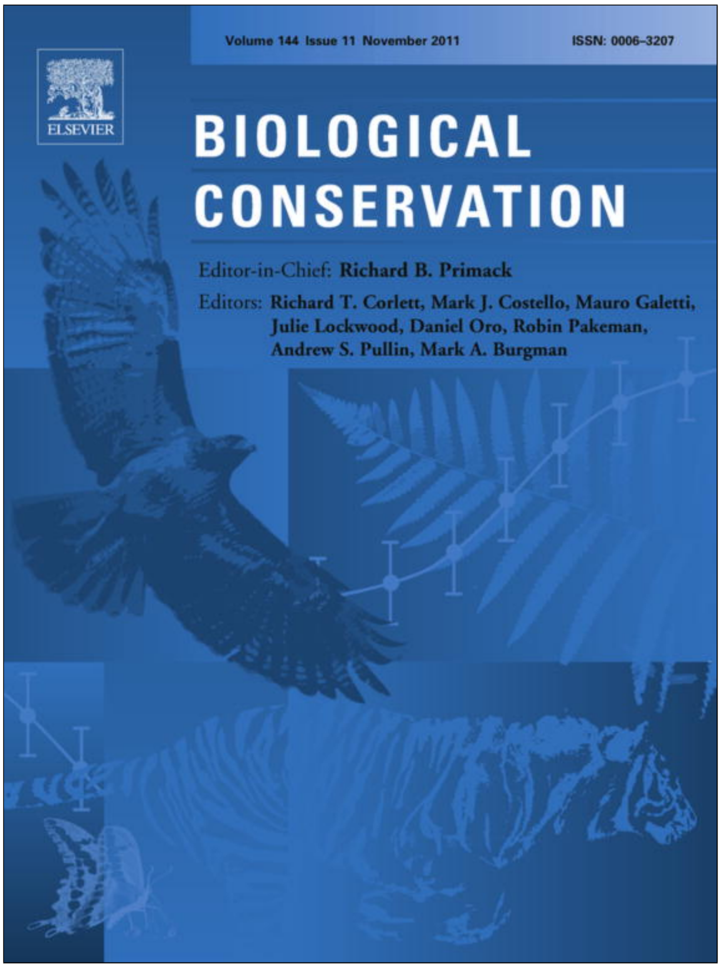
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Estimating mortality of Atlantic bluefin tuna (*Thunnus thynnus*) in an experimental recreational catch-and-release fishery

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ABSTRACT

The abundance of Atlantic bluefin tuna has been severely reduced since the advent of industrial fishing. A recreational catch-and-release fishery is currently being developed to target bluefin tuna in the southern Gulf of St. Lawrence, off the coast of Prince Edward Island, Canada. To evaluate the sustainability of this fishery, it is necessary to quantify post-release mortality for use in management models. Using pop-up archival satellite tags, we estimated the post-release mortality rate of bluefin tuna captured and released in an experimental recreational fishery. Fish were captured using bait on circle hooks and all fish were hooked in the jaw. Fish were released without being brought onboard the boat. Tags reported from 2 to 246 days post release. Two of 59 bluefin tuna died after catch-and-release yielding a mortality rate of 3.4% (95% C.I. = 0.8% < u < 12.6%). Four tags failed to report. Alternate estimates of the rate or mortality that included an incidental mortality (5.1%; 95% C.I. = 1.6% < u < 14.4%) and removal of the four tags that did not report from the sample (5.6%; 95% C.I. = 1.8% < u < 15.6%) were calculated. The range of fight times was 6–79 min (mean of 33 min; SD of 21 min). These data provide the first mortality estimates for angled and released bluefin tuna and will enable managers to evaluate the potential for developing a catch-and-release fishery in the southern Gulf of St. Lawrence.

1. Introduction

Catch and Release (C&R) fishing has recently become popular in the recreational fishery sector. Released individuals generally suffer low mortality (Cooke and Suski, 2005) and therefore a greater percentage of the fish in the population survive to contribute to subsequent populations (Wydoski, 1977; Cooke and Schramm, 2007; Donaldson et al., 2008) than if these fish were to be harvested. The reduced impact on the resource, due to employing C&R fishing procedures, generally appeals to conservation-minded anglers. However, all forms of fishing have some impact on fish survival. So, as new C&R fisheries are developed it is necessary to quantify the expected mortality rates of released fish for use in management models. In addition, by identifying the factors that contribute to mortality, it is possible to develop and promote strategies for reducing mortality (Cooke and Schramm, 2007).

A C&R sport fishery for Atlantic bluefin tuna (*Thunnus thynnus*) is currently being developed to access fish in the southern Gulf of St. Lawrence (GSL), Canada. Atlantic bluefin tuna are highly migratory marine pelagic fish that can grow to a mass in excess of 650 kg (Collette and Nauen, 1983) and are valued by both recreational and commercial fishers. A commercial Atlantic bluefin tuna fishery operates in the GSL from July to October when Atlantic bluefin tuna aggregate to feed on seasonally-abundant Atlantic herring (*Clupea harengus*) and Atlantic mackerel (*Scomber scombrus*). Atlantic bluefin tuna harvested in the GSL are generally large (age 13 and older; Neilson et al., 2007) which increases their value to recreational and commercial fishers who prefer to catch large fish.

In the North Atlantic Ocean, Atlantic bluefin tuna are fished commercially by fishers from more than 40 countries (National Research Council, 1994). Atlantic bluefin tuna are managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT) as two separate stocks; a western stock that breeds in the Gulf of Mexico and an eastern stock that breeds in the Mediterranean Sea (National Research Council, 1994). The abundance of Atlantic bluefin tuna has been severely reduced since the 1970s (Anon., 2010). Because of the low abundance of Atlantic bluefin tuna they were recently proposed for listing and protection under the Convention on International Trade in Endangered Species (CITES), although the proposal was not accepted by CITES member nations. However, commercial quotas for Atlantic bluefin tuna in

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Canadian waters have been reduced in recent years (http://www.dfo-mpo.gc.ca/decisions/fm-2009-gp/bluefin-thonrouge-0714-01-eng.htm) as managers attempt to allow for the rebuilding of the western stock. The Atlantic bluefin tuna fished in the southern GSL are part of the western Atlantic Ocean stock (Rooker et al., 2008).

Because of conservation concerns over the abundance of Atlantic bluefin tuna, it is important to assess the impact of the development of a C&R fishery for them in the southern GSL. The biological consequences of C&R on many fish species, particularly those accessed in freshwater, have been well studied over the past 20 years (reviewed most recently in Arlinghaus et al., 2007). However, little is known about Atlantic bluefin tuna or other tuna (Skomal and Chase, 2002) as it is logistically difficult to determine post-release mortality for a fast, valuable, oceanic, highly migratory fish (Donaldson et al., 2008). A few studies have examined Atlantic bluefin tuna behaviour and migration after C&R angling and report relatively low rates of mortality for tagged and released fish. These studies generally deal with small numbers of bluefin tuna and involve pop-up archival tags (PATs) that allow researchers to determine if post-release the fish died, did not die, or in the cases that the tags did not report the fate of the fish was left in question (Block et al., 1998, 37 fish tagged, 0 mortality, 2 non-report; Lutcavage et al., 1999, 20 fish tagged, 0 mortality, 3 non-report; Stokesbury et al., 2004, 35 fish tagged, 1 mortality, 3 non-report; Wilson et al., 2005, 68 fish tagged, 1 mortality, 8 non-report; Stokesbury et al., 2007, 6 fish tagged, 0 mortality, 3 non-report; Galuardi et al., 2010, 41 fish tagged, 0 mortality, 5 non-report). These studies were not explicitly designed to evaluate C&R mortality, but simply used angling as a means of catching fish to tag for studies of fish migration and spatial ecology. As such, those data were not obtained under the auspices of a sanctioned fishery and often intentionally used techniques that were intended to minimize fight duration which could result in biased estimates of mortality.

In this study, we examined the rate of mortality caused by an experimental C&R fishery for Atlantic bluefin tuna that mimicked the proposed procedures for the developing C&R fishery in the southern GSL. We used PATs equipped with a pre-release program that caused tags to report when fish mortality occurred. Tags were deployed on Atlantic bluefin tuna caught and released in the southern GSL, off the coast of PEI, Canada. Additional data with respect to hooking location, fish size and fish condition were also recorded while the fish was at large (up to 9 months). This information meets the recommendation of the Standing Committee for Research and Statistics of ICCAT, which asks that Contracting Parties within the Convention Area with recreational fisheries produce estimates of release mortality to facilitate the quantification of fish released alive that subsequently die due to interaction with the fishery (Anon., 2010).

2. Materials and methods

In this study, we attempted to mimic the procedures that would be followed in a recreational C&R fishery in the southern GSL. To do this we notified Captains of commercial Atlantic bluefin tuna fishing vessels who would be given the option to participate in the developing C&R fishery that this study was being performed. We then gave the Captains the option to register for a random draw to select participants. Twenty Captains were chosen to participate in the study. Each Captain employed an angler who was either an experienced commercial Atlantic bluefin tuna fisher or an experienced recreational angler. Two information sessions were held to inform the participants of the theoretical basis for the project, the goal of the study and the procedures to be followed. Also, because the use of circle hooks is mandatory in Canadian Atlantic bluefin tuna sports fisheries, standardized Korean made 16/0 barbless circle hooks with a minor offset (approximately 10°; www.highliner.com) were distributed to be used in the project.

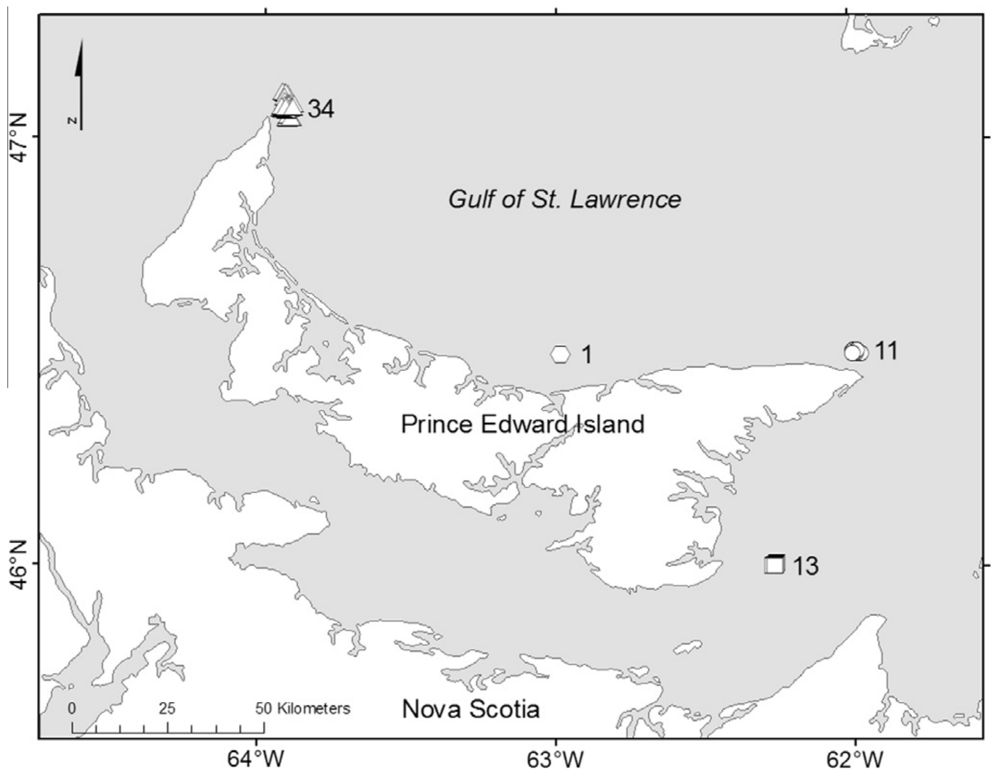

Fig. 1. Number of Atlantic bluefin tuna captured, tagged with pop-up archival tags, and released in areas off Prince Edward Island, Canada, in four different areas during an experimental catch-and-release fishery in late summer 2010.

Atlantic bluefin tuna were fished in four geographical locations in the southern GSL (Fig. 1). All hooks were baited with dead fresh Atlantic herring. Atlantic bluefin tuna were captured using tended line rod and reel. Leader line test used in the experiment varied between 75 kg and 187.5 kg. In each location, Atlantic bluefin tuna were hooked by one of several tuna fishing boats. When a fish was hooked, the fishers on the boat that hooked the fish recorded the time and location from their Geographic Positioning System (GPS) then radioed the fishing boat that had the taggers on board (called here the "tagging boat"). The tagging boat then moved to a position adjacent to the fishing boat that had a fish hooked. The tagging boat crew then threw a rope with a metal clip to attach to the rod to the crew of the boat that had the fish on the line. When the fishing line was tight (fish pulling slightly but not actively swimming away from the boat), the fishers reduced the drag on the reel, pulled the rod out of the rod holder (located in the gunnel) and passed the rod across to the crew on the tagging boat. The butt-end of the rod was then placed in the rod holder on the tagging boat, and the drag setting on the reel was then increased. The crew of the tagging boat then had control of the rod and the fish was fought by an experienced angler until the fish was brought along the side of the tagging boat at the water's surface. When the fish was along the side of the tagging boat, the whole weight of the fish was estimated in pounds (later converted to kg) and the location of the hook was noted.

The fish was tagged by inserting a nylon dart attached to a leader into the musculature on the dorsal side of the fish as close to the base of the second dorsal fin as possible. The aim was to push the dart through the pterygiophores and therefore provide a solid point of attachment. However, as the fish was often thrashing this was seldom accomplished. The dart was speared into the dorsal side of the fish using a 1.52–3.35 m scoping Swobbit Perfect Pole™, with stainless steel bushings and application tips (see Domeier et al., 2005). The umbrella shaped nylon tip was inserted to an approximate depth of 10 cm. A single piece of monofilament (113.6 kg test) connected the nylon dart to the Wildlife Computer MK10 PAT in standby mode by a loop and crimp at each end. The information portion from a spaghetti tag (Floy™ Manufacturing Ltd.) was inserted inside clear shrink wrap so that the tag leader would provide the contact and serial numbers associated with the tag. After the fish was tagged where possible the hook was removed from the fish's mouth by inserting a loop of thin rope over the sharp end of the hook, cutting the fishing line, and pulling it through the wound. If not, the leader was cut as close to the hook as possible, and the fish was released. General condition of the fish at time of release was also noted (i.e. relative level of vigour and ability to maintain equilibrium and swim away from the boat) as indicators of reflex impairment (Davis, 2009). Fight times were defined as the time from the fish taking the hook to the time that the fish was released from the side of the vessel post tagging. When necessary and possible at time of release, individual fish were briefly towed beside the boat to revive the fish to a point where it could maintain equilibrium.

One PAT was attached externally to each captured fish. The tags acquired data at 30-s intervals for pressure (depth), ambient temperature and ambient light levels. Data were summarized into 4-h bins prior to data transmission to the ARGOS satellite system. Summary data for each 4-h bin included percent distributions of time-at-depth and time-at-temperature. Temperature–depth profiles were calculated by dividing maximum depth during each interval into eight evenly-distributed depths, including surface and maximum depth. Minimum and maximum values for temperature were archived and transmitted for each of these depths. The tags were programmed to activate when the pressure sensor measured a depth of 10 m.

Tags were equipped with pre-release software. Pre-release was determined when depth measurements did not vary by more than ±2.5 m for a period of 24-h. Therefore, if the fish suffered mortality and was immobile on the substrate the tag would detach, float to the surface and report. Or, if the tag detached from the fish due to a weak attachment point and was floating at the surface, the tag would report. By examining the pressure (depth) data in the hours prior to pre-release it was determined if the fish was alive at the time of the tag pre-release, or if the fish had suffered mortality.

This study focused on the first 30 days post tag deployment. Past PAT tagging studies on Atlantic bluefin tuna reported that mortality due to C&R occurred soon (m–h) after tagging (Stokesbury et al., 2004; Wilson et al., 2005). Therefore, if mortality occurred after the first 30 days post tag deployment it would be likely that the mortality was not due to the catch-and-releases procedure employed during this study. Due to the relatively small scale of geographical movements of fish over 30 days, and the error associated with back calculated light based geolocation (Teo et al., 2007) we report locations based on GPS readings at time of tagging, and for Doppler-estimated positions for tags that pre-released and reported (ARGOS location class 3 root mean square error <150 m). Tags that reported after the 30 day period were noted as the successful functioning of these tags was relevant to the soundness of the estimates of mortality. We assumed that if the tag detached from a live Atlantic bluefin tuna there would be variation in the mean maximum depth indicated for the 24-h period immediately before the tag reported indicative of a living fish moving vertically through the water column.

Sample size was determined by a simulation study performed prior to data collection. Since it was not known in advance exactly what information would be available for potential predictors, a hypothetical logistic regression model was considered with parameter settings for the generating model based on data from Lutcavage et al. (1999). The generating model was

$$\log[p/(1-p)] = 8.20 - 2.81L + b_2(F - 30)$$

where L was the length of the fish in metres and F the fight time in minutes. In the simulations, lengths were generated from a normal distribution with mean 2.12 m and standard deviation 0.21. Fight times were generated uniformly in the interval 0 through 1 h. Over 1000 simulation, the resulting proportions of time the null hypothesis that $b_2 = 0$ was rejected at the 5% level for differing sizes of n are

b_2[a]	n					
	50	75	100	125	150	1000
0.00	18	29	48	41	45	51
−0.02	37	86	112	143	165	792
−0.03	148	279	353	493	529	1000
−0.05	318	569	712	833	872	1000
−0.06	562	826	925	979	992	1000
−0.08	760	945	993	996	1000	1000

[a] Numbers are rounded to two digits.

This suggested that large effects of fight time on mortality might be detectible with a sample size of approximately 50 fish.

To determine potential predictors of mortality among the information collected, we fit a logistic regression model to the data of the form:

$$\log[p/(1-p)] = b_0 + b_1F + b_2W + b_3S$$

where p is the probability of mortality, F is the fight time, W is the weight of the fish and S is the sea-surface temperature.

Mortality rate was calculated in three ways: (1) by dividing the number of post-release mortalities by the total number of fish tagged, (2) by dividing the total fishing induced mortalities by the total number of fish caught, and (3) by dividing the total fishing induced mortalities by the total number of tags that reported. Confidence intervals were obtained by obtaining a normal-theory confidence interval for the logistic transform of the rate and then transforming back.

3. Results

A total of 60 Atlantic bluefin tuna were caught and 59 were tagged with PATs in four locations off the coast of PEI in late summer 2010 (Table 1). One bluefin tuna appeared to be moribund when examined alongside the vessel (i.e., immediate mortality). The fish was hooked in the jaw but it was clear from markings on the fish that the line had been wrapped around the tail such

Table 1
Information from the tagging of 59 Atlantic bluefin tuna that were tagged with pop-up archival tags in an experimental catch-and-release fishery off Prince Edward Island, Canada in 2010.

#	Deployment information								
	Tag #	Programmed pop-off date (dd/mm/yy)	Date (dd/mm/yy)	Time (AST)	Lat. (°N)	Lon. (°W)	Fight time (m)	Est. weight (kg)	SST (°C)
1	899	05/01/11	28/08/10	8:08	47.093	63.905	15	307	18.7
2	900	05/01/11	28/08/10	11:31	47.111	63.922	10	386	19.0
3	901	05/01/11	28/08/10	11:55	47.114	63.932	14	273	19.0
4	902	06/01/11	28/08/10	14:14	47.116	63.939	28	386	19.1
5	903	06/01/11	28/08/10	15:25	47.113	63.929	20	455	19.3
6	904	06/01/11	28/08/10	16:34	47.104	63.931	11	227	19.6
7	905	09/01/11	29/08/10	9:34	47.056	63.906	20	455	18.2
8	906	09/01/11	29/08/10	10:24	47.054	63.920	15	318	20.5
9	907	09/01/11	29/08/10	11:50	47.055	63.925	20	295	19.0
10	908	10/01/11	29/08/10	15:25	47.060	63.921	18	261	19.3
11	910	10/01/11	30/08/10	10:17	47.089	63.920	10	182	19.3
12	911	10/01/11	30/08/10	11:13	47.077	63.921	12	227	19.3
13	873	10/01/11	31/08/10	6:34	47.090	63.914	08	170	18.8
14	876	10/01/11	31/08/10	6:55	47.087	63.933	45	386	18.8
15	877	10/01/11	31/08/10	7:24	47.090	63.923	32	307	19.5
16	871	09/01/11	31/08/10	7:42	47.088	63.932	36	330	19.5
17	870	09/01/11	31/08/10	7:53	47.094	63.931	09	227	19.5
18	875	10/01/11	31/08/10	8:56	47.087	63.899	50	386	18.8
19	868	09/01/11	31/08/10	9:08	47.085	63.928	48	386	19.5
20	872	10/01/11	31/08/10	9:15	47.084	63.913	20	352	18.2
21	909	06/01/11	31/08/10	9:34	47.085	63.918	29	377	19.5
22	96058	06/01/11	31/08/10	10:21	47.078	63.912	11	193	18.2
23	99150	06/01/11	31/08/10	11:01	47.082	63.928	10	114	19.0
24	866	09/01/11	31/08/10	11:25	47.078	63.931	20	341	19.3
25	867	09/01/11	31/08/10	11:26	47.084	63.930	63	307	19.5
26	864	06/01/11	31/08/10	12:25	47.056	63.909	15	341	19.3
27	99151	06/01/11	31/08/10	12:38	47.072	63.922	68	423	19.5
28	93554	05/01/11	31/08/10	13:05	47.074	63.938	35	295	19.3
29	96080	05/01/11	31/08/10	14:00	47.077	63.944	20	375	19.6
30	96084	05/01/11	31/08/10	14:20	47.079	63.939	30	409	19.6
31	96083	05/01/11	31/08/10	15:00	47.082	63.940	15	386	19.6
32	96082	05/01/11	01/09/10	10:40	47.082	63.923	10	227	18.7
33	96081	05/01/11	01/09/10	11:06	47.079	63.928	06	182	18.7
34	865	06/01/11	08/09/10	6:10	46.507	61.995	20	216	16.7
35	893	09/01/11	08/09/10	6:12	46.014	62.257	29	295	17.5
36	869	09/01/11	08/09/10	7:00	46.501	61.967	60	318	18.3
37	885	06/01/11	08/09/10	7:15	46.502	61.985	65	432	16.7
38	891	09/01/11	08/09/10	7:42	46.006	62.265	72	341	17.5
39	896	10/01/11	08/09/10	7:48	46.006	62.268	50	273	17.3
40	890	09/01/11	08/09/10	8:45	46.008	62.267	28	318	17.5
41	888	06/01/11	08/09/10	8:54	46.008	62.267	48	364	17.5
42	898	10/01/11	08/09/10	8:54	46.008	62.267	48	364	17.5
43	886	06/01/11	08/09/10	9:45	46.006	62.265	51	295	17.5
44	887	06/01/11	08/09/10	10:00	46.010	62.263	36	364	16.1
45	884	06/01/11	08/09/10	10:31	46.502	61.985	62	386	16.7
46	889	06/01/11	08/09/10	10:37	46.010	62.263	15	318	17.4
47	897	10/01/11	08/09/10	10:38	46.009	62.263	19	273	17.5
48	912	10/01/11	08/09/10	11:37	46.012	62.259	59	318	17.4
49	883	05/01/11	08/09/10	11:42	46.504	61.994	63	250	16.1
50	892	09/01/11	08/09/10	12:57	46.506	61.995	27	295	16.1
51	882	05/01/11	08/09/10	14:40	46.509	61.990	79	318	16.1
52	895	09/01/11	08/09/10	9:16	46.502	61.991	15	136	17.2
53	874	10/01/11	09/09/10	9:52	47.080	63.903	25	307	18.2
54	879	05/01/11	09/09/10	9:57	46.006	62.271	48	364	17.5
55	878	05/01/11	09/09/10	10:00	46.503	62.986	15	182	17.2
56	880	05/01/11	09/09/10	10:07	46.006	62.265	47	341	17.5
57	881	05/01/11	09/09/10	10:15	46.006	62.265	56	364	17.5
58	894	09/01/11	09/09/10	11:15	46.508	61.982	50	250	17.2
59	913	10/01/11	09/09/10	13:38	46.502	61.996	66	409	16.7

that the fish was reeled in tail first. As this fish was already dead, it was not tagged.

Two of 59 Atlantic bluefin tuna died after they were captured, tagged and released. Four tags failed to report within the life of the project (246 days post-release). The calculated rate of mortality was 3.4%. A binomial adjustment for the finite ($n = 59$) sampling, gives a 95% confidence interval for the mortality rate as 0.8–12.6%. The fit of the logistic regression model

$$\log[p/(1-p)] = b_0 + b_1F + b_2W + b_3S$$

gave the following table of estimated coefficients, standard errors and p-values for the null hypothesis that the corresponding coefficient is 0.

	Estimate	SE	p-Value
b_0	−0.008	14.387	1.000
b_1	0.042	0.048	0.391
b_2	0.002	0.013	0.881
b_3	−0.322	0.778	0.679

Considering the coefficient for fight time in the logistic regression, the estimated increase in the log odds of mortality corresponding to a 20 min increase in fight time, holding all other variables fixed, was 0.042 times 20 or 0.84. Thus, for a fish with the estimated 3.4% chance of mortality, increasing fight time by 20 min was expected to increase the chance of mortality to 7.4%. All of the standard errors were large however, and none of the tests gave significant results.

In a developing recreational fishery, novice anglers will often participate. Novice anglers may be less skilled at keeping fishing lines tight when fighting Atlantic bluefin tuna with rod and reel. In this case tail wrapping of bluefin tuna may occur. Therefore we have calculated mortality rates including the tail wrapped tuna (3 mortalities out of 60) and also calculated a ratio where tags that did not report (4 of 59) were removed from the sample (3 mortalities out of 55). These calculations provide mortality estimates of 5.1% (95% C.I. = $1.6\% < u < 14.4\%$) and 5.6% (95% C.I. = $1.8\% < u < 15.6\%$) respectively and may be viewed as more realistic estimates than the 3.4%, which is likely a best case scenario.

Fight times were variable (Fig. 2) and were correlated with estimated whole weight (Fig. 3) and sea surface temperature (Fig. 4), but the proportion of observed variation in fight time accounted for by those variables was small ($R^2 = 0.18$ and 0.21, respectively).

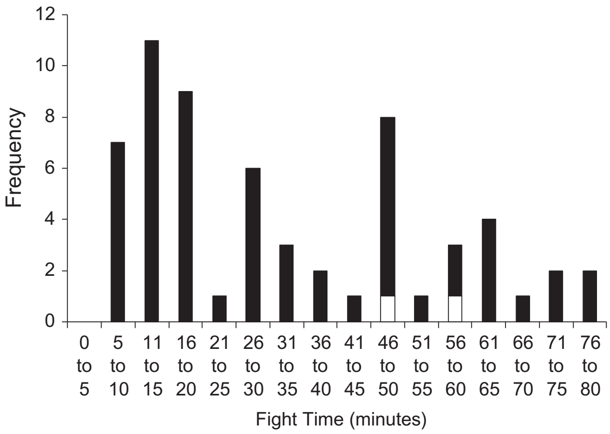

Fig. 2. Fight times for Atlantic bluefin tuna captured, tagged and released in an experimental recreational catch-and-release fishery off Prince Edward Island in 2010, black area represents fish that survived catch-and-release, white area represent fish that suffered mortality.

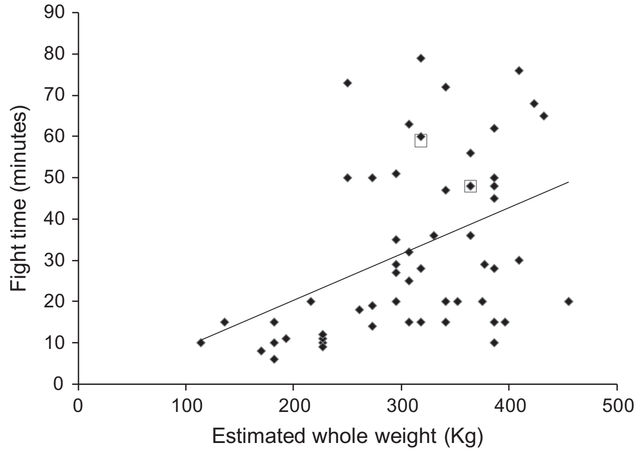

Fig. 3. Relationship of fight time to estimated whole weight for 59 Atlantic bluefin tuna captured, tagged and released in an experimental recreations catch and release fishery off the coast of Prince Edward Island, Canada, in 2010, (black fill ◇ = fish that survive catch-and-release, transparent fill □ = mortalities; $y = 0.1116x - 1.9151$; $R^2 = 0.181$).

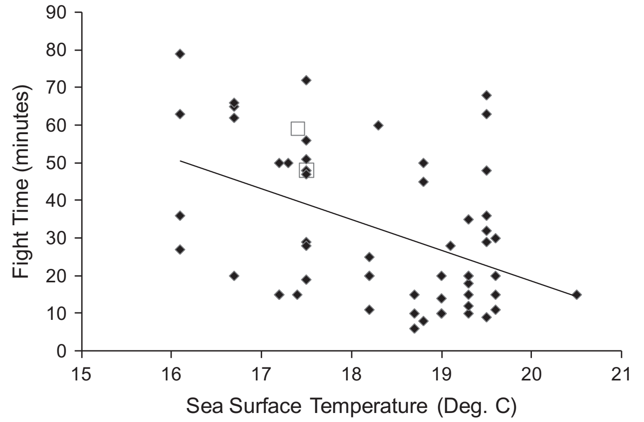

Fig. 4. Relationship of fight time to sea surface temperature for 59 Atlantic bluefin tuna captured, tagged and released in an experimental recreations catch and release fishery off the coast of Prince Edward Island, Canada, in 2010 (black fill ◇ = fish that survive catch-and-release, white fill □ = mortalities; $y = -8.2x + 182.62$; $R^2 = 0.211$).

The fight time for fish with estimated whole weights that were less than 250 kg ($N = 12$, $X = 11$; SD = 3.73) was significantly (t-test, $p < 0.0002$) less than for fish whose estimated whole weight was greater than 250 kg ($N = 47$, $X = 38$, SD = 19.88). The two fish that suffered mortality were fought for 48 and 59 min (Fig. 2). These fight times were longer than the mean. However, more than 18% of the fight times among survivors were at least as long as the longer of the two fight times for the two mortalities.

All fish were hooked superficially (i.e., jaw), so no statistical analyses were conducted using hook placement as a variable. Bleeding at the hook wound site was negligible.

During the 30 day period post deployment for each tag, nine tags detached from the Atlantic bluefin tuna carrying the tag, and reported data to the ARGOS satellite system (Table 2). Of the nine tags that reported, seven tags detached prematurely from live fish and transmitted data (Fig. 5). Data from two of the nine tags that released indicated that the fish suffered mortality as they remained at the same depth for the 24-h period prior to the tag initiating pre-release (Fig. 6). This pattern was demonstrated by tags number 898 and 912. Both fish that died sank to the substrate at 48 m, and

Table 2
Pop-up archival tags that reported within 30 days of tag deployment.

#	Tag #	Date (dd/mm/yy)	Lat. (°N)	Lon. (°W)	Tag depth at initiation of pre-release (m)	Out (d)	Distance traveled (km)[a]
1	910	05/09/10	46.731	61.033	0	6	223
2	871	07/09/10	46.978	64.208	0	7	24
3	870	29/09/10	44.120	62.385	0	29	830+
4	898	10/09/10	45.979	61.663	48	2	47
5	889	10/09/10	46.226	61.784	0	2	44
6	912	10/09/10	45.977	62.116	48	2	12
7	869	14/09/10	46.896	61.280	0	6	112
8	881	02/10/10	43.060	61.750	0	23	702+
9	894	02/10/10	47.012	60.629	0	23	117

[a] Distances are straight line except in cases where animals traveled around points of land (indicated with a "+").

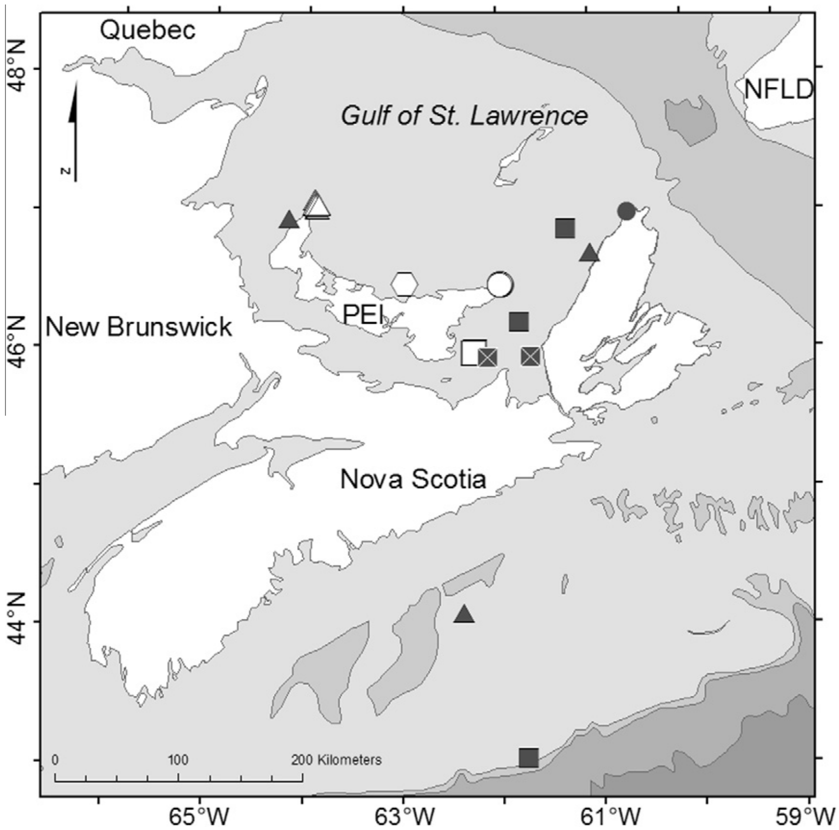

Fig. 5. Position of fish release (white shapes) and pop-up satellite tags that reported data to the ARGOS satellite system (black shapes) within 30 days of deployment on Atlantic bluefin tuna in areas off Prince Edward Island, Canada, during an experimental catch-and-release fishery in late summer 2010 (black shape with white *X* = tags that detached and reported from dead fish; solid black shape = tags that detached and reported from live fish).

remained there until the PAT pre-release program was initiated and the tag detached, floated to the surface and reported. There was nothing particularly anomalous with those two fish with respect to condition at time of capture or release, fish size or water temperature (Figs. 2–4). Depth by time profiles for a typical fish that did not suffer mortality and for a fish that suffered mortality directly after release (Fig. 6) show how clearly a mortality event is demonstrated in the depth data.

4. Discussion

This study provides the first quantitative estimates of post C&R mortality for angled Atlantic bluefin tuna. The calculated mortality rate for Atlantic bluefin tuna captured, tagged and released in the experimental C&R recreational fishery was 3.4%. The estimate may represent a best case scenario as during this project all predicted standard operating procedures were followed. Estimates of mortality that include the tail wrapped fish (incidental mortality; mortality rate of 5.1%) and removal of tags from the sample that did not report before or on their programmed report data (mortality rate of 5.6%) may be more applicable to the developing C&R fishery. For context, Bartholomew and Bohnsack (2005) reviewed C&R mortality rates from 53 studies on salmonids and determined a post release mortality rate of 18% (range 0–95%). Mean mortality varied greatly by species and within species (Bartholomew and Bohnsack, 2005). Muoneke and Childress (1994) suggested that mortality of less than 10% could be considered "low". However, they reported that the level of mortality that is acceptable for a given species will depend largely on its life-history, fishing effort, population size and capture efficiency.

For the calculated mortality rates to be applicable to a C&R recreational fishery for Atlantic bluefin tuna in the southern GSL, that fishery must be executed in a similar fashion to the fishing

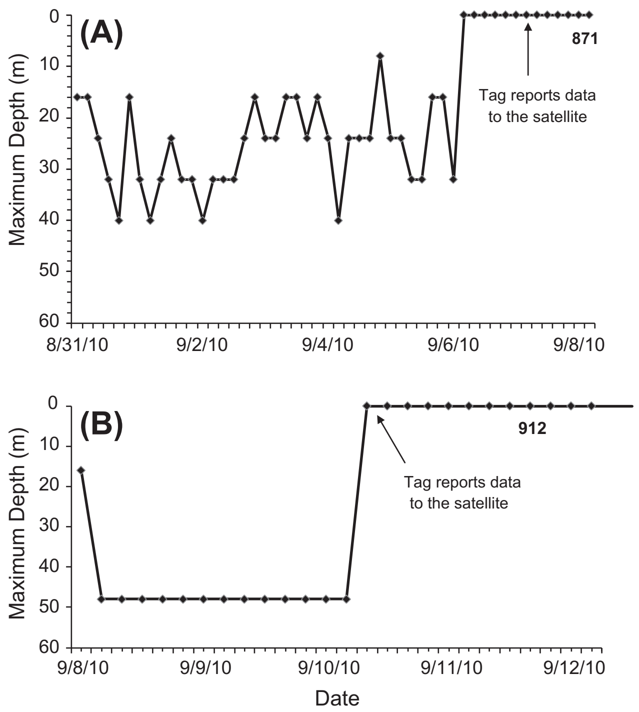

Fig. 6. Depth profiles for Atlantic bluefin tuna captured, tagged and released off the coast of Prince Edward Island in late summer 2010, data are maximum depth measurements per 4 h bins, from PAT tags attached to the bluefin tuna: (A) Tag 871 released prematurely from a live bluefin tuna and floated on the surface for 24 h prior to report; (B) Tag 912 pre-released from a dead bluefin tuna after the tuna remained at 48 m for 24 h.

performed in this study. For example, the geographical (e.g., depth) and physical oceanographic (e.g., temperature) conditions must be similar to those present in the southern GSL in late summer early autumn. Moreover, the gear type (e.g., hook style and being barbless), gear strength and fight times must be similar to those used here. The portion of the fight time used for the actual tagging of the fish at the side of the vessel was generally short and although not measured explicitly seemed consistent. The time spent tagging the fish would likely be similar to the amount of time needed to take a photograph of the fish at the side of the boat as would be common in a catch and release fishery. Finally, the fish must not be exposed to the air and must be released beside the boat after minimal handling and any physical damage from tag implantation events must be minimized to prevent changes in behaviour (Hoolihan et al., 2011) or condition that may be an artefact of the tagging procedure. Any significant deviations in fishing gear, environment or fisher behaviour could alter mortality levels. In some cases, knowledge about the factors that contribute to mortality can be used to generate regulations or educational materials that can be used to reduce mortality (Cooke and Suski, 2005). In the case of this study, we did not identify anything particularly unique about the two fish that perished after release.

Anatomical hooking location is the single most important factor in influencing the outcome of a C&R event for fish (Bartholomew and Bohnsack, 2005). Fish that are deeply hooked tend to experience greater levels of bleeding, experience damage to vital organs (e.g., liver, heart), and subsequently experience high rates of immediate and short-term mortality (reviewed in Bartholomew and Bohnsack, 2005; Cooke and Suski, 2005; Arlinghaus et al., 2007). In this study, fish were captured using barbless circle hooks. Circle hooks have been shown to result in shallower hooking (i.e., hooking the jaw) and thus reduced levels of injury and mortality relative to conventional hook styles in a wide range of species (reviewed in Cooke and Suski, 2005). In this study, all fish captured were hooked in the corner of the mouth, a finding consistent with earlier work on Atlantic bluefin tuna where circle hooks yielded higher post-release survival than fish captured with J-hooks (Skomal et al., 2002). The circle hooks in this study were offset by 10°. In some fisheries, offset hooks can actually reduce the conservation benefits of circle hooks (Cooke and Suski, 2005; Prince et al., 2002). As such, we would recommend not using hooks offset by more than 10° as used in the current study. Hooks used in this study were also barbless. Although barbless hooks do not tend to reduce mortality directly (Cooke and Suski, 2005), they do facilitate rapid hook removal which can reduce handling time and associated stress (Cooke et al., 2001). Even with barbless hooks, roughly half of the fish were released by cutting the line near the hook to minimize danger for the fish and the fisher. Hook retention may represent a source of secondary longer term mortality (Borucinska et al., 2002) and therefore hooks should be removed when practical.

We are confident that the mortality of the Atlantic bluefin tuna that was tail wrapped was a result of our tagging protocol. When the rod was being passed from the fishing boat to the tagging boat the fishing line went slack and we assume that at that time the tuna became tail wrapped. This occurs when a tuna is swimming directly away from the fishing boat. The fishing line that is connected to the hook runs back along the flank of the tuna and through the water back to the rod and reel. Occasionally, if the line becomes slack, the fishing line wraps and cinches around the tuna's tail. The tuna is then pulled backward through the water to the vessel. Bluefin tuna are ram ventilators and therefore must swim forward to ventilate their gills. A tuna that becomes tail wrapped dies very quickly. Given that this fish died as a result of the tagging procedure, not as a result of the C&R fishing procedure that we were attempting to mimic, this tuna was excluded from our formal estimate of mortality. Nonetheless, if the recreational C&R fishery were to attract novice anglers, the potential for tail wrapping does exist so a mortality estimate was calculated that included this mortality. Given that tail wrapped fish are typically landed in poor condition (or dead), it would be relatively easy to monitor the frequency with which tail wrapping has occurred and to adjust management activities accordingly.

As there were only two mortalities of tagged fish in this study fight time and mortality were not significantly related. However, longer fight times are typically associated with greater levels of physiological disturbance (e.g., Skomal and Chase, 2002; Cooke et al., 2008) which can delay post-release recovery and in some cases lead to death (Wood, 1991). The increase in the mean and variance of fight time for larger fish indicates that when fish are smaller they can be overpowered by the angler and the fight times can be kept short. However, when the fish are large the fight time depends on the strategy used by the angler to catch the fish, and by the fish to attempt to avoid capture. Given that the recreational C&R fishery would see tourists of varied experience and physical strength and stature involved in the fight, there would be some expectation that the vessel captain/guide would monitor the fight and at times intervene if the fight time was to become protracted. This highlights the need for strong leadership by Captains participating in this fishery, and strong governance and oversight by managerial bodies. Only by adhering to standard operating procedures and by taking care to conserve, as much as possible, the Atlantic bluefin tuna resource will this developing industry go forward in a sustainable and productive manner.

To our knowledge, the results presented here represent the first estimates of Atlantic bluefin tuna post-release mortality in recreational fisheries. They are also a good example of non-traditional applications for pop-up archival tags, which are more typically used for studies of movements and migrations.

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