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Review

Global overview of the major constituent-based billfish tagging programs and their results since 1954

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Abstract. Release and recovery files from the world's five major constituent-based billfish (Istiophoridae) tagging programs were assembled into a single composite database. Data sources included the National Marine Fisheries Service's (NMFS) Cooperative Tagging Center (MIA) in the Atlantic Ocean, the NMFS's Cooperative Billfish Tagging Program (LJA) in the Pacific and Indian Oceans, the Australian Cooperative Tagging Program in the Pacific and Indian Oceans, the New Zealand Cooperative Game Fish Tagging Program in the Pacific Ocean, and The Billfish Foundation's (TBF) tagging program in the Atlantic, Pacific and Indian Oceans. Results for the main target species, including black marlin (*Makaira indica*), blue marlin (*Makaira nigricans*), white marlin (*Tetrapturus albidus*), striped marlin (*Tetrapturus audax*) and sailfish (*Istiophorus platypterus*) were compared and contrasted based on species, ocean body and tagging program. A total of over 317 000 billfish have been tagged and released, and 4122 have been recovered since 1954. Tag recovery percentages were generally higher for a recently developed double-barb nylon anchor tag compared with the typically used stainless steel dart tag. Greatest distances moved were largest for blue marlin and black marlin, followed by striped marlin, white marlin and sailfish. The TBF program had the highest tag recovery percentages for white marlin (2.4%) and blue marlin (1.7%), whereas the MIA program had the highest percentage recovery for sailfish (1.8%). The LJA program had the highest recovery percentages for black marlin (1.9%) and striped marlin (1.4%). The annual number of releases and recoveries for each target species tended to increase over the time series, particularly during the last decade. Cyclic annual movement patterns and/or seasonal site fidelity were evident for black marlin and white marlin. The data suggest that tag recovery percentages can be affected by tag type, reporting rate, localized fishing activities, outreach activities, and a variety of logistical issues indirectly related to size of ocean body. The efficiencies of the tagging programs are compared and recommendations are made to improve the programs. The composite tagging database provides the opportunity for a more comprehensive evaluation of the data and tagging programs than has previously been possible by examining the individual programs in isolation. The main advantage of constituent-based tagging programs is that large numbers of billfish can be tagged at a minimum cost. The main drawbacks are a lack of control over the tagging event and return of recovery data. Constituent-based tagging programs provide essential data on billfish movement and biology, and should be expanded and improved to meet the increasing need for this information.

Introduction

Major recreational fisheries for billfishes (*Istiophoridae*) exist throughout the world's tropical oceans, thus establishing billfishes as among the most sought-after big gamefish (IGFA 2001). Billfish species are large, relatively rare, highly mobile predators that are sparsely distributed over extensive geographical ranges (Prince and Brown 1991). Because of these characteristics, billfish are often referred to as 'rare event species' and this situation results in a conspicuous lack of information on their movements and distribution patterns, as well as their basic life histories (Prince and Brown 1991). This lack of information greatly hinders attempts to conserve and manage billfish stocks on a sustainable basis (ICCAT 2001*a*). In order to address some of these information deficiencies,

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constituent-based tagging programs (CBTPs) have been developed, which rely on recreational and commercial fishers to voluntarily tag, release and recover billfish. Constituent-based tagging programs have been immensely popular with recreational constituents and, in almost all cases, are the only logistically and economically feasible way to tag large numbers of billfish (Pepperell 1990*a*; Fisher and Ditton 1992).

This paper represents the first attempt to summarize and compare the results of the five major CBTPs currently operating worldwide. The tagging programs examined here are restricted to those that identified billfish as among their primary target species and have operated ocean-wide programs for at least 10 years. The five major programs included in this overview are: (*i*) the National Marine Fisheries Service (NMFS) South-east Fisheries Science Center's Cooperative Tagging Center in Miami, Florida, USA (MIA); (*ii*) the NMFS South-west Fisheries Science Center's Billfish Tagging Program, La Jolla, California, USA (LJA); (*iii*) the New South Wales Fisheries Tagging Program, Australia (NSW); (*iv*) the New Zealand Cooperative Game Fish Tagging Program (NZL); and (*v*) the Billfish Foundation Tagging Program (TBF), Fort Lauderdale, Florida, USA. Although there are other billfish tagging activities at other locations, the five examined here represent the vast majority of large-scale constituent-based tagging efforts that target billfish worldwide. The objectives of this paper were to: (*i*) assemble in common format a composite worldwide conventional billfish tagging database from the five major programs; (*ii*) compare tagging results by target species, ocean body and tagging program; and (*iii*) gain insight into the efficiency of individual tagging program operations by evaluating the advances in conventional tagging technology and their potential effects on tag recovery percentages. Each agency kindly agreed to provide its historical release and recovery billfish tagging databases in an effort to gain a global perspective of billfish life history, movement and the fisheries with which they interact. From the onset, making estimates of population dynamics parameters was deemed beyond the scope of this paper.

Brief history of the five major billfish tagging programs

A historical review of each CBTP is presented in chronological order. A common objective among the five programs is to promote the concept of tag and release to fishers, while also gaining basic information on: (*i*) movement and migration patterns; (*ii*) age, growth and longevity; and (*iii*) stock structure or defining management units. Although some of the programs targeted other species in addition to billfish, this paper focuses only on species belonging to the family Istiophoridae, namely, black marlin (*Makaira indica*), blue marlin (*Makaira nigricans*), white marlin (*Tetrapturus albidus*), striped marlin (*Tetrapturus audax*), sailfish (*Istiophorus platypterus*), longbill spearfish (*Tetrapturus pfluegeri*), and shortbill spearfish (*Tetrapturus angustirostris*).

South-east Fisheries Science Center Cooperative Tagging Center

The Cooperative Tagging Center (known as the Cooperative Game Fish Tagging Program prior to 1995) was started in the USA in 1954. Initiated at Woods Hole Oceanographic Institute by Dr Frank Mather, this program (MIA) involves both recreational and commercial fishing constituents, as well as scientists for release and recovery activities (Scott *et al.* 1990). The program was transferred in 1978 to the South-east Fisheries Science Center in Miami, Florida and, historically, has supplied constituents with tagging equipment at no cost. The MIA program is the longest operating CBTP of its type in the world (Scott *et al.* 1990), and the structure and operation of this program has been used as a model for the development of other CBTPs (Miyake 1990; Pepperell 1990*a*).

The stainless steel dart tag (model FH69; Floy Tag Manufacturing Company) was used as the primary tag from 1954 to 1980; followed by the modified stainless steel dart tag (R series; Scott *et al.* 1990) through 1995, when the MIA Program switched over to the double-barb nylon anchor tag (HM series). The change to the double-barb nylon anchor tag was made in response to the higher retention qualities found with this tag compared with the stainless steel dart tag (Prince *et al.* 2002). From 1954 to 1990, MIA used a monetary reward for recoveries (US$10). However, since 1990, embroidered caps were given as incentive rewards for most recoveries. In certain areas of the Atlantic (i.e. Venezuela), monetary rewards are still used. In addition, the International Commission for the Conservation of Atlantic Tunas (ICCAT) holds an annual lottery reward (US$500) for tag recoveries of temperate tunas, tropical tunas and billfish (Miyake 1990). The development of the ICCAT Enhanced Research Program for Billfish in 1987 actively expanded the MIA program to include the East Atlantic (Prince and Brown 1991). The MIA program also participates in the Axelson Fishing Tackle Company (AFTCO) incentive award program started in 1989. The AFTCO gives annual awards for the largest numbers of highly migratory fishes tagged, including billfish. More recently, ICCAT developed a tag recovery network in 1996 to assist with recovery of archival and conventionally tagged tuna and billfish in the Atlantic Ocean and Mediterranean Sea (Prince and Cort 1997). Further information on the MIA Program can be found by referring to the SEFSC web site at: http://www.sefsc.noaa.gov (accessed July 2003).

Southwest Fisheries Science Center's Billfish Tagging Program

Based in La Jolla, California, USA, the South-west Fisheries Science Center's billfish tagging program (LJA) began in 1963 as the US west coast counterpart of the MIA Program (Squire and Nielsen 1983). The LJA program relies mainly on recreational billfish anglers for release activities, although commercial fishers are encouraged to participate. Tagging supplies are distributed at no cost to fishers in the Pacific and Indian Oceans. The stainless steel dart tag (model FH-69 or H series tags; Floy Tags) was the main tag used in the program through 1987, followed by the Hallprint steel dart tag (A and W series) used between 1987 and 1999. In late 1999, the LJA program began using the double barb nylon anchor tag developed by TBF and MIA.

Until about 1985, the reward for returning data on a recovered billfish was US$5. Since 1985, embroidered caps have been provided to anglers and vessel captains who report tagged billfish. All participants in the LJA billfish tagging program also receive the annual publication of the Billfish Newsletter. Anglers and captains tagging billfish are acknowledged and their names listed each year in the newsletter. Participants in the LJA program have also been recognized in the AFTCO incentive award program since the mid 1990s. Information on the LJA tagging program can be found by referring to the SWFSC web site at: http://www.swfsc.nmfs.noaa.gov (accessed July 2003).

New South Wales Game Fish Tagging Program

The New South Wales (NSW), Australia, Game Fish Tagging Program was established in 1973 primarily to recruit recreational fishers to assist in gathering research data (Pepperell 1990*a*). The NSW Program supplies tags and equipment free of charge to members of registered fishing clubs affiliated with the Game Fishing Association of Australia and/or the Australian National Sport Fishing Association. The program operates through 177 fishing clubs throughout Australia, but most are concentrated along the east coast (138 clubs). Virtually 100% of releases are made by recreational fishers. Two types of tags have been used historically in the NSW program: the single-barb nylon dart tag used on the smaller target species, and the stainless steel anchor dart tag used on larger fish including billfish and sharks (Pepperell 1990*a*). The NSW supplies tagging kits to anglers on request or to tagging officers of clubs who distribute the kits to members. No monetary rewards have ever been offered for recovery information, rather, certificates and jacket patches have been offered as incentives for both tagging and recovery information. All the large saltwater sport fishing tournaments currently held in Australia are either tag and release only, or have a large tagging section format within them. Further information on the NSW Game Fish Tagging Program can be found by referring to: http://www.fisheries.nsw.gov.au (accessed July 2003).

New Zealand Cooperative Game Fish Tagging Program

The Ministry of Agriculture and Fisheries initiated the New Zealand Cooperative Game Fish Tagging Program (NZL) in 1975, following requests from game fishing clubs (Murray 1990). Billfish have been tagged predominantly by recreational fishers, but some commercial tuna longline fishers have participated in recent years. Tags are supplied free of charge to recreational and commercial fishers who express an interest in tagging billfish. Between 1975 and 1984, stainless steel dart tags (model FH-69; Floy Tags) supplied by the LJA Program were issued (H series). After 1985, the Hallprint stainless steel dart tag has been the primary tag used in the program (G series). Tags made for the NZL Program by Hallprint were modified so that the stainless steel wire used to attach the tag head extended the full length of the tag. This modified stainless steel dart tag has been the primary tag used since December 1996. Since 1988, gamefish anglers and clubs have observed a voluntary minimum size of 90 kg for marlin. From 1975 to 1991, fishers who reported recoveries were given a cash reward (NZ$10). After 1991, printed T-shirts have been offered as incentive rewards. Further information on the NZL Cooperative Game Fish Tagging Program can be found by referring to the Ministry of Agriculture and Fisheries web site at: http://www.fish.govt.nz (accessed July 2003).

Billfish Foundation Tagging Program

The Billfish Foundation (TBF), located in Fort Lauderdale, FL, USA, is a non-profit organization dedicated to billfish conservation worldwide (Peel *et al.* 1998). Its tagging program was initiated in 1990, but unlike the other programs, TBF does charge a fee for tagging equipment and distributes gear through a commercial outlet. Although TBF operates in three ocean bodies, the majority of tagging has taken place in the Atlantic Ocean. From its inception, TBF has had a cooperative agreement with the US National Marine Fisheries Service tagging program in Miami (MIA) to share tagging data and to operate in a manner similar to the MIA Program. The TBF tagging data is routinely transferred to the MIA Program computer database so information can be shared with the scientific community. The TBF has utilized the double barb nylon anchor dart tag (Floy Tag) throughout the history of its program (1990 to present). This double barb nylon anchor dart tag was jointly developed by the TBF and MIA programs (Prince *et al.* 2002). Participants involved in tagging are largely recreational anglers and captains, but some commercial fishers also participate. Those responsible for reporting recoveries are sent a complete history of the tagged fish and a TBF T-shirt as a reward. The TBF tagging program participants have been recognized in the AFTCO award program and the ICCAT annual lottery since the mid 1990s. Further information on the TBF tagging program can be found by referring to the TBF web site at: http://www.billfish.org (accessed July 2003).

Materials and methods

Data compilation and quality control

The composite billfish tagging database was compiled from the five major CBTPs (i.e. MIA, LJA, NSW, NZL and TBF). Data included all historic release and recovery information for all Istiophorid species. The data were converted into a single relational database format (Microsoft

Table 1. Numbers of billfish, by species and program, tagged/released and recovered
See text for details on agency (program), calculation of recovery percent (and standard errors), maximum days at-large, and longest distance travelled (km)

Species	Agency	Tagged	Recovered	Percent recovered	Standard error (%)	Maximum days at large	Longest distance travelled
Billfishes (unidentified)	MIA	440	1	0.23	–		
Billfishes (unidentified)	LJA	4266	2	0.05	0.03	419	1387
Billfishes total		4706	3	0.06			
Black marlin	NSW	35 178	213	0.61	0.04	2044	14 556
Black marlin	LJA	3227	62	1.92	0.24	1454	1357
Black marlin	MIA	729	5	0.69	0.31	68	621
Black marlin	TBF	2746	5	0.18	0.08	442	1569
Black marlin	NZL	39	1	2.56	2.53		
Black marlin total		41 919	286	0.68			
Blue marlin	LJA	5303	46	0.87	0.13	1503	8262
Blue marlin	MIA	24 108	220	0.91	0.06	4024	14 893
Blue marlin	NSW	2215	3	0.14	0.08	567	9095
Blue marlin	TBF	21 582	376	1.74	0.09	2706	6765
Blue marlin	NZL	306	3	0.98	0.56		1465
Blue marlin total		53 514	648	1.21			
Longbill spearfish	LJA	3			–		
Longbill spearfish	TBF	753	3	0.40	0.23	1945	1924
Longbill spearfish	NSW	76			–		
Longbill spearfish	MIA	349			–		
Longbill spearfish total		1181	3	0.25			
Sailfish	MIA	65 868	1204	1.83	0.05	6568	3861
Sailfish	NZL	55			–		
Sailfish	NSW	16 370	182	1.11	0.08	1628	2288
Sailfish	LJA	7601	39	0.51	0.08	1717	686
Sailfish	TBF	36 822	498	1.35	0.06	2191	2597
Sailfish total		126 716	1923	1.52			
Shortbill spearfish	NZL	94			–		
Shortbill spearfish	NSW	43			–		
Shortbill spearfish	LJA	985	1	0.10	0.10	34	293
Shortbill spearfish total		1122	1				
Striped marlin	LJA	20 206	273	1.35	0.08	987	6713
Striped marlin	LJA	8256	71	0.86	0.10	467	1773
Striped marlin	TBF	7603	29	0.38	0.07	295	5006
Striped marlin	NZL	9471	49	0.52	0.07		5815
Striped marlin total		45 536	422	0.93			
White marlin	MIA	31 483	577	1.83	0.07	5488	6517
White marlin	TBF	10 883	258	2.37	0.15	2146	5862
White marlin	LJA	13	1	7.69	7.39	125	1675
White marlin total		42 379	836	1.97			
Grand total		317 073	4122	1.30			

MIA, The National Marine Fisheries Service (NMFS) South-east Fisheries Science Center's Cooperative Tagging Center in Miami, Florida, USA; LJA, the NMFS South-west Fisheries Science Center's Billfish Tagging Program, La Jolla, California, USA; NSW, the New South Wales Fisheries Tagging Program, Australia; NZL, the New Zealand Cooperative Game Fish Tagging Program; TBF, the Billfish Foundation Tagging Program, Fort Lauderdale, Florida, USA.

Access) using the following common variables: agency, tag number (alpha numeric code), tag date, species, length and/or weight estimates at release (and related information on unit type and type of measurement), and location (latitude, longitude). For quality control purposes, all datasets were examined for obvious errors before further analysis. For example, scatter plots of initial releases and recoveries were then used to identify outliers. The database used the tag number–agency variables as unique identifiers for each fish; thus only first releases and recoveries were included. Duplicated records of releases (i.e. same tag number–agency) were either eliminated if the tagged species were different, or one was retained if the same tag date and species was represented twice. Records of recoveries were restricted to the first recovery (by tag date), and those for which corresponding release information existed. Records in which the species reported at recovery differed from that reported at release were eliminated. A revised version of the compiled database was then reviewed and corrected by each agency.

Target species

Each of the five major target species (black marlin, blue marlin, white marlin, striped marlin and sailfish) were evaluated in terms of: (*i*) the historical release and recovery by agency; (*ii*) release and recovery by gear; (*iii*) spatial pattern of releases and recoveries on a 5° × 5° latitude by longitude grid; (*iv*) proportion of recoveries versus time at large; (*v*) proportion of recoveries versus minimum distance moved; (*vi*) global pattern of dispersion of straight line plots of recoveries (movement as inferred from linear vectors joining release and recovery locations); (*vii*) the percentage of recoveries by tag type; and (*viii*) longest straight-line distance travelled by each species.

Pattern of release and recovery, time at large and minimum travel distance

To identify the main areas of release and recoveries, records with geographical information were grouped into 5° × 5° latitude by longitude grids and total release and recovery numbers within each grid were computed. Time at large for recoveries was estimated as the number of days between release and first recovery. Minimum travel distance (MTD) was defined as the great circle distance between the release and recovery locations. This distance was estimated using standard algorithms for geodetic solutions assuming the GRS80/WGS84 ellipsoid as reference; only records with complete latitude/longitude information for release and recovery were included (NOAA/NGS 1998: www.ngs.noaa.gov/TOOLS/Inv_Fwd/Inv_Fwd.html; Vincenty 1975). The longest straight-line distance travelled for each billfish species represents the highest ranked MTD estimate. The MTD values do not imply the route taken by the fish.

Tag recovery percentages and tag type

Tag recovery percentages were estimated for each species as the total number of recoveries divided by the total number of releases. To compare tagging performance over the years, annual percent recoveries were estimated for the two main tag types (the stainless steel dart tag and the double barb nylon anchor dart tag). If $R_{A,T,y}$ represents the number of releases from agency A, using tag type T during year y; and $X_{A,T,y,i}$ is the number of first-time recoveries from agency A, using tag type T and year y, over the time period i when $i \geq y$. Given this notation, three annual percent recoveries were estimated and plotted against time.

(*i*) Nominal annual percent recovery (P) as the number of all recoveries from all agencies, tag-type T and year y, divided by the number of releases of that particular year y:

$$P_{T,y} = 100 \times \left[\sum_{A} \sum_{i \geq y} X_{A,T,y,i} \Big/ \sum_{A} R_{A,T,y} \right]$$

(*ii*) The cumulative annual percent recovery as the number of all recoveries since the first year of release (m) of tag type T from all agencies, divided by the accumulated number of releases of tag type T up to year y by all agencies:

$$P'_{T,y} = 100 \times \left[\sum_{A} \sum_{i=m}^{y} X_{A,T,i} \Big/ \sum_{A} \sum_{i=m}^{y} R_{A,T,i} \right]$$

The cumulative percent recovery (P') was used to smooth some of the yearly variation associated with changes in fishing effort.

(*iii*) The pooled annual cumulative percent recovery (P'') for a given billfish species (all tag types and all agencies), as:

$$P''_{y} = 100 \times \left[\sum_{A} \sum_{T} \sum_{i=n}^{y} X_{A,T,i} \Big/ \sum_{A} \sum_{T} \sum_{i=n}^{y} R_{A,T,i} \right]$$

where n is the first year of tag-release.

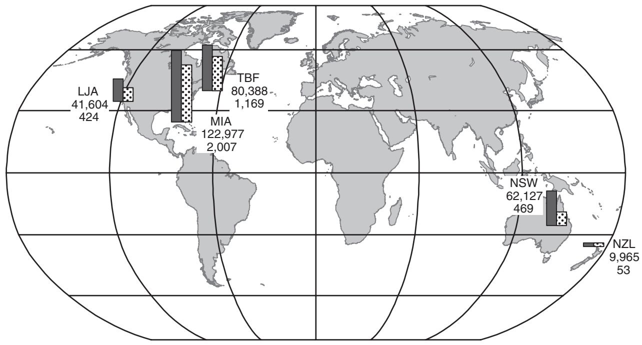

Fig. 1. Total numbers of billfish released (solid bars) and recovered (shaded bars) since 1954 in the five major constituent-based tagging programs.

Results

The worldwide billfish tagging database comprised 317 073 releases and 4122 recoveries for seven species and one 'unidentified billfish' group (Table 1). The overall recovery percentage for all species and agencies combined was 1.3%. In terms of agency release and recovery activities, MIA had the most releases (122 977) and recoveries (2007), followed by TBF (80 388 releases, 1169 recoveries), NSW (62 127 releases, 469 recoveries), LJA (41 604 releases, 424 recoveries), and NZL (9965 releases, 53 recoveries) (Fig. 1). Sailfish was by far the most common billfish species tagged (40%) with 126 716 releases, followed by 53 514 releases for blue marlin (17%), 45 536 releases for striped marlin (14%), 42 379 releases for white marlin (13%), and 41 919 releases for black marlin (13%). Sailfish also had the highest number of recoveries with 1923 tagged fish recovered (47%). This was followed by 836 recoveries for white marlin (20%), 648 recoveries for blue marlin (16%), 422 recoveries for striped marlin (10%), and 286 recoveries for black marlin (7%). Spearfish (*T. angustirostris* and *T. audax*) and unidentified billfish release and recovery data were limited. There were about 2200 spearfish (of both species) released and only four recoveries; thus, data for these species, as well as unidentified billfish, were excluded from further analysis.

Historical trends by major target species

Black marlin

The Cooperative Billfish tagging program at LJA initiated tagging of black marlin off Cairns, Australia, in 1968 (Squire and Nielsen 1983). The LJA effort off Australia was phased out in the late 1970s when the NSW Billfish Tagging Program was formed. Since the late 1970s, the NSW program dominated tag release activities for black marlin (Fig. 2*A*) and had a recovery percent of 0.61% (Table 1). In general, annual release and recovery numbers have increased over time, with historic highs in both occurring in the most

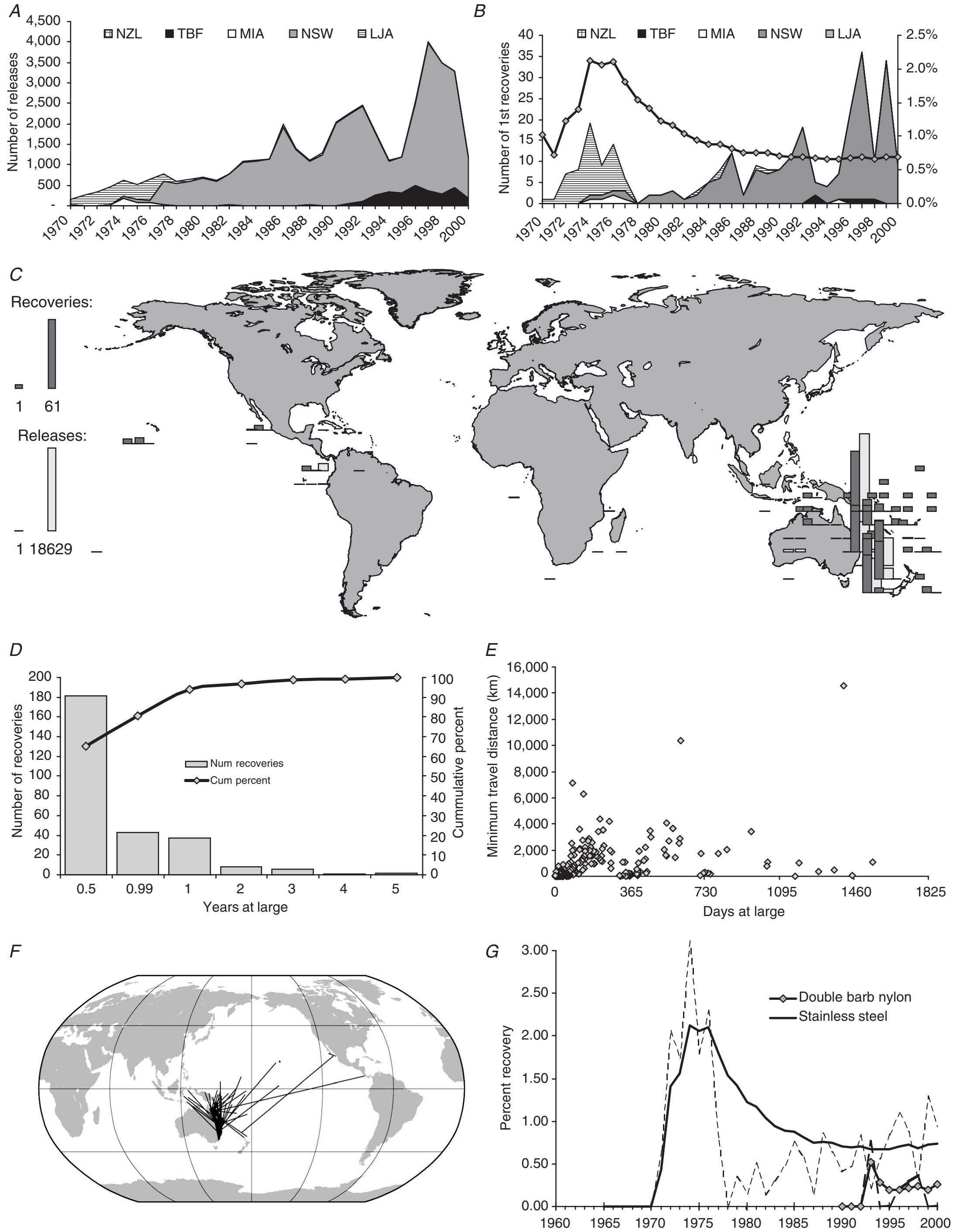

Fig. 2. Black marlin. (*A*) Numbers of fish tagged and released by year and agency; (*B*) numbers of fish recovered by year and agency with line indicating annual cumulative recovery percentage (all agencies and tag types pooled); (*C*) geographic distribution of tagged and released fish (light bars) and recovered fish (dark bars) by 5° latitude–longitude squares (all years, agencies and tag types pooled); (*D*) frequency distribution of time-at large (bars) with line indicating cumulative percentage frequency. Time bins are in years; (*E*) scatter plot of time-at large (years) versus minimum travel distance (MTD); (*F*) geographic distribution of fish recoveries with MTD values greater that 10 km. Solid lines connect the point of release (diamonds) and point of recapture (note: vectors are not meant to indicate routes taken); (*G*) recovery percentage by tag type. Lines are annual cumulative recovery percentages (solid) and nominal annual recovery percentages (broken lines).

Table 2. Number and corresponding percentage (in parentheses) of billfish tagged and recovered by major types of fishing gears
Other gear category includes hand lines, trawls, purse seines and harpoon

	Rod and reel		Longline		Gillnet		Other	
	Releases	Recoveries	Releases	Recoveries	Releases	Recoveries	Releases	Recoveries
Black marlin	40 209 (95.9%)	157 (54.9%)	11 (0.0%)	96 (33.6%)	0 (0.0%)	1 (0.3%)	1 (0.0%)	24 (8.4%)
Blue marlin	39 350 (73.5%)	159 (24.5%)	1489 (2.8%)	132 (20.4%)	1 (0.0%)	262 (40.4%)	11 (0.0%)	21 (3.2%)
Striped marlin	37 673 (82.7%)	134 (31.8%)	231 (0.5%)	240 (56.9%)	0 (0.0%)	5 (1.2%)	7 (0.0%)	1 (0.2%)
White marlin	32 269 (76.1%)	323 (38.6%)	2920 (6.9%)	351 (42.0%)	0 (0.0%)	78 (9.3%)	19 (0.0%)	17 (2.0%)
Sailfish	103 795 (81.9%)	1483 (77.1%)	1068 (0.8%)	122 (6.3%)	18 (0.0%)	134 (7.0%)	16 (0.0%)	38 (2.0%)

recent years (Fig. 2*A* and *B*). The trajectory for cumulative recovery percentage (Fig. 2*B*) indicated an historical high in 1974 (about 2.3%) and then declined and stabilized near the end of the time series. The LJA program also had the highest recovery percent (1.92%) of the tagging agencies (Table 1). Recreational anglers using rod-and-reel were responsible for releasing about 96% of all tagged black marlin (Table 2). This sector also obtained most (55%) of the recovered black marlin, but a substantial proportion (34%) of recoveries were also obtained by commercial longline fishers (Table 2). The highest concentration of tag and recovery efforts for this species lies in the Pacific waters that stretch between the eastern Australian coast and New Zealand (Fig. 2*C*). About 95% of the black marlin was recovered after being at large for 1 year or less, with few fish recovered after 3 years at large (Fig. 2*D*). The maximum time at large for black marlin was 5 years. The plots of MTD against years at large suggest that black marlin may make cyclic annual movements and/or exhibit some degree of seasonal site fidelity (Fig. 2*E*). Global plots of release–recovery vectors (Fig. 2*F*) indicate inter-ocean movements from the Pacific to the Indian Ocean, as well as trans-oceanic and trans-equatorial movements in the Pacific Ocean. Considerable black marlin movement activity appears off the eastern coast of Australia, north into Papuan, Micronesian and Indonesian waters, but also south along the Australian coastline. Cumulative recovery percentages associated with fish tagged with double-barb nylon anchor tags were about half of those associated with fish marked with stainless steel tags (Fig. 2*G*).

Blue marlin

Blue marlin and sailfish are the only circum-tropical billfish species targeted in all five tagging programs. The MIA and TBF programs were responsible for the majority of blue marlin releases and recoveries (Fig. 3*A* and *B*). Declines in annual release numbers by the MIA program, evident from the early 1990s to the present, were more than compensated by increases in the TBF program over the same time period. As with black marlin, the overall trends in blue marlin releases and recoveries were highest during the most recent years (Fig. 3*A* and *B*), and the TBF recovery percent for blue marlin (1.74%) was the highest among agencies with substantial returns for this species (Table 1). The cumulative recovery percentage trajectory for blue marlin gradually increased throughout the time series, reaching a peak in the most recent years (Fig. 3*B*). The primary gear used in the tag-release process was rod-and-reel, whereas three gears dominate for blue marlin recoveries: gillnet, rod-and-reel and longline (Table 2). For this species, therefore, recreational anglers were responsible for the majority of fish tagged, but commercial fishers provided the most recoveries. Most of the blue marlin tagging and recovery efforts have been restricted to the western north Atlantic Ocean, with particularly intense activities off the US Caribbean (including Puerto Rico and US Virgin Islands) and the north-eastern coast of South America near La Guaira, Venezuela (Fig. 3*C*). Tagging and recovery activities in the Pacific Ocean has been concentrated off San Diego and the Hawaiian Islands, with lesser amounts along the Australian eastern seaboard (Fig. 3*C*). Although about 85% of the blue marlin recovered were at large for 3 years or less (Fig. 3*D*), many fish were recovered up to 6 years after release. The maximum time at large for blue marlin was 11 years (Table 1). Plots of MTD versus years-at large revealed no clear patterns that might indicate site fidelity and/or cyclic annual movements for this species (Fig. 3*E*). Global plots of the release–recovery vectors (Fig. 3*F*) indicate that blue marlin are capable of trans-oceanic and trans-equatorial movements in the Atlantic and Pacific Oceans, as well as inter-oceanic movements (i.e. from the Atlantic to Indian Ocean and from the Pacific to the Indian Ocean). Strong seasonal movement patterns were evident in the Atlantic Ocean, from the US mid-Atlantic coast and Mexican Caribbean to Venezuela (Fig. 3*F*). Cumulative recovery percentages associated with fish tagged with double-barb nylon anchor tags were over twice those for fish bearing stainless steel tags (Fig. 3*G*).

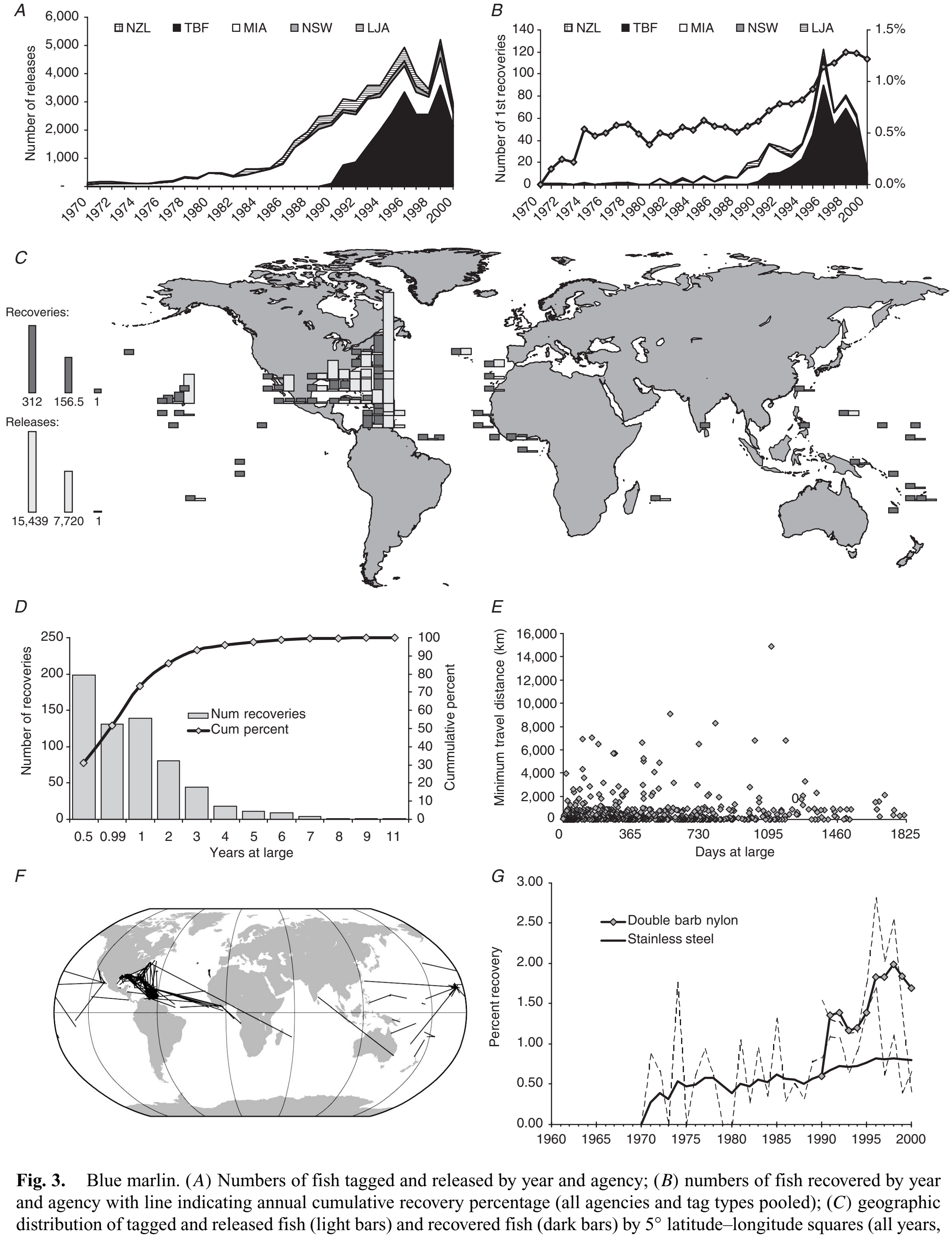

Fig. 3. Blue marlin. (*A*) Numbers of fish tagged and released by year and agency; (*B*) numbers of fish recovered by year and agency with line indicating annual cumulative recovery percentage (all agencies and tag types pooled); (*C*) geographic distribution of tagged and released fish (light bars) and recovered fish (dark bars) by 5° latitude–longitude squares (all years, agencies and tag types pooled); (*D*) frequency distribution of time-at large (bars) with line indicating cumulative percentage frequency. Time bins are in years; (*E*) Scatter plot of time-at large (years) versus minimum travel distance (MTD); (*F*) Geographic distribution of fish recoveries with MTD values greater that 10 km. Solid lines connect the point of release (diamonds) and point of recapture (note: vectors are not meant to indicate routes taken); (*G*) recovery percentage by tag type. Lines are annual cumulative recovery percentages (solid) and nominal annual recovery percentages (broken lines).

White marlin

Tagging data on white marlin were derived exclusively from two programs: MIA and TBF (Fig. 4*A* and *B*). The overall trends in numbers of releases and recoveries increased throughout the time series. As with blue marlin, declines in the number of fish released and recovered by the MIA program were countered by the efforts of the TBF program from the early 1990s forward. The trajectory for the cumulative recovery percentage for white marlin (Fig. 4*B*) generally increased through the time series, but not as rapidly as blue marlin recoveries. The TBF recovery percentages for white marlin (2.37%) were by far the highest for agencies tagging this species, which was also the case for blue marlin (Table 1). Rod-and-reel was the major gear utilized in the tagging process; about equal numbers of recovered fish were reported by commercial longlining crews and recreational rod-and-reel anglers (Table 2). White marlin tagging and recovery activities are almost exclusively restricted to the western Atlantic Ocean, with the highest release and recovery numbers off Maryland, USA, and in the Caribbean Sea off La Guaira, Venezuela (Fig. 4*C*). Recovered white marlin tended to be at large for longer time periods than any of the other istiophorids examined: while modal time-at large was 1 year or less, 30% of the recovered fish had been at large between 2 and 15 years. (Fig. 4*D*). The white marlin MTD versus years-at large plot suggests that this species makes cyclic annual movements (i.e. demonstrate seasonal area fidelity) or are very restricted in their movements (Fig. 4*E*). The release–recovery vectors indicate trans-Atlantic movements, but no trans-equatorial or inter-oceanic movements (4*F*). As with blue marlin, considerable movement between the US east coast, the Gulf of Mexico and Venezuelan waters is apparent (Fig. 4*F*). The historical trend in percent recoveries indicates that double barb nylon anchor tags were superior to stainless steel tags (Fig. 4*G*).

Striped marlin

Four programs share roughly equal responsibility for providing tagging data on striped marlin: LJA, NSW, NZL and TBF (Fig. 5*A* and *B*). However, the LJA program has the longest history with this species. The historical release and recovery trends increase over the time series, as is the case for the other marlins, with historical highs in the most recent years. The trajectory for cumulative recovery percentage for striped marlin was characterized by a steep decline (as with black marlin) through the early 1970s, followed by an increasing trend through the 1980s, and then tended to decline during the remainder of the time series (Fig. 5*B*). The LJA recovery percentage for striped marlin (1.35%) was the highest of the four agencies tagging this species (Table 1), while the maximum time at large for striped marlin was only 2.7 years, the shortest of all species (Table 1). Most striped marlin were tagged and released by recreational rod-and-reel anglers (82%), while almost twice as many recoveries were obtained from the commercial longlining industry versus recreational fishers (Table 2). Tagging and recovery activities targeting striped marlin are the most globally widespread, with the highest release and recovery numbers occurring in Pacific waters in the general vicinity of the four major programs' locations (Fig. 5*C*). The majority of recovered striped marlin were at large for very short time periods; over 90% were recovered by the end of the first year at large (Fig. 5*D*). Also, unlike white marlin, there was no suggested site fidelity and/or cyclic annual movement for this species (Fig. 5*E*). The data showed that striped marlin are capable of trans-equatorial movements, although the release–recovery vectors within this dataset did not indicate any trans-Pacific or inter-oceanic movements (Fig. 5*F*). Annual plots of cumulative recovery percentages by tag type suggest stainless steel tags may have superior retention to double-barb nylon anchor tags for this species (Fig. 5*G*).

Sailfish

The MIA and TBF programs have led in sailfish tag release and recovery activities, although the NSW program has increased tagging activities in recent years (Fig. 6*A* and *B*). The same relationship between MIA and TBF statistics for blue and white marlin is evident for sailfish: TBF effectively countered MIA's decreases in the number of released and recovered sailfish. As with the other istiophorids, historical trends in numbers of releases and recoveries generally increased over the time series, as did the cumulative recovery percentage, with historical highs generally occurring during the most recent years (Fig. 6*B*). The MIA recovery percent for sailfish (1.83%) was the highest among agencies (Table 1). Recreational anglers were responsible for 82% of all sailfish released and 77% of those recovered (Table 2). Most of the tagging information on sailfish pertains to populations in the western north Atlantic off the US eastern seaboard, the Gulf of Mexico, Mexican Caribbean, and the northern coast of Venezuela (Fig. 6*C*). Although overall modal time-at large for recaptured sailfish was 0.5 years, several hundred sailfish (about 30% of all sailfish recoveries) have been at large between 1 and 4 years (Fig. 6*D*). Furthermore, this species also has the longest time-at large (17 years) recorded for any billfish (Table 1). Plots of MTD versus years-at large (Fig. 6*E*), suggest that sailfish in different areas make either cyclic annual movements, exhibit some degree of site fidelity, or some combination of the two behaviors. For the most part, global release-recovery vectors (Fig. 6*F*) showed restricted movement, with no trans-Atlantic/Pacific or trans-equatorial movements in the Atlantic and Pacific Oceans. Two records, however, indicate trans-equatorial movement in the Indian Ocean. Sailfish appear to take the same general pathways as white marlin and blue marlin in the western Atlantic Ocean, namely, within and among the waters of the Gulf of Mexico, eastern US seaboard and Caribbean Sea (Fig. 6*F*). In the early 1990s, sailfish tagged with double barb nylon anchor

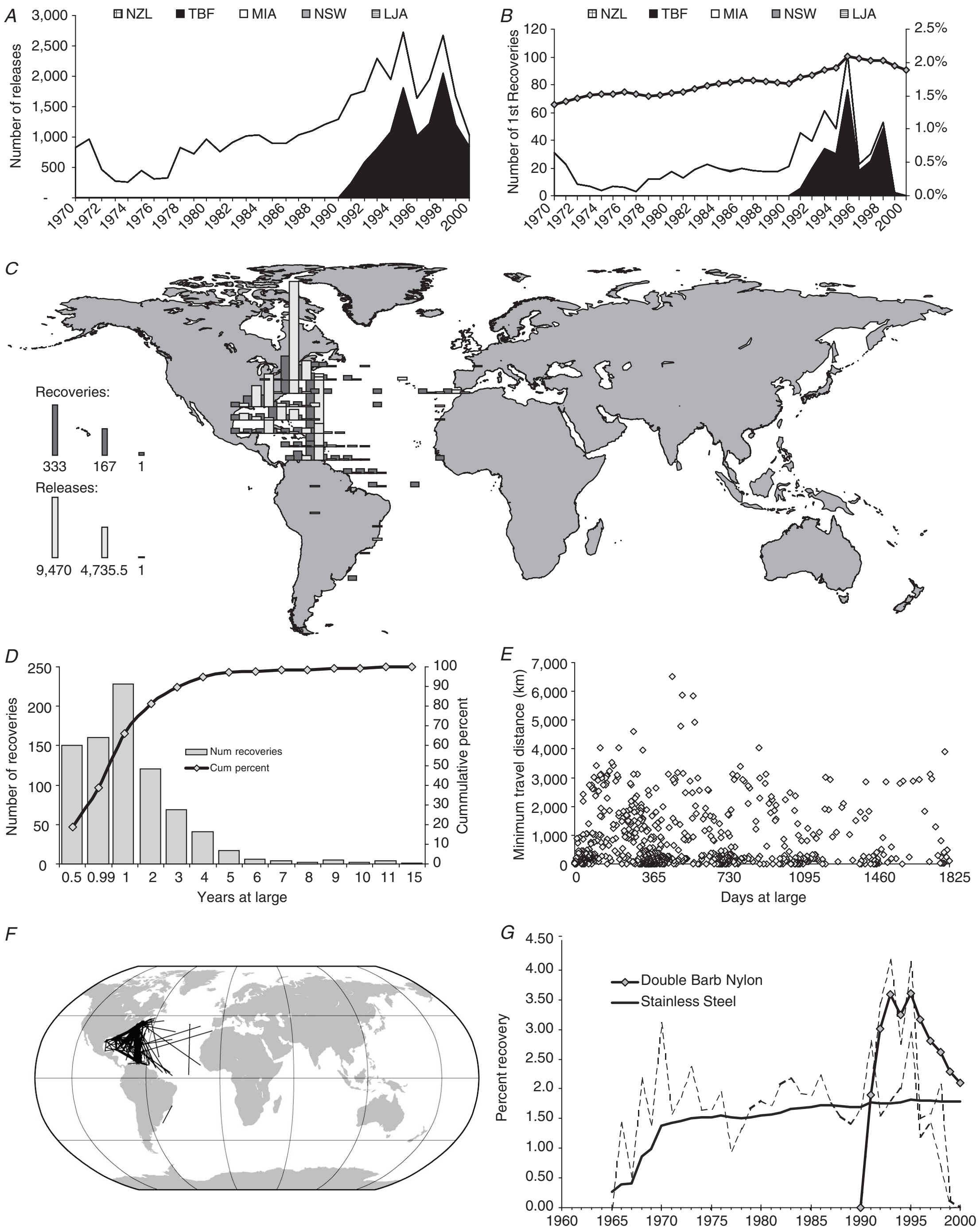

Fig. 4. White marlin. (*A*) Numbers of fish tagged and released by year and agency; (*B*) numbers of fish recovered by year and agency with line indicating annual cumulative recovery percentage (all agencies and tag types pooled); (*C*) geographic distribution of tagged and released fish (light bars) and recovered fish (dark bars) by 5° latitude–longitude squares (all years, agencies and tag types pooled); (*D*) frequency distribution of time-at large (bars) with line indicating cumulative percentage frequency. Time bins are in years; (*E*) scatter plot of time-at large (years) versus minimum travel distance (MTD); (*F*) geographic distribution of fish recoveries with MTD values greater that 10 km. Solid lines connect the point of release (diamonds) and point of recapture (note: vectors are not meant to indicate routes taken); (*G*) recovery percentage by tag type. Lines are annual cumulative recovery percentages (solid) and nominal annual recovery percentages (broken lines).

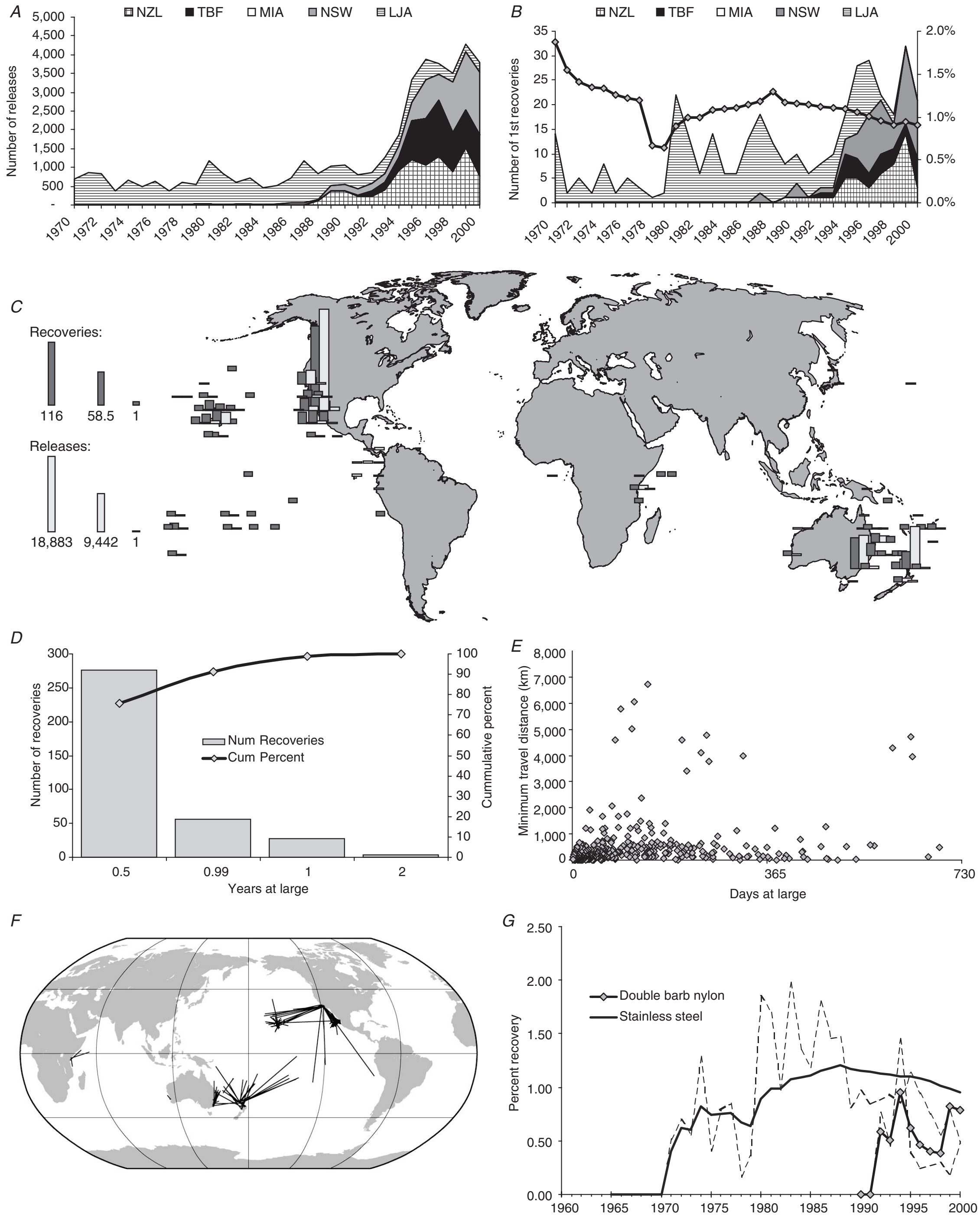

Fig. 5. Striped marlin. (*A*) Numbers of fish tagged and released by year and agency; (*B*) numbers of fish recovered by year and agency with line indicating annual cumulative recovery percentage (all agencies and tag types pooled); (*C*) geographic distribution of tagged and released fish (light bars) and recovered fish (dark bars) by 5° latitude–longitude squares (all years, agencies and tag types pooled); (*D*) frequency distribution of time-at large (bars) with line indicating cumulative percentage frequency. Time bins are in years; (*E*) scatter plot of time-at large (years) versus minimum travel distance (MTD); (*F*) geographic distribution of fish recoveries with MTD values greater that 10 km. Solid lines connect the point of release (diamonds) and point of recapture (note: vectors are not meant to indicate routes taken); (*G*) recovery percentage by tag type. Lines are annual cumulative recovery percentages (solid) and nominal annual recovery percentages (broken lines).

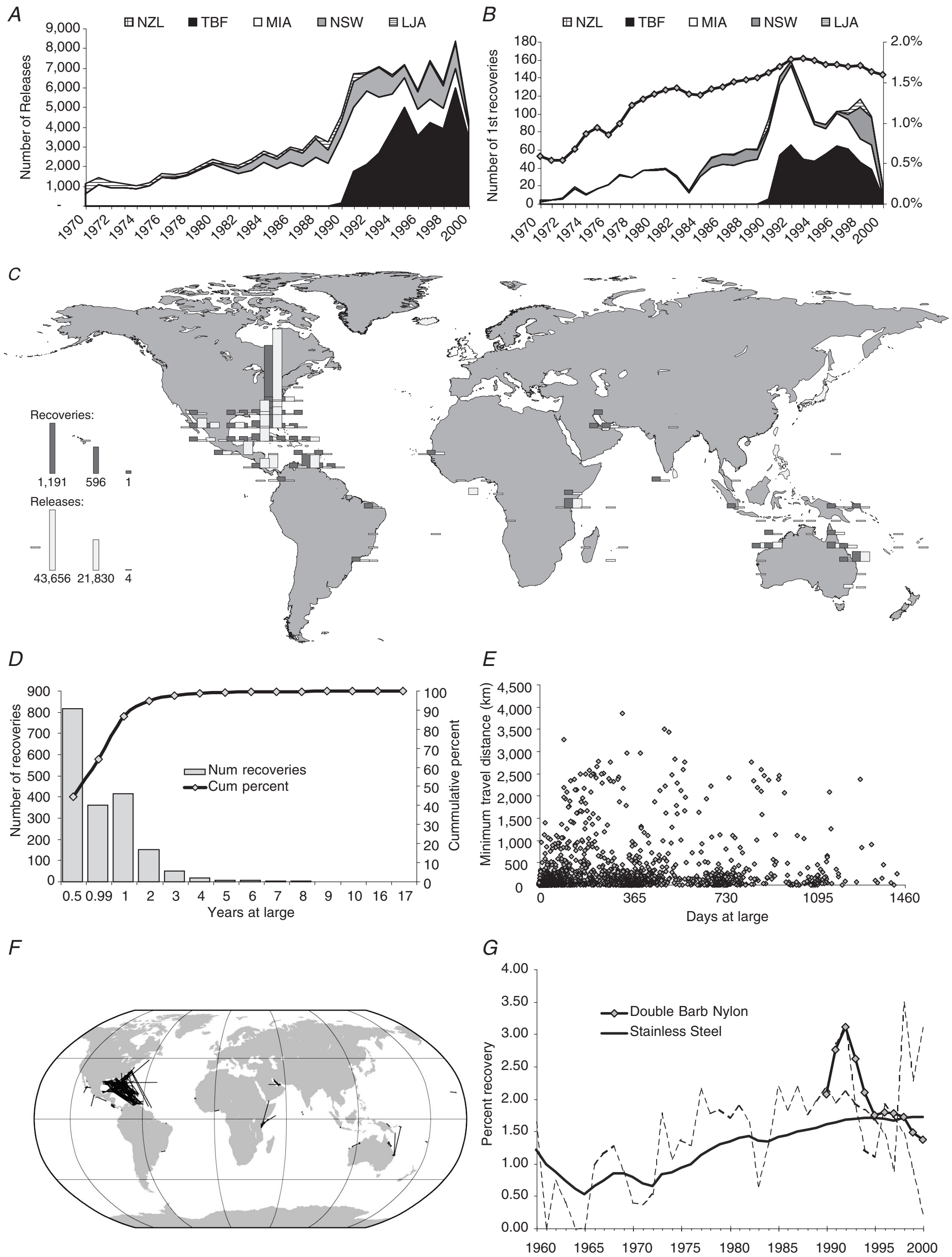

Fig. 6. Sailfish. (*A*) Numbers of fish tagged and released by year and agency; (*B*) numbers of fish recovered by year and agency with line indicating annual cumulative recovery percentage (all agencies and tag types pooled); (*C*) geographic distribution of tagged and released fish (light bars) and recovered fish (dark bars) by 5° latitude–longitude squares (all years, agencies and tag types pooled); (*D*) frequency distribution of time-at large (bars) with line indicating cumulative percentage frequency. Time bins are in years; (*E*) scatter plot of time-at large (years) versus minimum travel distance (MTD); (*F*) geographic distribution of fish recoveries with MTD values greater that 10 km. Solid lines connect the point of release (diamonds) and point of recapture (note: vectors are not meant to indicate routes taken); (*G*) recovery percentage by tag type. Lines are annual cumulative recovery percentages (solid) and nominal annual recovery percentages (broken lines).

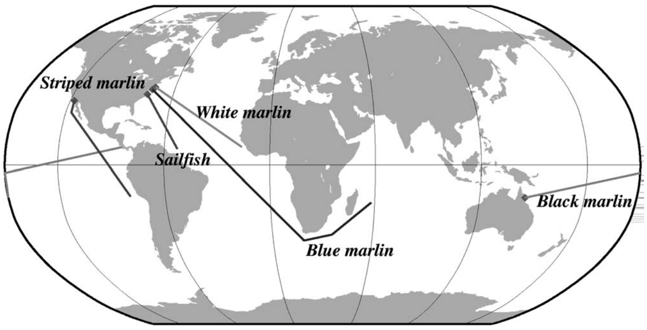

Fig. 7. Longest distance travelled for each billfish species from tag release–recovery information. Each vector indicates the shortest straight line route between release and recapture locations. Blue marlin = 14 893 km after 1108 days at large; black marlin = 14 556 km after 1412 days at large; striped marlin = 6713 km after 141 days at large; white marlin = 6517 km after 474 days at large; and sailfish = 3861 km after 332 days at large. See text for further details.

tags appeared to show higher cumulative annual recovery percentages than those marked with stainless steel tags (Fig. 6*G*). Since about 1995, however, no clear difference in recovery percentages by tag type was evident.

Longest distance travelled

The longest straight-line distance travelled for each of the five major billfish target species is illustrated in Fig. 7 (distances are provided in Table 1). Blue marlin had the longest movement (14 893 km) and this pattern included trans-Atlantic, trans-equatorial, and an inter-ocean movement from Delaware (USA) in the Atlantic to Mauritius in the Indian Ocean. The longest distance moved by a black marlin (14 556 km) was remarkably similar to blue marlin, including a trans-Pacific, trans-equatorial movement from Cairns, Australia, to the Pacific coast of Costa Rica. The longest distances moved for striped marlin and white marlin were less than half that of blue and black marlins, being 6713 and 6517 km respectively. The longest movement for striped marlin was a trans-equatorial movement, while white marlin demonstrated a trans-Atlantic movement. Sailfish exhibited the shortest distance travelled (3861 km).

Discussion

Results of CBTPs have typically been reported in the literature by summarizing data of individual tagging agencies (Squire and Nielsen 1983; Miyake 1990; Murray 1990; Pepperell 1990*a*; Scott *et al.* 1990; Peel *et al.* 1998). Compilation of the data from the five major CBTPs into one database allows a more comprehensive perspective than was previously possible.

Spatial considerations

Four of the five programs (MIA, NSW, LJA and NZL) have restricted operational jurisdictions to specific ocean water bodies. Only the TBF program operates in Atlantic, Pacific and Indian Oceans. In terms of program operation, the size of the ocean body can indirectly influence the success of CBTPs by affecting program logistics. For example, the smaller the water body, the easier it is to identify critical billfishing centers and off-loading locations, communicate with program participants, and implement the necessary tag release and, importantly, recovery protocols. In the smaller Atlantic Ocean (about a third the size of the Indo-Pacific), the longevity of the tagging activity within the Atlantic basin has no doubt contributed to the high tag recovery percentages obtained (Table 1) for blue and white marlin (TBF) and sailfish (MIA) by enhancing the rate of reporting of recovered tags. However, other factors such as tag type and the effective implementation of outreach activities also contributed to these high Atlantic recovery percentages, although the relative contribution of each factor can not be distinguished. In addition, the Atlantic tagging activities are still confined primarily to the north-western Atlantic Ocean (Figs 3*C*, 4*C* and 6*C*) and conclusions drawn from Atlantic tagging results need to be tempered accordingly (ICCAT 1994). Despite ICCAT's best efforts to expand Atlantic billfish tagging activities in the east and south Atlantic (Prince *et al.* 1988; Miyake 1990) and to promote more coordinated Atlantic-wide recovery activities (Prince and Cort 1997), progress in balancing tag release and recovery efforts throughout the North Atlantic has been slow (Figs 2*C*, 3*C* and 6*C*).

The large size of the Pacific Ocean, in combination with the isolated location of Australia and New Zealand, certainly has made it logistically difficult to establish well-balanced CBTPs in the tropical and subtropical Pacific where billfish live. In many Pacific island nations, billfish are taken for food and income rather than tagged and released. In addition, unlike the Atlantic, which has one international fisheries commission to administer tagging protocols, the Pacific Ocean has three international fisheries commissions with overlapping jurisdictions. This situation complicates coordination of tagging activities, particularly because a large source of recoveries would be expected from the distant water fisheries (primarily longline fleets). The patterns of recoveries for black marlin (Fig. 2*F*) and striped marlin (Fig. 5*F*), showing vectors radiating out from their release points, is indicative of the spatial challenge faced by the Pacific-based programs. For these two species, the only major recreational billfishing center between Australia/New Zealand and the west coast of the US is Hawaii. Squire and Nielsen (1983) and Pepperell (1990*b*) also point out the problem of relying on highly localized fishing effort to recover widely dispersing black marlin in the Pacific basin. This likely negatively impacts reporting of long distance recoveries and overall recovery percentage for this species. Thus, over 90% of the recoveries for black and striped marlin are made in the first year at large, mostly near the tagging location, whereas the Atlantic marlin and sailfish continue to be recovered in substantial numbers

4–5 years (and longer) after release. Despite these problems, the Pacific tagging results, in terms of numbers released and recovery percentage, are comparable with those observed in the Atlantic. Constituent-based tagging programs in the Indian Ocean are in their infancy, hence release or recovery efforts are minimal at this time (Figs 2*C*, 3*C*, 5*C* and 6*C*). However, plans are currently underway to enhance a CBTP in this ocean basin (A. Fonteneau, personal communication), while some limited billfish tagging activity has recently been reported from the United Arab Emirates in the Persian Gulf (J. P. Hoolihan, personal communication).

Participation of recreational and commercial sectors

An obvious pre-requisite for establishing successful tagging programs is publicizing the programs to as many fishing sectors as possible to encourage participation. The recreational sector is particularly key for tag release activities. Conversely, the majority of worldwide billfish landings (about 70–90%) are a bycatch of commercial offshore longline fleets; this sector represents the greatest potential for tag recoveries (Squire and Nielsen 1983; ICCAT 2001*a*). However, the proportion of billfish tag recoveries reported by commercial longline fleets do not match the proportions of total landings reported for billfish species worldwide. Non-reporting by the commercial offshore longline sectors, probably for all species of billfish in all oceans, is a major problem (Jones and Prince 1998). Although non-reporting of recoveries is known to exist in recreational as well as other fishing sectors, this problem is not believed to be as severe as with the distant water longline fleets (Jones and Prince 1998). The black marlin fishery of north-east Australia is a good example of how effective fishing effort from offshore longline fleets can affect recovery percentages. From 1968 to 1981, the recovery percentage for black marlin in this location was 2.3%, while the Japanese longline fleet was operating in the 200-mile Australian Fishing Zone. However, after this longline fleet was excluded from the Australian Fishing Zone in 1981, the cumulative recovery percentage fell to 0.61% by the year 2000 (Pepperell 1990*b*).

Recreational gear is responsible for about 55% of black marlin recoveries (34% for commercial gear) and 77% of sailfish recoveries, while commercial gear (both longline and gillnet combined) account for about of 59–67% of the recoveries for white, blue and striped marlin. The dominance of sailfish recreational recoveries is understandable given that sailfish are more coastal (where recreational fisheries operate) than the marlins (ICCAT 2001*b*). The recovery gear situation for black marlin appears to be related, in part, to the NSW program structure, which is focused almost entirely on the recreational sector, as well as the movement of foreign-based commercial longline activity (i.e. Japanese) away from the Australian Fishing Zone in recent years (Pepperell 1990*b*). Thus, in areas that lack commercial fisheries that capture billfish, the recovery percentages from CBTPs can be expected to be low. In other words, lack of recreational billfishing activity generally leads to greatly reduced tagging activity, while diminished commercial fishing activity reduces the number of recoveries. In addition, non-reporting of recaptured fish, particularly from the offshore longline fleets, is likely one of the most important factors further lowering billfish recovery percentages. These factors obviously negatively impact the amount of data from tagged fish, thus leaving voids in our understanding of the movement, behavior, and longevity of billfish within and among the world's oceans.

Outreach activities

Developing aggressive outreach and educational activities has been a key in improving recovery percentages for billfish in the Atlantic Ocean (Bayley and Prince 1994). This is particularly true when the primary landings result as a bycatch of fisheries targeting other species (Prince and Brown 1991). Participation of international fisheries commissions, such as the ICCAT, is especially valuable in developing the infrastructure necessary to promote international communications that encourage the reporting of tag recoveries. These activities usually take the form of publicizing tagging programs through reward posters and annual lotteries. In addition, a certain amount of refinement of outreach activities has taken place over the years in the Atlantic Ocean (Bayley and Prince 1994). These include translating all tagging program announcements (including special tag recovery cards; Prince *et al.* 2002) into the native language of the localized fishing fleets, modifying incentive rewards to match the needs and desires of specific constituents, appointing country-specific tagging program coordinators to communicate program activities, and presenting prizes to winners of annual lotteries at fisheries association meetings or other appropriate venues.

The long history of developing outreach activities in the Atlantic Ocean is regarded as one of the major factors that has contributed to improved recovery percentages in this ocean body. For example, the MIA outreach activities already present in the Atlantic Ocean, when the TBF program was initiated in 1990, certainly benefited that program in achieving the high recovery percentages for blue and white marlin, despite being the youngest of all CBTPs. The TBF program originated in the Atlantic Ocean and expansion of this program to the Pacific and Indian oceans only occurred over the last few years. To date, about 70% of the TBF tagging effort has occurred in the Atlantic Ocean. Similar outreach activities exist in the Pacific (Squire and Nielsen 1983; Murray 1990; Pepperell 1990*a*; and Holts and Prescott 2000), although these appear to be much more difficult to fully implement and coordinate. For the reasons mentioned previously, new emphasis on CBTPs, as well as additional collateral studies, was begun by LJA in 1999 (Hunter and Holts 1999). This included working with the constituents to plan and promote all aspects of tagging and data collection. Recent trends in

LJA tag releases have shown that increased collaboration between scientist and angler greatly promotes tag release activities.

Tag type

The type of tags used for highly migratory species in general (Yamashita and Waldron 1958) and used specifically for billfish (Prince *et al.* 2002) have been reported to affect the number of tag returns. Based on a double tagging experiment conducted in the Atlantic Ocean over a 10-year period, Prince *et al.* (2002) found higher tag retention for most istiphorids using the double barb nylon anchor tag, compared with the standard stainless steel dart tag. Our analysis of tagging results by tag type (Figs 3*G*, 4*G* and 6*G*) are consistent with the conclusions of Prince *et al.* (2002) that the double barb nylon dart tags are retained better compared with the stainless steel dart tags for blue and white marlin, and, to a lesser extent, sailfish. However, this did not seem to be true for black and striped marlin (Figs 2*G* and 5*G*) in the Pacific, although the fact that far less double barb nylon tags have been used on the Pacific marlins (nylon tag distribution in the Pacific by TBF since 1990 and by LJA since 1999) makes it difficult to draw definitive conclusions in these cases. Moreover, it is important to reiterate that non-reporting of recoveries, or exclusion of longline fishing activity in areas of marlin abundance can confound conclusions drawn about tag performance.

Species comparisons

Blue and black marlin

There are strong similarities in physical appearance and maximum size (both exceed 500 kg) of the *Makaira* congeners. Most of the agency recovery percentages for *Makaira* were below 1%, except for the TBF program for blue marlin (1.74%) and the LJA program for black marlin (1.92%). However, the historical trend (all agencies combined) for blue marlin recoveries has gradually increased over time, whereas this trend for black marlin reached a peak in the late 1970s and then declined thereafter. Pepperell (1990*b*) attributes the historical reduction in recovery percentages to the drastic reduction in effective fishing effort in the 200-mile Australian Fishing Zone after the Japanese longline fleet was excluded from the Australian fishing zone in 1981. Conversely, the high blue marlin recovery percentage for the TBF program was likely owing to the increased release activities and development of intense outreach activities in the Atlantic Ocean, particularly off northern Venezuela (Jones and Prince 1998).

The fact that over 90% of the black marlin have been recovered within 1 year at large appears related to the isolated location of the majority of releases and the dispersal of fish from this area, without interacting with major fisheries. In other words, within a year at large, most of the black marlin tagged off Australia may disperse from the Cairns area (Fig. 2*D*) and have much more limited interaction with fisheries in other parts of the Coral Sea and Pacific Ocean basin. Occasionally, black marlin are recovered off Hawaii and on the Pacific side of central and South America. In contrast, only 70% of blue marlin recoveries have been recorded after 1 year at large (Fig. 3*D*) and considerable numbers of have been recorded up to 4 years after release. The maximum time at-liberty for black marlin is only 5 years, whereas for blue marlin it is 11 years, yet the maximum size of both species suggests a similar lifespan. Although maximum time at-liberty has not permitted estimates of maximum longevity for *Makaira* spp. to this point, this has been done for other istiphorids (see sailfish).

Black marlin show a tendency towards annual site fidelity off the north-east coast of Australia (Pepperell 1990*b*). Conversely, blue marlin do not show a similar pattern of seasonal site fidelity, although the majority of blue marlin recoveries were taken in the same general area of release. Numerous instances of trans-oceanic and trans-equatorial movements were also observed in the Atlantic and Pacific Oceans, and blue and black marlin exhibited the first and second longest distance travelled respectively. Blue marlin are the only species that demonstrated inter-ocean movements: from Delaware, USA, in the Atlantic to Mauritius in the Indian Ocean and from south-eastern Australia in the Pacific Ocean to an area south of Sri Lanka in the Indian Ocean. There appears to be a relationship between the longest distance travelled and the maximum size of billfish species; the larger species (blue and black marlin) tend to move considerably greater distances (including trans-oceanic, trans-equatorial and inter-ocean movements) than the smaller *Tetrapturus* congeners (striped and white marlin) and sailfish. However, the longest distance travelled represents a single observation per species and thus conclusions based solely on this parameter should be tempered accordingly. The extended circum-tropical distribution of blue marlin, combined with the extensive movement patterns as well as two inter-ocean movements for this species, suggest that this istiophorid can be characterized as a true world traveller.

White and striped marlin

Comparisons between the two *Tetrapturus* congeners are characterized by the fact that both white marlin and striped marlin are endemic only to the Atlantic Ocean or to the Pacific/Indian Oceans, respectively, but do not co-exist together as do *Makaira*. The *Tetrapturus* congeners are similar in physical appearance, but striped marlin have a larger maximum size than white marlin (IGFA 2001). White marlin represented about 13% of the releases and over 20% of the billfish recovered worldwide, whereas striped marlin represented 14% of the total billfishes tagged, but only about 10% of the billfish recovered (Table 1). Apart from sailfish, more white marlin have been recovered than any other billfish species, and they are the only istiophorid to show an overall recovery percentage of over 2% (TBF 2.34%; Table 1). As discussed previously for blue marlin, the large number of white marlin recoveries is a result of accelerated release activities and outreach programs in the Atlantic Ocean, particularly in the area of La Guaira, Venezuela (Fig. 3*F*). The overall trend in historical white marlin recovery percentages has gradually increased over time, while the trend for striped marlin generally decreased, with stable percentages over the last two decades. Conversely, striped marlin are restricted in distribution to the Pacific and Indian Oceans where development of fisheries commission-administered outreach activities lags behind the Atlantic and very limited tagging of striped marlin occurs in the Indian Ocean. This species is particularly abundant off Baja California, where relatively high concentrations of striped marlin are known to occur seasonally (Squire 1974; Squire 1987; Squire and Suzuki 1990). More than half of the striped marlin recoveries (LJA 1.35%) have historically been reported by commercial longline fleets and a pattern of movement has been suggested between Baja California and Hawaii (Fig. 4*F*).

Almost all of the striped marlin have been recovered within 1 year at large, which contrasts with white marlin, for which recoveries have been recorded over 5 to 6 years after release. Similarly, the maximum time at-liberty for striped marlin is only 2.5 years, whereas white marlin have been recovered up to 15 years at large. Estimates of longevity for *Tetrapturus* have not been reported, although the larger maximum size of striped marlin (IGFA 2001) could suggest possible increased longevity compared with white marlin. As with black marlin, the isolation of the Australian and New Zealand landmasses, and their great distance from striped marlin peak abundance areas in Baja California and Hawaii, makes it difficult to implement ocean-wide tag recovery networks. In addition, these factors also negatively impact the numbers of tagged billfish that can be released between these distant locations, which further reduces the likelihood of documenting mixing between these distant points. The displacement vectors for striped marlin (Fig. 4*F*) radiating out from release locations off Baja California, New Zealand and Australia illustrate this problem. Also, striped marlin catches are made in the Indian Ocean (van der Elst 1990), but only a limited amount of tagging results are available from this ocean body (J. Hoolihan, personal communication). Bayley and Prince (1994) evaluated the tag recovery percentages of billfish, including white marlin, in the south-east Caribbean Sea (primarily north central coast of Venezuela) before and after the ICCAT Enhanced Research Program for Billfish was implemented in 1987. They found that white marlin recoveries in this area increased from about 10% of the recovery database before 1987, to over 33% by 1993, 6 years after the ICCAT Enhanced Research Program for Billfish was implemented. This increase was largely attributed to outreach activities developed for this area, particularly the close monitoring of the artisanal gillnet fisheries.

The longest distance travelled for white marlin (Fig. 7) is considerably shorter than the longest travel distance observed for blue and black marlin, and appears to be similar in this regard to its congener, the striped marlin. Numerous trans-Atlantic movements have been recorded for white marlin, mostly from the US east coast and Caribbean Sea to the west coast of Africa and Morocco, whereas striped marlin have made relatively few trans-equatorial movements (from Baja California to the west coast of South America off Peru) and no trans-Pacific crossings to date.

Sailfish

Sailfish comprised more than 40% of the total billfishes tagged and 46% of the billfish recovered worldwide since the first program started in 1954. Both totals are the highest among the billfish target species (Table 1). Sailfish is the only istiophorid among the target species for which recreational rod-and-reel fisheries dominated both the release and the recovery activities (Fig. 5*C* and *D*). The coastal orientation of sailfish (ICCAT 2001*b*), the near-shore operation of the recreational fleets in tropical and sub-tropical waters, and the circum-tropical, worldwide distribution of this species all act to increase the availability of sailfish for CBTPs. The MIA program recorded the highest sailfish recovery rate among the major tagging programs (Table 1). The factors that contributed to high recovery percentages discussed previously for blue and white marlin in the Atlantic Ocean, also acted to enhance recoveries for sailfish. The family of outreach activities developed over four decades in the Atlantic Ocean and administered through ICCAT and National Marine Fisheries Service certainly contributed to the gradual increase in sailfish cumulative recovery percentage found for this species, as was the case for blue and white marlin. The worldwide distribution of sailfish releases is very similar to the pattern seen for blue and white marlin, with most activity in the western North Atlantic Ocean. Sailfish tend to concentrate in localized areas that are targeted by recreational and artisanal fisheries. In such areas, relatively large numbers of recoveries have been recorded, especially when artisanal gillnet fisheries are operating.

Although 88% of the sailfish recaptures are taken within the first year at large, substantial sailfish recoveries continue to be caught 4 years or more after release (Fig. 5*F*). This trend is most similar to blue and white marlin, but with fewer recoveries over time for sailfish. There is also some indication that sailfish show seasonal fidelity to the original tag release sites, but this pattern is not as strong as the trends shown for black and white marlin (Fig. 5*G*). The maximum time at-liberty for sailfish stands at 17.9 years. Prior to this current record for sailfish longevity, Prince *et al.* (1985) estimated maximum longevity for Atlantic sailfish at 13–15 years, based on analysis of dorsal spines and otoliths from a sailfish recovered after 13 years. Previous to this estimate by Prince *et al.* (1985), de Sylva (1957) had suggested Atlantic sailfish longevity was only 3 to 4 years, based on length–frequency analysis. The movement vectors for sailfish recoveries (Fig. 5*H*), as well as the longest travel distance for sailfish, demonstrate a strong pattern of near-shore movements with no trans-oceanic, trans-equatorial, or inter-ocean movements, despite more than three times the number of sailfish recoveries compared with any of the other billfishes (Table 1).

Future of constituent-based tagging programs

Value of conventional tagging

Hilborn *et al.* (1990) estimate that 50–80% of what is known about a fishery comes from tagging data. This general premise also seems to apply to billfishes, as the major source of data on the distribution, movement and migration patterns, stock structure and biology of billfishes all flow directly from CBTPs (Prince *et al.* 1985; Squire and Suzuki 1990; Murray 1990; Pepperell 1990*a*, 1990*b*; Scott *et al.* 1990; Pepperell and Davis 1999; Prince *et al.* (2002) and others). However, the value of using conventional tags through CBTPs has sometimes been questioned, particularly in light of recent advances in pop-up satellite tag technology (Block *et al.* 1998; Graves *et al.* 2001; Holland 2003; Kerstetter *et al.* 2003), but also considering the limitations associated with conventional tagging (McFarlane *et al.* 1990; Gillanders *et al.* 2001).

The unique characteristics of billfish fisheries and their biology contribute to the difficulty of studying these species and impede progress in data acquisition (Prince and Brown 1991; Hunter and Holts 1999). Moreover, the 'rare event' status of billfishes makes them difficult to sample and expensive to collect and study in sufficient numbers (Prince and Brown 1991). Any review of the benefits and liabilities of CBTPs needs to take into account these factors and how they impact on conventional tagging efforts. In the case of tagging billfish, the characteristics of the fisheries, as well as their biology severely limit any kind of conventional tagging program because of limited access to live fish, and this manifests itself into an extremely high cost of tagging operations (Prince and Brown 1991). In fact, Pepperell (1990*a*) correctly concluded that information accumulated on billfish collected through CBTPs would be difficult, if not impossible, to achieve at a reasonable cost with any other approach. As documented in this study, operation of CBTPs has resulted in a very large number of billfish (over 300 000 since 1954 or about 6746 billfish per year) being tagged with conventional tags, at a very small cost. The cost of tagging operations is a major concern, as indicated by Hilborn *et al.* (1990), who made the point that much innovation is needed to reduce the cost of tagging programs. Given that a financially viable conventional billfish tagging system comparable with CBTPs does not currently exist, CBTPs fill a need that at this point is not accommodated by any other tagging technique.

Other more sophisticated tagging technologies (i.e. acoustic or pop-up satellite tagging) can provide increased precision on movements, migrations and other aspects of biology compared with conventional tagging (Block *et al.* 1998; Pepperell and Davis 1999). One of the primary downsides of using conventional tags on billfish is that data are acquired only on the points of release and recovery; movements in between these points are unknown. In addition, CBTPs are characterized by a lack of control over the tagging process, which is carried out by unsupervised fishery constituents. Lack of control over tagging hinders implementation of statistically designed experiments, particularly those dealing with estimates of mortality. There is also a problem with over-estimates of size at release (Squire and Nielsen 1983; Scott *et al.* 1990), as it is difficult to precisely estimate or measure the size of a live billfish at boat-side. This is also a common problem with in-water tagging of large fish regardless of tag type (Prince *et al.* 2002). As mentioned earlier, the problem of non-reporting of recaptured fish negatively impacts the quality and quantity of information derived from CBTPs. However, non-reporting of recoveries also affects some of the more sophisticated tagging technologies (i.e. implantable archival tags) as well. Tag seeding techniques, often applied in purse seine fisheries targeting tuna for estimating non-reporting of tags (Hampton 1995), are particularly difficult and impractical because of the types of fisheries that are most often involved with CBTP recoveries (i.e. recreational vessels, gillnets or offshore longline fleets). Future research on methods for estimating non-reporting of billfish tags from the CBTBs is certainly warranted. Although data from conventional tags placed on billfish by fishery constituents are rarely sufficient to estimate mortality, some progress in this regard has been made by Porch (1999) and Porch *et al.* (2001) who developed estimates of mortality of Atlantic bluefin tuna, *Thunnus thynnus*, from the MIA CBTP database. Moreover, the growth curve for Atlantic bluefin tuna currently used in ICCAT stock assessments was also developed from the MIA CBTP database (Turner and Restrepo 1991; Turner and Restrepo 1994). Unlike istiphorids, Atlantic bluefin tuna have an intense, directed commercial fishery and, historically, the highest conventional tag recover rate (about 13%; Prince *et al.* 2002) in the MIA program. These features provided greater opportunity for development of bluefin tuna mortality rates and growth curves than for billfish.

There are also long-term benefits of using conventional tags, which have been recovered from billfish for as many as 17 years after release, that have not been demonstrated using any other technologies. Long-term recoveries not only allow estimates of longevity (Prince *et al.* 1985), but also provide an important means for validating ageing methods for billfish, provided that hard parts can be collected and ages can be closely approximated from tagging records (Prince and Pulos 1982; Prince *et al.* 1985; Lee and Prince 1995; Prince *et al.* 1995). The issue of stock structure, or identifying management units, is a critical need relative to assessment and management of billfish (ICCAT 1994). The CBTPs are the only source of direct evidence for or against mixing of individual fishes across large distances (Miyake 1990; Murray 1990; Pepperell 1990*a*; Scott *et al.* 1990; Squire and Suzuki 1990; Begg *et al.* 1997) and are often the over-riding factor in the stock structure decision-making process (ICCAT 1994, 1998, 2001*a*). This type of information also provides data on mixing rates (Pepperell 1990*b*; Begg *et al.* 1997), which is vital for international management considerations, as well as to supplement genetic studies (Graves and McDowell 1995). In terms of justifying CBTPs, every displacement vector referred to in this document is the result of a recreational or commercial fisher, captain or crew (or someone involved in the program) putting a tag into a billfish voluntarily at no direct cost to the programs, except for the tagging equipment. This fact alone would seem to justify all CBTP efforts as these programs are the primary contributors to the current body of knowledge on these species. In addition, the financial advantages of CBTPs, together with the concurrent promotion of non-consumptive fishing practices (i.e. catch and release fishing) by participating constituents, should not be overlooked as among the primary benefits of these programs (Lucy and Studholme 2002). Therefore, despite the limitations of CBTPs for billfish research, we believe these programs are a critically important source of information on this species group that, in many ways, cannot yet be fully addressed using more advanced technologies. As evidenced by tagging results in the Atlantic Ocean, the problems associated with low recovery percentages can be improved over time. Improving the development and administration (through international fisheries commissions) of outreach activities, in combination with using better tags, should be adopted by programs over the long term to improve recovery percentages and the quality and quantity of data on billfishes.

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Disclaimer

The mention of commercial products or trade names does not imply endorsement by the authors.

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