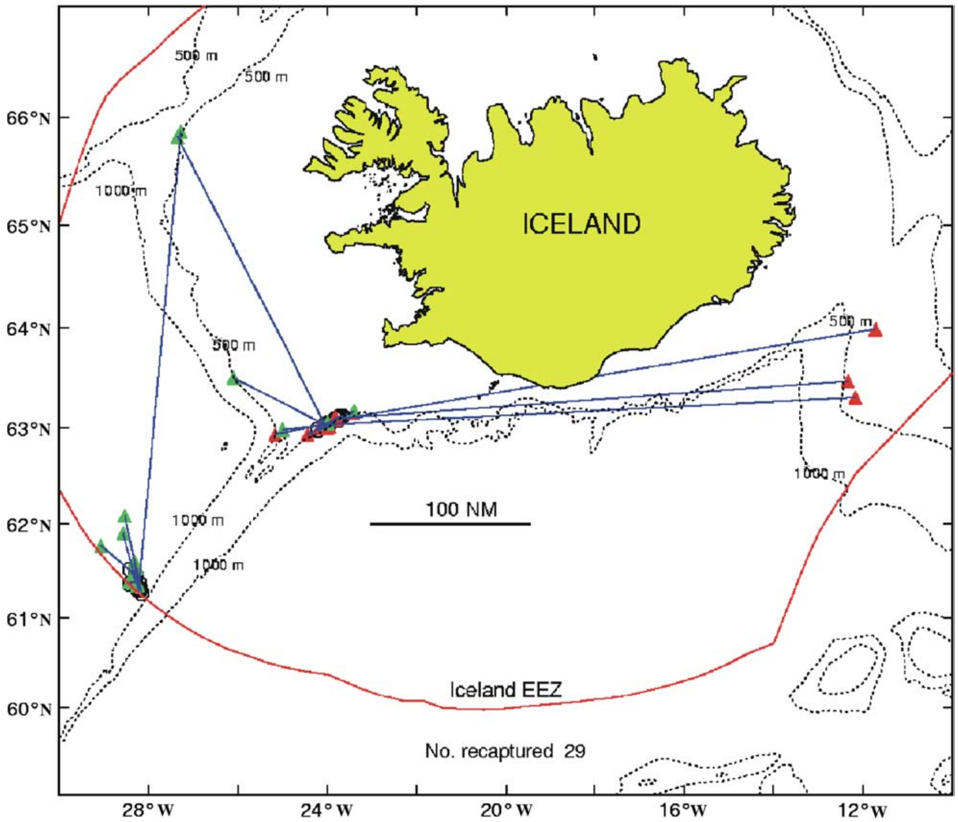

Figure 5. Tagging (○) and recapture (▲) locations for deep-sea redfish tagged in October 2003 and June 2004. Red indicates recaptures from the release in October 2003 and green indicates those from the batch released in June 2004. The lines between the two points indicate simply the shortest distance between the two positions.

tagged, but in June 2004 they were tagged from both management units. Recaptures from the shelf unit have all been taken on the shelf itself, close to the tagging area and on the western and eastern fishing grounds of the Icelandic shelf. Of the 378 fish caught and tagged by pelagic trawl in the Irminger Sea in June 2004, 12 (3%) have been recaptured. Ten of these were recaptured close to the tagging area shortly after tagging (less than 2 weeks), and one close to the tagging area during the next fishing season, 45 weeks later. One fish was, however, recaptured on the shelf west of Iceland after about 18 weeks at liberty (Table 2). This fish was therefore recaptured from a management unit different from that in which it was tagged.

The UTE has several advantages over traditional tagging methods. First, it is specifically designed to tag fish in deep water, so avoiding the large pressure changes and concomitant physiological problems incurred by raising fish to the surface. Moreover, this method could be considered an improvement in fish welfare (Erickson, 2003), because there is no manual handling of the fish and no anaesthetic is applied. The tagging procedure itself is fast and the fish show no obvious fright reactions. As they are tagged in their natural environment, there are hardly any changes in pressure, temperature, or light intensity. Therefore, the UTE tagging process should be less stressful than traditional tagging methods, so might result in lower mortality.

When tagging using traditional methods, pressure changes associated with bringing the fish to the surface can have more serious effects on the fish than the tagging procedure itself. The survival of fish through capture and handling varies between species (Blaxter and Tytler, 1978; Thorsteinsson, 2002), but for most species, tagging mortality could be reduced by using an underwater, tagging-equipment technique. The new technology of underwater tagging is therefore likely to have a significant potential for application in various other projects.

As would be expected with new technologies in fisheries research, there may still be obstacles to overcome. The UTE is complicated, and although it is relatively simple to operate, technical checking and overhauling between operations is needed. Each operation can last for about 6 h before the batteries need to be recharged, the device overhauled, and the tag magazine filled. Therefore, someone with good working experience of the UTE is needed on all surveys. Further, although the tagging phase is short, the number of fish that can be tagged during a 24-h period is relatively small compared with traditional tagging. This is caused by the relatively long handling time before a fish can be manoeuvred into the right position in the holding mechanism.

During the first few days of the surveys, several adjustments of the UTE had to be made, meaning that relatively few fish were tagged. When the technical difficulties had been overcome, we were able to tag between 70 and 130 fish daily. As operator experience increased during the surveys, so did the number of fish tagged daily. Therefore, we would expect a further increase in the number of fish tagged on future surveys, and it is not unrealistic to expect that more than 120 fish can be tagged daily.

When planning the project there was considerable discussion between the MRI and STAR−ODDI Ltd on shedding of tags, because the incision wound is not closed after tagging. Questions were raised as to whether the tag could slip back out through the incision. Instead of closing the cut, which would technically be very difficult, it was decided to make an incision smaller than the diameter of the tag. This technique allows the wound to close partially after the tag has been inserted into the peritoneal cavity, which in turn probably prevents the tag from slipping out of the fish. The relatively high recapture rate and healthy condition of the recaptured fish suggest that this technique of pushing the tags through a small cut is successful in preventing both tag shedding and permanent injury to the tagged fish.

The mortality of redfish tagged via the UTE has not been estimated because it is difficult to catch and hold them in cages at the depths where the experiments were carried out. There is considerable experience in tagging various species of fish with internal DSTs in the peritoneal cavity (Arnold and Dewar, 2001; Thorsteinsson, 2002). In experiments where cod have been kept in captivity for more than a year, excessive mortality of fish with DSTs in their peritoneal cavity have not been observed. Comparison of long-term rates of total mortality of cod tagged with conventional tags with that of those tagged with a conventional tag and a DST in the peritoneal cavity have not shown any difference in mortality rate between these groups.

During the experimental phase of the current project, tests were made on 20 cod in captivity in which tags were surgically inserted into the body cavity in a manner similar to that carried out by the UTE. All fish survived the tagging and no mortality was observed in the subsequent three weeks; after this period the experiment was ended.

During the surveys in 2003 and 2004, only dummy tags were used. In June 2005, the dummy tag was replaced by a working data-storage tag in order to obtain information on vertical migration and ambient temperature. Of these working DSTs, 49 were placed in redfish along with 975 dummy tags during a cruise lasting 12 days, of which 11 days were in the field.

Conclusions

Although redfish has been the target species during this work, the UTE could be useful for tagging a range of species. Overall, the experience obtained with the UTE has been positive, and has confirmed that the method is capable of tagging fish down to at least 850 m.

The advantage of the UTE is that it can be used for large-scale tagging using both pelagic and demersal commercial fishing trawls. The conditions in which the UTE has been used would probably not allow the use of submarine tagging or ingested baits, because of rough weather at times and the great depth of fishing.

Although many other deep sea, fish-behaviour research projects are generating highly valuable results, we believe that the tagging method described here might be the best choice for tagging physoclistous fish such as *Sebastes* species in deep water, especially when conventional tagging methods fail.

Acknowledgements

The UTE was developed in collaboration between the Marine Research Institute and STAR-ODDI Ltd. and has partly been funded by the Research Council of Iceland. We thank all those involved in the numerous surveys conducted during the last six years for their contributions and suggestions. Guðmundur Gunnarsson (HAMPIDJAN Ltd) is thanked for his advice on the placement of the UTE within the trawl gears used. Ólafur K. Pálsson, Hjálmar Vilhjálmsson, Sigurður Jónsson, Sveinn Sveinbjörnsson, and two anonymous referees are also thanked for valuable comments and suggestions on the manuscript.

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