9

Synopsis of biological characteristics of the flyingfish, *Hirundichthys affinis*, relevant to assessment and management

WAYNE HUNTE, ROBIN MAHON AND HAZEL A. OXENFORD

SEASONALITY

The abundance and reproduction of adult flyingfish (*Hirundichthys affinis*) off Barbados vary seasonally (Lewis *et al.* 1962, Storey 1983, Khokiattiwong *et al.* 2000). Adult flyingfish are captured by gillnets of commercial mesh size primarily between December and June. A similar pattern of seasonal variation in abundance, as indicated by commercial catch, is typical of other eastern Caribbean countries. As indicated by gonosomatic indices of adults and by the seasonal distribution of juvenile hatch dates, spawning of *H. affinis* occurs between November and July (Khokiattiwong *et al*. 2000, Oxenford *et al*. 1994), which largely coincides with the period of seasonal availability of adults to the commercial gear; and preliminary data suggest that individual fish may spawn several times within the season (Storey 1983). However, there appear to be two peaks in spawning activity, a minor one from November to January and a major one from May to July (Lewis *et al.* 1962, Storey 1983, Khokiattiwong *et al*. 2000, Oxenford *et al*. 1994). The suggestion of bimodal spawning activity is also supported by data indicating that seasonal variation in abundance of small juveniles of *H. affinis* off Barbados may also be bimodal, with peaks in February-March and from May to August (Khokiattiwong *et al*. 2000). Information on seasonal abundance of adults, on seasonal variation in spawning, and on the duration of spawning of individual fish, is important if closed seasons are considered as a management option for flyingfish.

The results of year-round fishing with gillnets of different mesh size (Khokiattiwong *et al*. 2000) confirmed earlier suggestions of Lewis *et al*. (1962) and Storey (1983) that 2 cohorts of *H. affinis* are simultaneously present off Barbados. In May-June, the last months of the commercial fishing season, a mature adult cohort is present, as well as an immature cohort (mean size: 19.8 cm fork length). The immature cohort is presumably the older/faster-growing fish hatched in the current breeding season (i.e. in the November to January peak of the November to July breeding season). These immature fish continue to be captured between July and November, but catch rates are low, probably because only mature spawning fish are attracted to the fishing gear. By September, the mature cohort is no longer present. Only one cohort is therefore captured by gillnets between September and April, mean fish size increasing from about 20.4 cm FL to about 22.0 cm FL.

The mean size of fish in the Barbados commercial catch typically decreases between April and June, i.e. towards the end of the fishing season. This may result from older/faster-growing fish of the immature cohort being captured along with the mature cohort in the last months of the fishing season. Alternatively, and perhaps more likely since immature fish have low catchability by the commercial gear, it could result from a higher mortality rate of older/larger fish than younger/smaller fish within the mature cohort in the last months of the fishing season.

The sharp reduction in abundance of the mature cohort after June, and its apparent disappearance by September, could result either from post-spawning migration or post-spawning mortality. However, size composition of the catch provides no evidence of the old mature cohort re-appearing again at the start of the next spawning/fishing season. Moreover, adults tagged late in the season (May) in 1988 and 1989 were not recovered in the following seasons (Oxenford 1994). Post-spawning mortality may therefore better explain the disappearance of the mature cohort in June, since the inability to detect this cohort by size composition analysis at the start of the following fishing season is only consistent with a post-spawning migration hypothesis if there is no growth of fish of that cohort between June and December, or if the emigrants do not return to Barbados for the following

spawning/fishing season. The plausibility of heavy post-spawning mortality during and following June is supported by the observations that *H. affinis* may cease or decrease feeding during spawning (Barroso 1967), and that flyingfish taken by the commercial Barbados fishery in June are typically in poor condition and are often heavily infested with parasites (Lao *et al*. 2007).

The most plausible explanation of the abundance, reproduction, and size composition data is therefore that *H. affinis* is essentially an annual species, its non-availability to the commercial gear between July and November being an interim period between successive adult cohorts. The contention that *H. affinis* is an annual species strongly influences the approaches that can be used for stock assessment. Specifically, it determines that assessment approaches based on annual surplus production and on annual surplus recruitment are virtually the same, and that stock-recruitment relationships can be investigated through use of adult abundance in any year as parental stock, and adult abundance the following year as recruits. A stock-recruitment relationship, which assumed that *H. affinis* was annual and which used catch and effort data from the northwest of Barbados, suggests reduced recruitment at the lowest stock sizes observed (Mahon 1989). However, there is considerable recruitment variation around the stock-recruitment curve, and much of the variation remains unexplained. This suggests that surplus recruitment yield can not be predicted in any year with much precision, and that a more appropriate management approach may be to estimate what long-term average annual catch may be possible without undue risk of recruitment overfishing and stock collapse, i.e. it suggests that a risk assessment approach based on stock recruitment modelling may be the most appropriate.

GILLNET SELECTIVITY

The results of year-round fishing with gillnets of stretched mesh size 1.00", 1.25", 1.50" (Barbados commercial mesh size) and 1.75" (Mahon *et al.* 2000) suggest that the selectivity of the commercial net is close to 1 over the full size range of fish available to the gear during the fishing season (the mature cohort). This indicates that the net is taking the sizes available with similar probability, and is therefore effectively targeting the size range of fish available during the fishing season (see also Storey 1983). Nets of mesh 0.25" smaller or larger than 1.50", but particularly the latter, provided substantially lower catch rates. These results suggest that there is little potential for managing the fishery through regulation of mesh size.

SPAWNING AND EARLY LIFE-HISTORY

Seasonal variation in distribution and abundance of flotsam (as potential flyingfish spawning substrate) and of larval and juvenile fish off Barbados, is described in Hunte *et al.* (1995, 2007); and the distribution and relative abundance of flotsam, and of flyingfish eggs, larvae and juveniles across the eastern Caribbean is described in Hunte *et al.* (1995) and Oxenford *et al.* (1995a). Flotsam and *H. affinis* were rare year-round off Barbados, and throughout the eastern Caribbean in April-May (the peak spawning period). This suggests that *H. affinis* may typically spawn on floating material until it submerges, and/or spawn on submerged or benthic substrates. The possibility that flyingfish may spawn on benthic substrates emphasises the need to determine whether they have preferred spawning areas, and is important if area closures are considered an appropriate management tool. Furthermore, the location of spawning areas has implications for the allocation of catch quotas between countries, if a regional approach to management is deemed necessary and if catch or effort quotas are considered desirable. The scarcity of flyingfish spawning substrate may suggest that its availability limits flyingfish population size. This raises the management issue of whether recruitment could be enhanced by fishermen setting egg-laden FADs adrift, rather than returning them to shore. Flotsam was most abundant off Barbados between March and September, which corresponds with the time when fresher water from the rivers on the north coast of South America approaches Barbados as the Guyana Current. This raises the question of whether deforestation in the vicinity of the major rivers of northern South America could influence flotsam availability, and hence flyingfish abundance, in the eastern Caribbean.

Flyingfish (Exocoetidae) larvae were most abundant off Barbados between February and June. Flyingfish (*H. affinis*) juveniles became increasingly abundant off Barbados from February through to August. Along with the information presented in Hunte *et al.* (2007, Chapter 11), these results suggest that all life stages of *H. affinis* may be sequentially present year-round off Barbados. Spawning occurs primarily between December and June, larvae are most abundant between February and June, and juveniles are most abundant between February and August. Individuals of this cohort can be taken by gillnets of small mesh size in September, and can be taken by commercial mesh size nets by November-December, when seasonal spawning again begins. These data strongly support the contention that *H. affinis* is essentially an annual species, the fishery in the eastern

Caribbean being directed primarily at a different cohort each year.

The distribution and relative abundance of flyingfish larvae, juveniles and adults in the eastern Caribbean is described in Oxenford *et al.* (1995a, 1995b) and Hunte *et al.* (1995). Abundance of flyingfish adults varied significantly across the eastern Caribbean, abundance being highest leeward of the Lesser Antilles island chain and in an area between and to the east of Barbados and Tobago. The locations of these centres of abundance may change temporally. Regional variation in abundance has implications for the appropriate location of fishing effort by fleets, and for the allocation of catch or effort quotas between countries, if quotas were considered appropriate under a regional management plan. The abundance of *H. affinis* adults did not appear to decrease towards the east or west boundaries of the area of the eastern Caribbean surveyed, suggesting that catch rates may be similar if fleets expanded their present geographical fishing range. The distribution of adult flyingfish was patchy within all geographical zones surveyed, suggesting that daily commercial catch rates are likely to be variable.

The abundance of all flyingfish larvae varied significantly across the area surveyed, but larvae of *H. affinis* were relatively rare. The abundance of flyingfish juveniles, and specifically those of *H. affinis*, also varied significantly across the area surveyed. The geographical distribution of different life history stages within a species differed, distributions becoming more similar the closer the life history stages. The size structure of *H. affinis* juveniles collected regionally was similar to that of *H. affinis* juveniles off Barbados at the same time of year (Hunte *et al.* 1995). This may suggest that all life stages of this species are sequentially present year round, not only off Barbados, but throughout the region. The size structure of *H. affinis* juveniles collected regionally is consistent with previous suggestions that the species is annual.

AGE AND GROWTH

The hypothesis that *H. affinis* is an annual species was directly investigated by an age and growth study using daily otolith increments (Oxenford *et al*. 1994). The estimated growth rate of *H. affinis* would allow them to reach sexual maturity in 7-8 months. A radiochemical analysis of adult otoliths confirmed a 1-year life span (Campana *et al*. 1993.). The data suggest that growth of *H. affinis* slows markedly after sexual maturity. This is consistent with the results of the experimental gillnet fishing (Khokiattiwong *et al*. 2000), which indicates little size variation within a mature cohort (the harvested fish), and hence little capacity to manage the fishery by gillnet mesh size regulations. The size at age data generated by these studies are necessary for yield per recruit modelling of flyingfish.

Growth rates at age of *H. affinis* juveniles varied seasonally off Barbados and spatially across the eastern Caribbean (Oxenford *et al*. 1994). Juvenile growth rates were higher nearer to islands than at more oceanic locations, and were higher where sea surface temperatures were higher. Growth rates were lower for fish hatched early in the season (November-March, colder months) than for fish hatched later in the season (April-July, warmer months). This indicates that most spawning occurs when juvenile growth is fastest. Variation in growth rate with hatch date has implications for management approaches based on closed seasons.

MIGRATION AND MOVEMENT

Movement of *H. affinis* in the eastern Caribbean was investigated by a large-scale (7,019 fish) tagging experiment (Oxenford 1994). Ten percent of all recaptures were from territorial waters other than those in which fish were released, emigrations were recorded in all directions, and migration between islands was often quite rapid. These results indicate considerable movement of *H. affinis* between countries in the eastern Caribbean, and indicate that the minimum appropriate management unit for *H. affinis* should be the combined EEZs of eastern Caribbean countries.

POPULATION STRUCTURE

Analyses of genetic variation of 360 *H. affinis* from five locations (Barbados, Dominica, Tobago, Curaçao and Caicara, Brazil) in the Western Central Atlantic were carried out using RFLP markers in the D-loop region of the mtDNA (Gomes et al. 1999) and RAPD markers in nuclear DNA (Gomes et al. 1998). The findings indicate three genetically discrete subregional stocks of *H. affinis* located in the eastern Caribbean, the southern Netherlands Antilles and off NE Brazil.

PREDATION

Predators of juvenile and adult flyingfish include large oceanic pelagics (e.g. sailfish, large tunas, dolphinfish and wahoo; Oxenford 1986), which are typically harvested on the same fishing trips as flyingfish, and/or for which flyingfish are the primary bait.

Management options for flyingfish must therefore be sensitive to the multispecies nature of the fishery, to the biotic dependency of large pelagics on flyingfish, and to the possibility that flyingfish may be increasingly harvested in the eastern Caribbean for bait.

REFERENCES

Barroso, L.M. 1967. Biologica e pesca de peixe-volador (*Hirundichthys affinis* Gunther) no estado do rio Grande do Norte. B. est. Pesca 7: 9-37.

Campana, S.E., H.A. Oxenford and J.N. Smith. 1993. Radiochemical determination of longevity in flyingfish (*Hirundichthys affinis*) using ^{228}Th:^{228}Ra. Mar. Ecol. Prog. Ser. 100: 211-219.

Gomes, C., H.A. Oxenford and R.B.G. Dales. 1999. Mitochondrial DNA D-loop variation and implications for stock structure of the four-wing flyingfish, *Hirundichthys affinis*, in the central western Atlantic. Bull. Mar. Sci. 64(3): 485-500.

Gomes, C., R. Dales and H.A. Oxenford. 1998. The application of RAPD markers in stock discrimination of the four-wing flyingfish, *Hirundichthys affinis* in the central western Atlantic. Molecular Ecology 7: 1029-1039.

Hunte, W., M.R. Lao, R. Mahon and H.A. Oxenford. 2007. Juvenile fishes off Barbados with particular reference to flyingfishes. In Oxenford, H.A., R. Mahon and W. Hunte (eds.) Biology and management of eastern Caribbean flyingfish. Centre for Resource Management and Environmental Studies, University of the West Indies, Barbados: 95-106.

Hunte, W., H.A. Oxenford and R. Mahon. 1995. Distribution and relative abundance of flyingfish (Exocoetidae) in the eastern Caribbean. II. Spawning substrata, eggs and larvae. Mar. Ecol. Prog. Ser. 117: 25-37.

Khokiattiwong, S., R. Mahon and W. Hunte. 2000. Seasonal abundance and reproduction of the fourwing flyingfish, *Hirundichthys affinis*, off Barbados. Env. Biol. Fish. 59:43-60.

Lao, M.R. 1989. Distribution and abundance of flotsam, larval fish and juvenile fish off Barbados with particular reference to the Exocoetidae. M.Sc. Thesis, McGill University, Montreal, Canada. 147pp.

Lao, M.R., W. Hunte and H.A. Oxenford. 2007. Larval fishes off Barbados with particular reference to flyingfishes and their spawning substrata. In Oxenford, H.A., R. Mahon and W. Hunte (eds.) Biology and management of eastern Caribbean flyingfish. Centre for Resource Management and Environmental Studies, University of the West Indies, Barbados: 75-94.

Lewis, J.B., J.K. Brunditt and A.G. Fish. 1962. The biology of the flyingfish, *Hirundichthys affinis* (Gunther). Bull. Mar. Sci. 12: 73-94.

Mahon, R. 1989. Developing a management strategy for the flyingfish fishery of the eastern Caribbean. Proc. Gulf Carib. Fish. Inst. 39: 389-403.

Mahon, R. 1990. Seasonal and interseasonal variability of the oceanic environment in the eastern Caribbean: With reference to possible effects on fisheries. FAO FI: TCP/RLA/8963 Field Document 5, 45 pp.

Mahon, R., S. Khokiattiwong and H.A. Oxenford. 2000. Selectivity of experimental gillnets for fourwing flyingfish, Hirundichthys affinis, off Barbados. Env. Biol. Fish. 59: 459-463.

Mahon, R., F. Murphy, P. Murray, J. Rennie and S. Willoughby. 1990. Temporal variability of catch and effort in pelagic fisheries in Barbados, Grenada, St. Lucia and St. Vincent: with particular reference to the problem of low catches in 1989. FAO FI:TCP/RLA/8963 Field Document 2, 74 pp.

Nesterov, A.A. and M. Ye. Grudtsev. 1981. The quantitative distribution of flyingfish of the family Exocoetidae (Beloniformes) in the tropical Atlantic. J. Ichth. 20(3): 137-140. Oxenford, H. A. 1986. Synopsis of the biological data on the four-winged flyingfish *Hirundichthys affinis* Gunther, pp. 51-84. In: Mahon, R., H. A. Oxenford and W. Hunte (eds.) 1986. Development strategies for flyingfish fisheries of the eastern Caribbean. International Development Research Centre, Ottawa, Canada, IDRC-MR 128e.

Oxenford, H.A. 1994. Movements of flyingfish (*Hirundichthys affinis*) in the eastern Caribbean. Bull. Mar. Sci. 54(1): 49-62.

Oxenford, H.A., R. Mahon and W. Hunte. 1995a. Distribution and relative abundance of flyingfish (Exocoetidae) in the eastern Caribbean. I. Adults. Mar. Ecol. Prog. Ser. 117: 11-23.

Oxenford, H.A., R. Mahon and W. Hunte. 1995b. Distribution and relative abundance of flyingfish (Exocoetidae) in the eastern Caribbean. III. Juveniles. Mar. Ecol. Prog. Ser. 117: 39-47.

Oxenford, H.A., R. Mahon and W. Hunte. 1993 [ed.]. The Eastern Caribbean Flyingfish Project. OECS Fishery Report No. 9, 187 pp.

Oxenford, H.A., W. Hunte, R. Deane and S.E. Campana. 1994. Otolith age validation and growth-rate variation in flyingfish (*Hirundichthys. affinis*) from the eastern Caribbean. Mar. Biol. 118: 585-592.

Parin, N.V. 1970. Icthyofauna of the epipelagic zone. Israel Program for Scientific Translations, Keter Press, Jerusalem, 205 pp.

Storey, K.W. 1983. Aspects of the biology and fishery of the flyingfish, *Hirundichthys affinis*, at Barbados. M.Phil. Thesis, University of West Indies, Barbados, 161 pp.