Flyingfish predators, prey and research methods: Lessons learned in the eastern Caribbean

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Flyingfishes – Exocoetidae

Order: Beloniformes

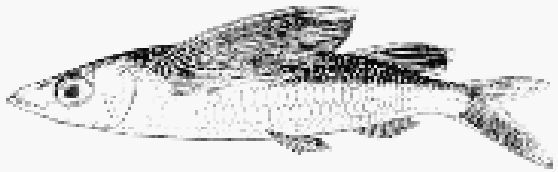
8 genera 67 species

- Cheilopogon
- Cypselurus
- Danichthys
- Exocoetus

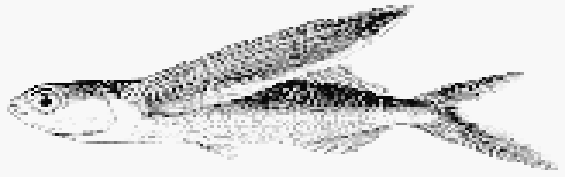
Source: Fishbase. Photo by C. Jesson

- Fodiator
- Hirundichthys
- Parexocoetus
- Prognichthys

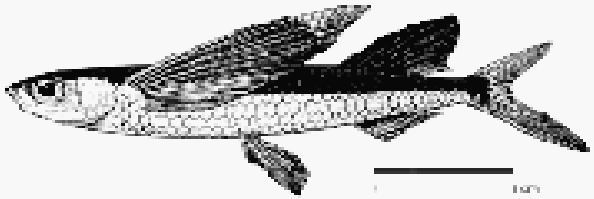
Two-winged flyingfishes



Fodiator (2 spp)

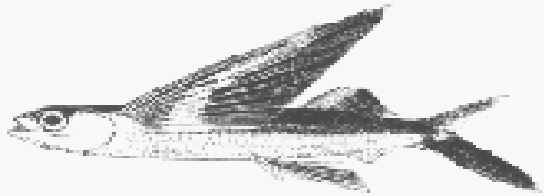


Exocoetus (5 spp)

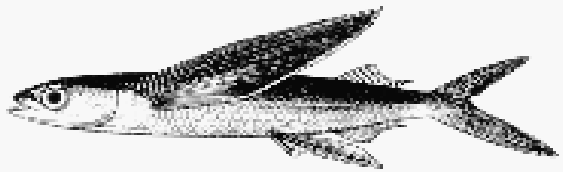


Parexocoetus (3 spp)

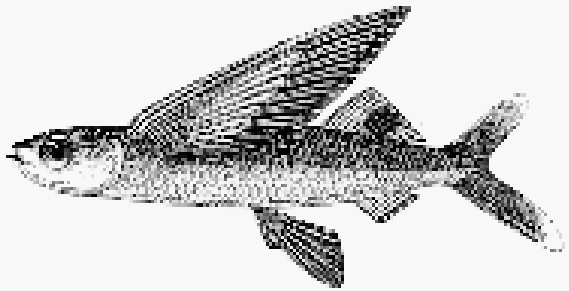
Four-winged flyingfishes



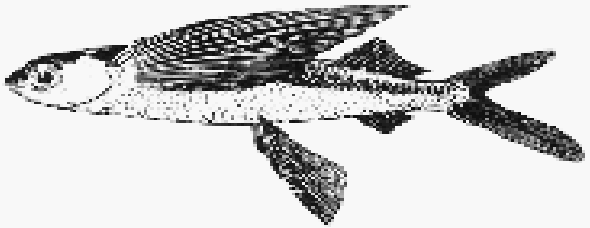
Cypselurus (12 spp)



Hirundichthys (8 spp)

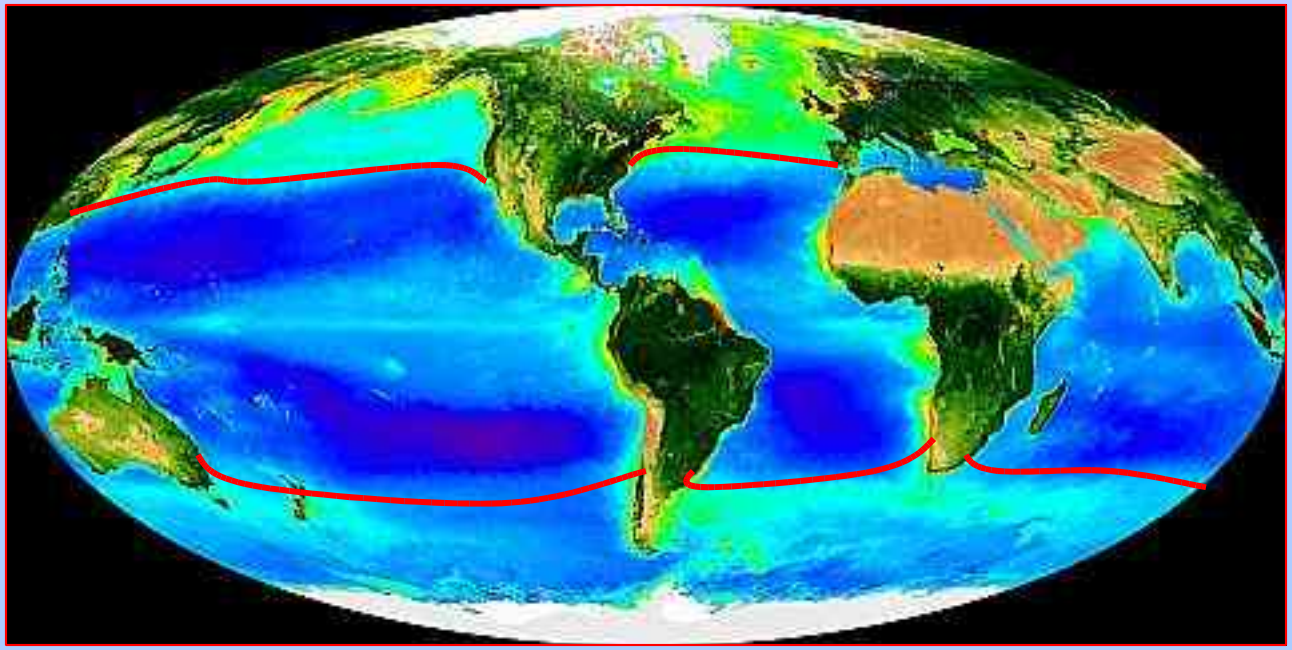


Cheilopogon (30 spp)



Prognichthys (6 spp)

Distribution and characteristics of flyingfishes



Source of image: SeaWifs

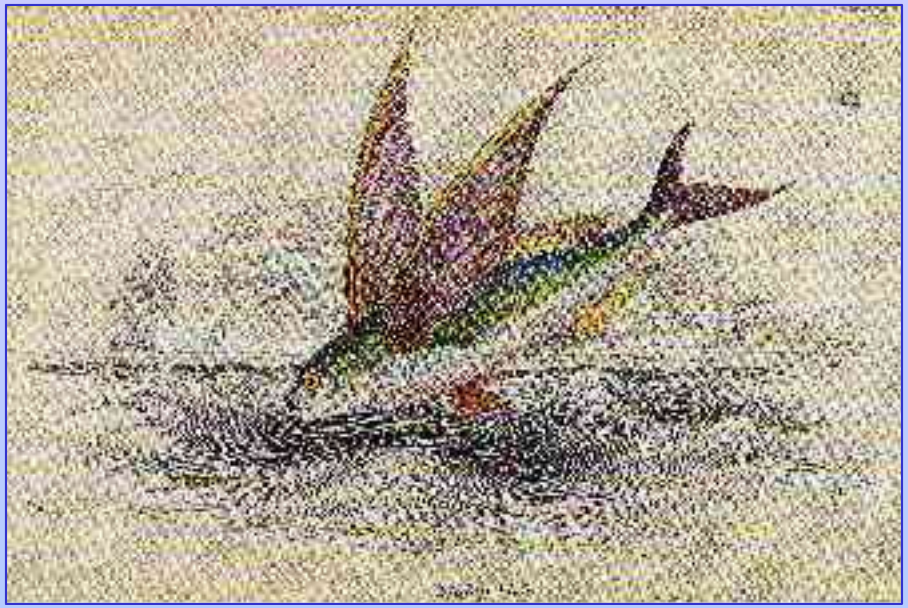
- Global distribution in tropics and subtropics
- Strictly epipelagic
- Oceanic and neritic species

- Most restricted to single ocean (some circum-global)
- Small (most < 30 cm)
- Capable of gliding flight

Importance to global fish yield

- Majority of species (> 30) support small scale fisheries
- Annual landings globally > 73,000 mt
- Best known flyingfish fishery is in Barbados
- The target species is the Atlantic fourwing flyingfish (*Hirundichthys affinis*)


Gulf of Mexico
North Atlantic Ocean
THE BAHAMAS
CUBA
JAMAICA
MEXICO
Caribbean Sea
North Pacific Ocean
COLOMBIA
VENEZUELA
BRAZIL



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Traditional fishery in Barbados

- Ligon 1651
- Hughes 1750
- Schomburgk 1848
- Up to 1950s sailing boats

Economic importance of flyingfish to Barbados

- 300 day-boats, 150 ice-boats
- 1,100 fishers, 450 persons in post harvest

Economic importance of flyingfish to Barbados

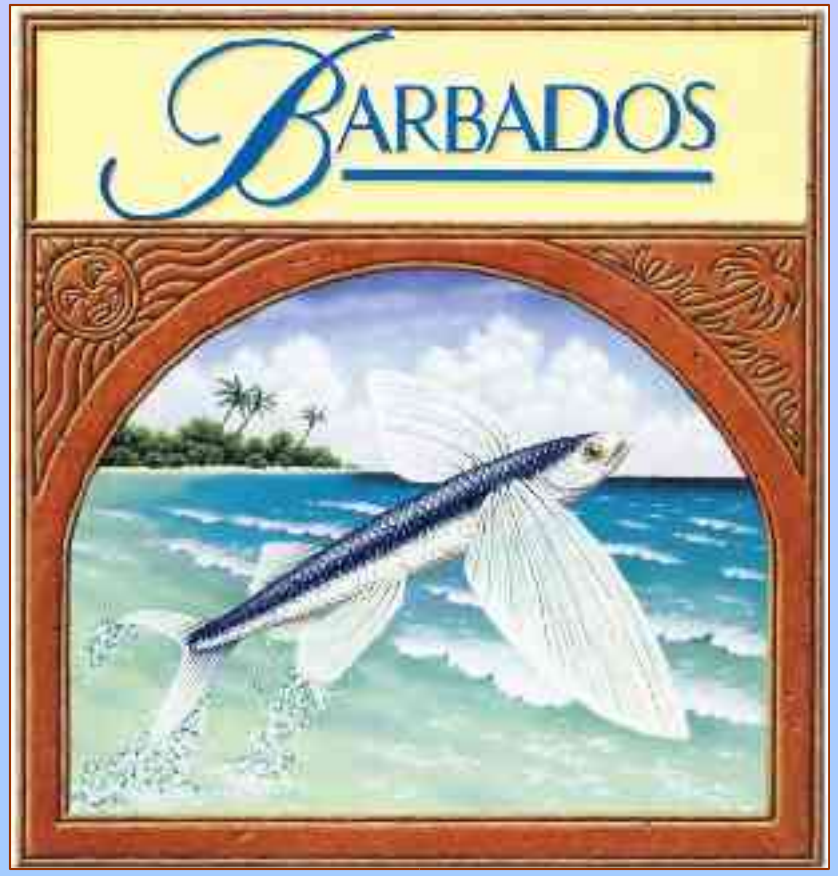
- Landings > 2,000 mt per year
- Represent > 60% of annual fish landings
- Ex-vessel value of US $ 2.65 million
- 6 fish processing companies

Cultural importance of flyingfish to Barbados

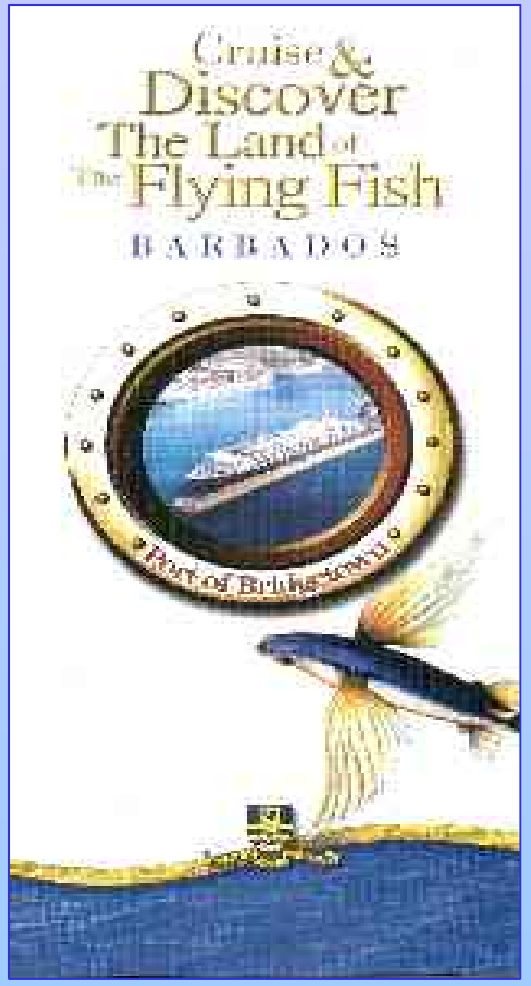
- National dish
- Dollar coin
- Definitive stamps
- Promotionary material

Source: Fishbase

Cultural importance of flyingfish to Barbados



BARBADOS
Tourism Authority



Barbados Port Authority

Cultural importance of flyingfish to Barbados

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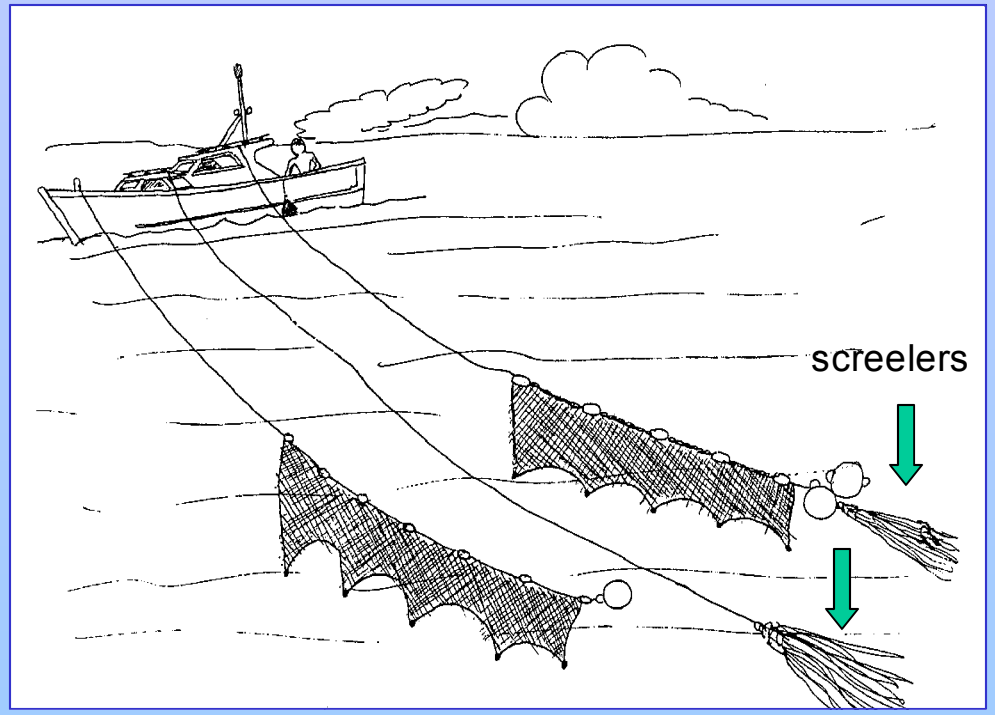
A way of life for many Barbadians

Fishing Techniques in Barbados

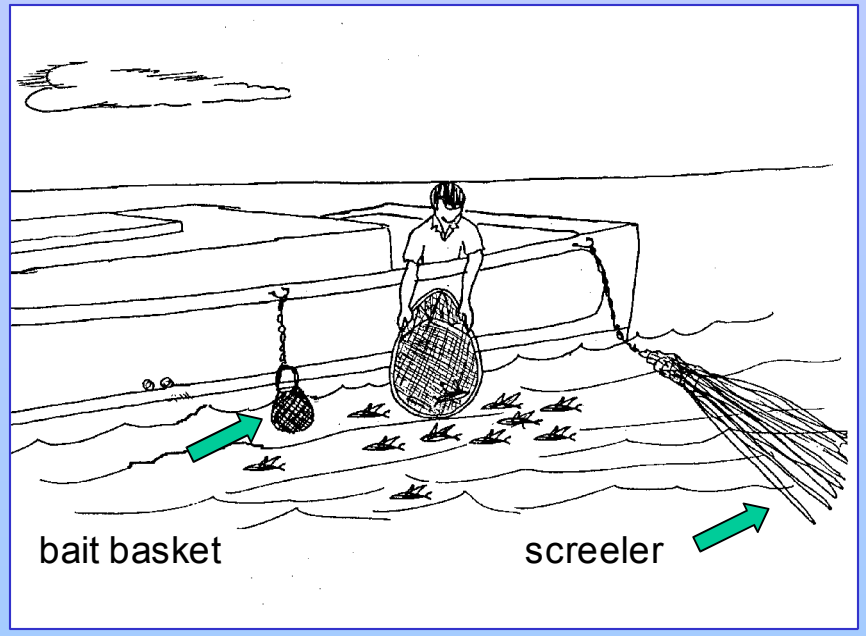
- Surface floating gillnets
- FADs ("screelers")



Courtesy of the Fisheries Division

Fishing Techniques in Barbados

- Dipnets
- Chum basket

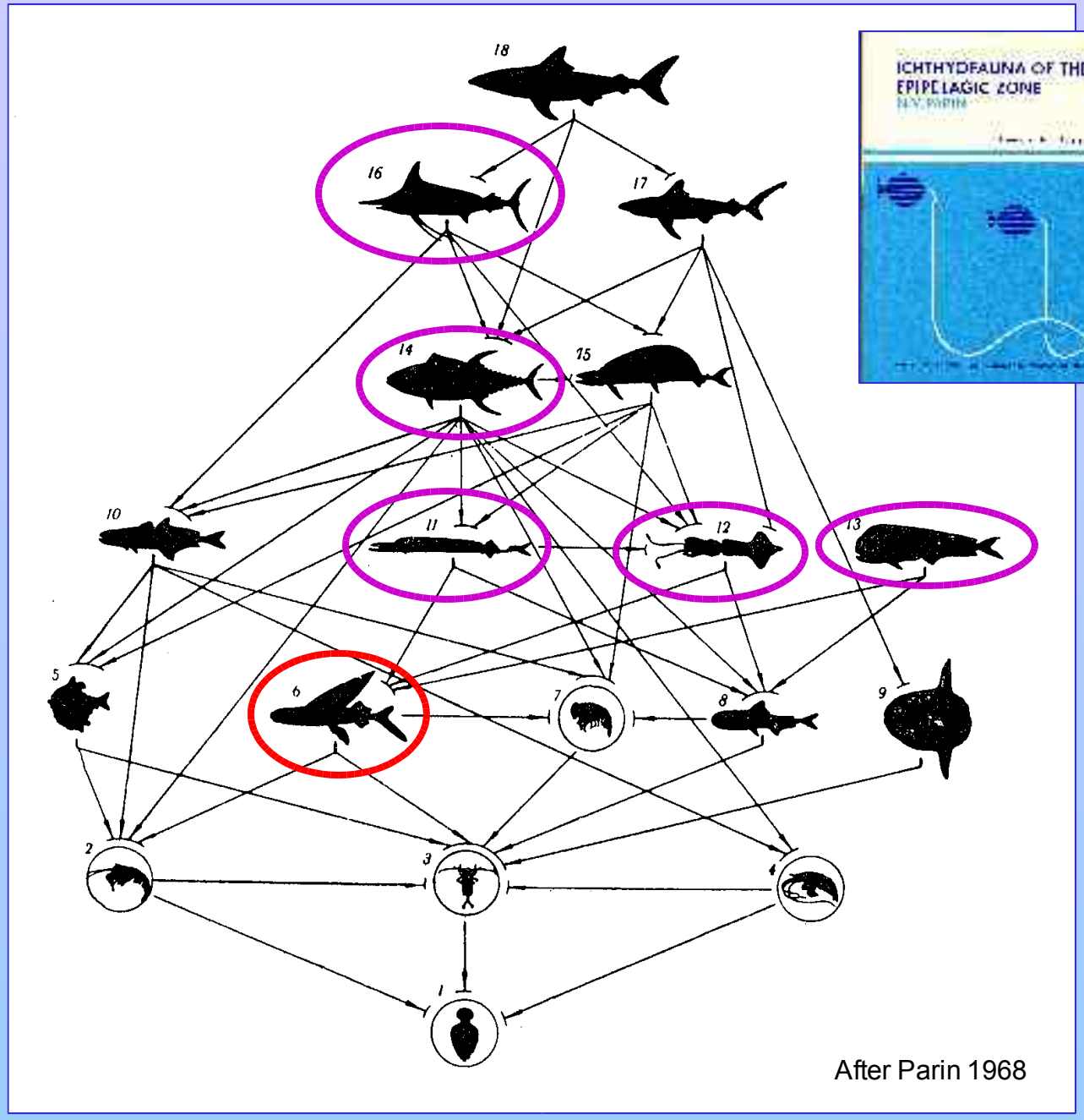


Courtesy of the Fisheries Division

Predators

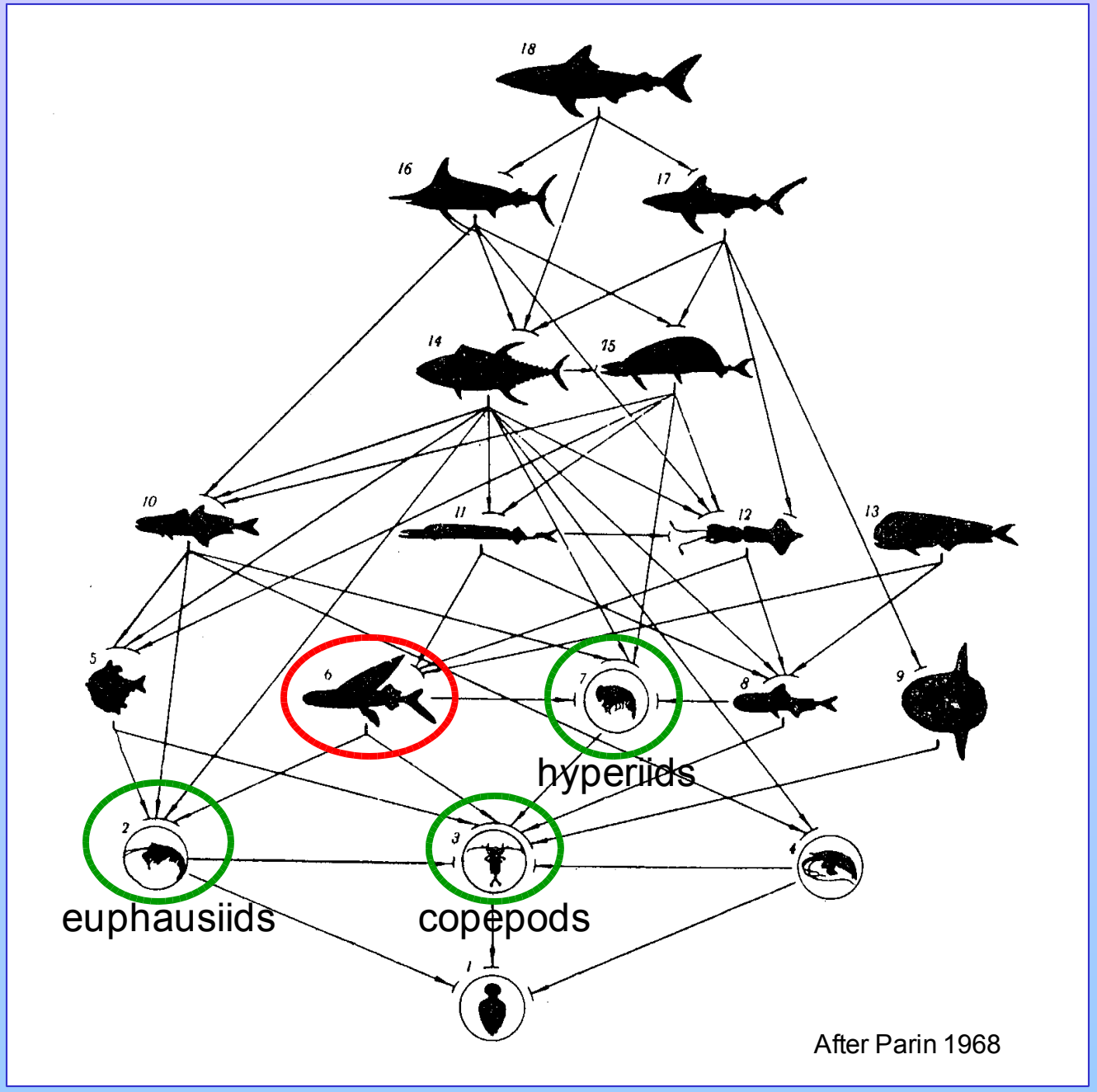
Marine mammals
- dolphins
- sea lions

Sea birds
- boobies
- noddies
- frigate birds



Prey

- small finfishes
- pteropods
- ostracods
- amphipods
- decapods
- chaetognaths
- ascidians
- siphonophores
- salps



Flyingfish prey studies

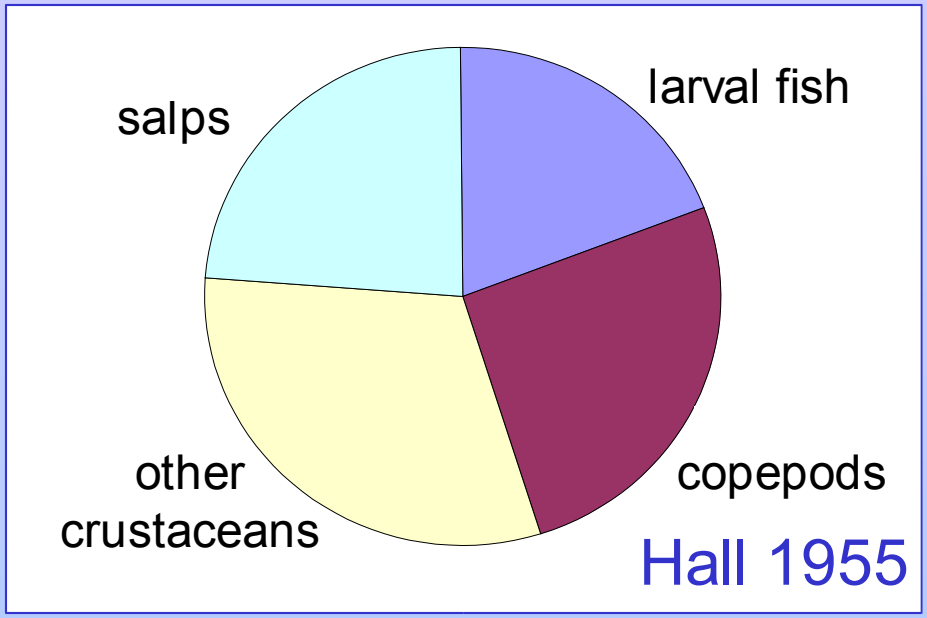
Flyingfish species	Common name	Prey items	Age	Tropic level	References	n
Exocoetus monocirrhus	barbel flyingfish	planktonic copepods, pelagic gastropods,	juvenile		Gorelova 1980	
		radiolaria, salphidae, chaetognatha				
Prognichthys sealei	sailor flyingfish	planktonic copepods, ostracods, gastropods	juvenile		Gorelova 1980	
Hirundichthys affinis	fourwing flyingfish	small finfishes, planktonic copepods, euphausid amphipods, chaetognaths, siphonophores, gastropods, pteropods, squids, salps, fish eggs, macroalgae fragments, marine insects	adult		Hall 1955, Lewis et al 19 Barroso 1967 Cruz & Araujo 1971	441, 293 317, 931,
Cheilopogon cyanopterus	margined flyingfish	planktonic crustaceans, other zooplankton	juv/adult		Heemstra and Parin 1986	
Parexocoetus brachypterus	sailfin flyingfish	zooplankton	juv/adult		Lewis 1961 Masuda and Allen 1993	
Cheilopogon heterurus	Mediterranean flyingfish	planktonic copepods, euphausiids, fish eggs/larvae	larvae	3.1	Lipskaya 1987	17, 22
Exocoetus obtusirostris	oceanic two-wing flyingfish	ascidians, planktonic copepods	larvae	3	Lipskaya 1987	20, 10
Exocoetus volitans	tropical two-wing flyingfish	planktonic copepods, ascidians	larvae	3.0 - 3.1	Lipskaya 1987	0, 10, 4, 3, 15
Hirundichthys speculiger	mirrorwing flyingfish	planktonic copepods	larvae	3	Lipskaya 1987	
Cheilopogon agoo	Japanese flyingfish	zooplankton	juv/adult		Masuda and Allen 1993	
Cheilopogon doederleinii	n/a	zooplankton	juv/adult		Masuda and Allen 1993	
C. pinnatibarbatus japonicus	n/a	zooplankton	juv/adult		Masuda and Allen 1993	
Cypselurus hiraii	n/a	zooplankton	juv/adult		Masuda and Allen 1993	
Cypselurus poecilopterus	yellow-wing flyingfish	zooplankton	juv/adult		Masuda and Allen 1993	
Cheilopogon rapanouiensis	Easter island flyingfish	small finfishes, zooplankton	juv/adult		Parin 1996	
Cheilopogon furcatus	spotfin flyingfish	finfishes, zooplankton	juv/adult		Parin 1999	
Cheilopogon intermedius	n/a	small finfishes, zooplankton	juv/adult		Parin 1999	
Cheilopogon pitcairnensis	n/a	small finfishes, zooplankton	juv/adult		Parin 1999	
Cheilopogon spilonotopterus	stained flyingfish	small finfishes, zooplankton	juv/adult		Parin 1999	
Cheilopogon spilopterus	manyspotted flyingfish	small finfishes	juv/adult		Parin 1999	
Cheilopogon suttoni	Sutton's flyingfish	small finfishes, zooplankton	juv/adult		Parin 1999	
Cypselurus hexazona	n/a	small finfishes, zooplankton	juv/adult		Parin 1999	
Cypselurus oligolepis	largescale flyingfish	small finfishes, zooplankton	juv/adult		Parin 1999	
Cypselurus opisthopus	black-finned flyingfish	small finfishes, zooplankton	juv/adult		Parin 1999	
Cheilopogon pinnatibarbatus	Bennett's flyingfish	zooplankton, finfishes	juv/adult		Parin and Gibbs 1990	
C. pinnatibarbatus melanocerus	n/a	zooplankton, planktonic crustacean	juv/adult		Paulin et al 1989	

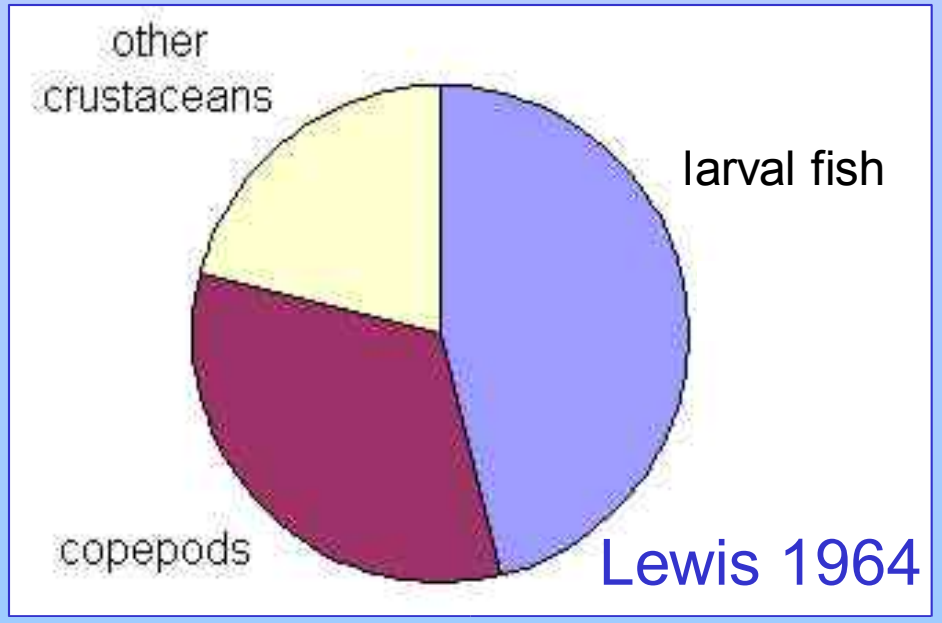
Primary source: FishBase

Detailed diet composition

Hirundichthys affinis

Early studies used frequency of occurrence in stomachs





Feeding Habits

- Feed exclusively on small zooplankton
- Actively hunt mostly for small finfishes, copepods and other crustaceans
- Also eat other planktonic invertebrates
- Can be considered tertiary-level feeders
- Feed mostly at night
- Feed actively through the spawning season

Competitors

For Euphausiids:

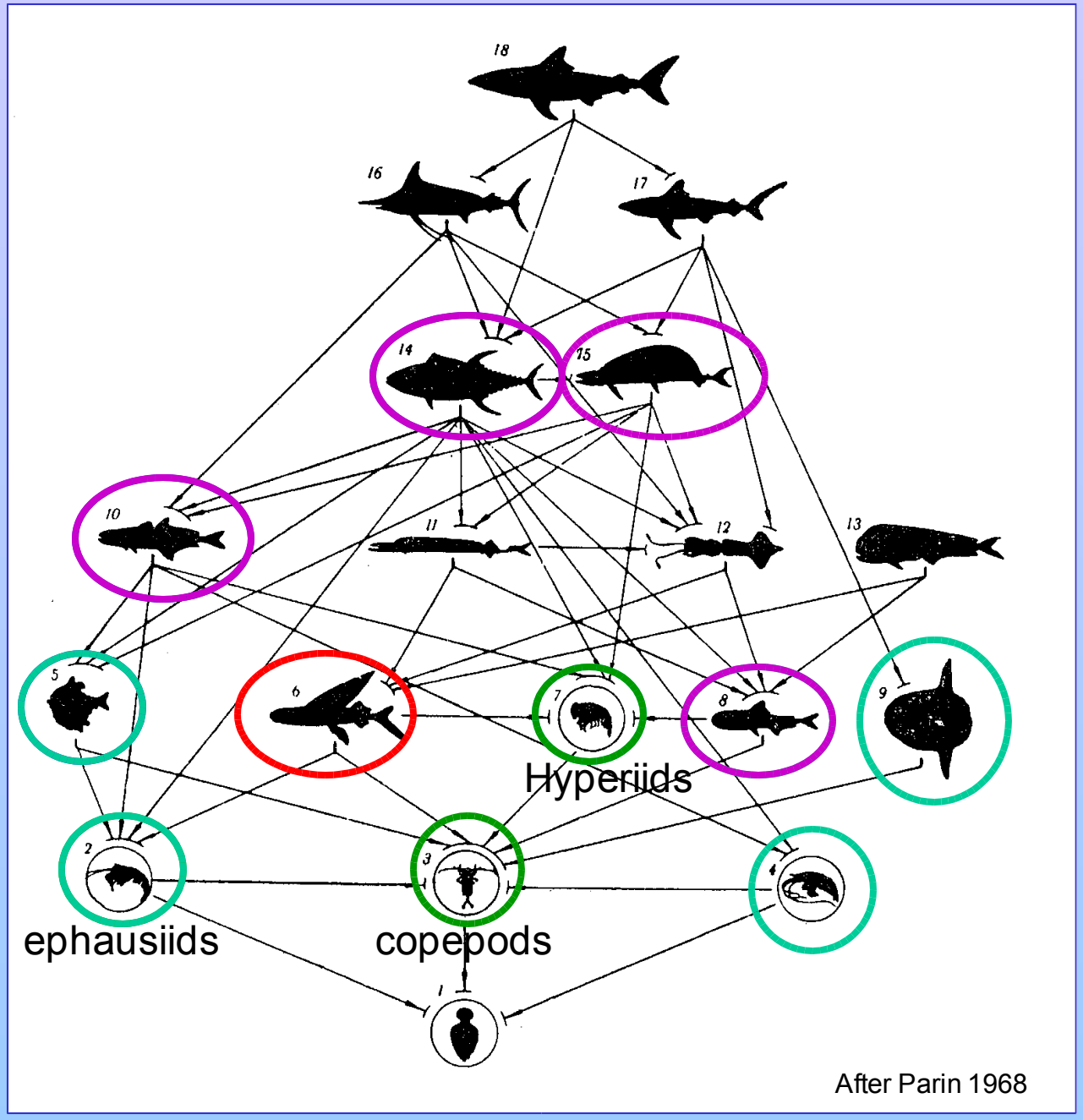
- fishes of the ‘shifting layers’
- small deep water fishes (Chiasmodon)
- Tuna

For Copepods:

- euphausiids
- shrimp
- shifting layer fishes
- hyperiids
- myctophiids
- molas

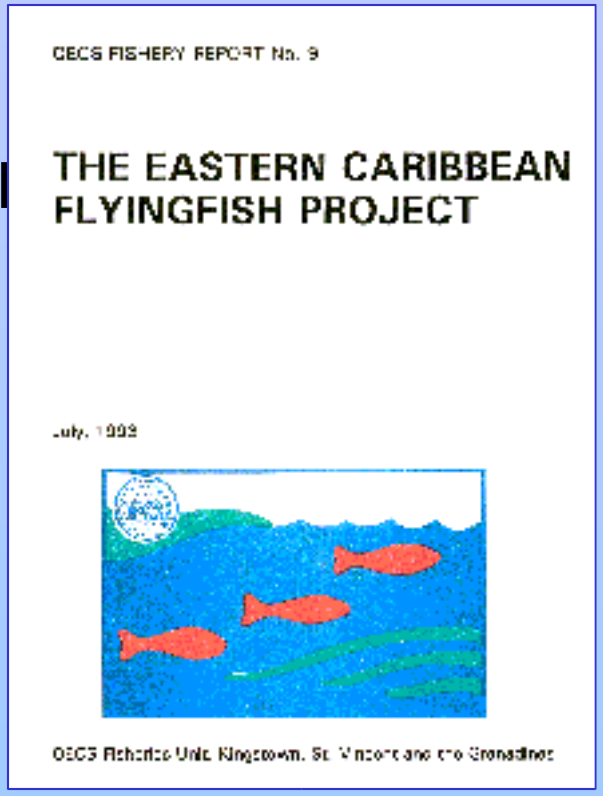
For Hyperiids:

- myctophids
- small deep water fishes
- tunas
- snake mackerels



Research Methods

- Eastern Caribbean Flyingfish Project
- Funded by IDRC
- 5-year duration (1986-1991)
- University of the West Indies and Research Institute
- Fishery Divisions of 7 countries
- 3 scientists, 4 MPhil students



Research Methods

- Distribution and abundance of adults, juveniles, larvae and eggs
- Movements
- Age determination
- Spawning behaviour
- Genetic population structure

Distribution and Relative Abundance

Adults and Juveniles

- Acoustic gear
- Visual survey
- Night-lighting
- Predator gut contents
- Fishery catch data

Eggs and Larvae

- Neuston net tows

Survey vessel

Sonar Technology
Adults and juveniles

- Hull mounted fish finder (vertical and side scan)
- Surface towed sonar (looking up, looking down)

Conclusion

Significant failure!

Visual Survey

Adults and juveniles

EASTERN CARIBBEAN FLYINGFISH PROJECT
ABUNDANCE SURVEY CRUISE

VISUAL COUNT DATA SHEET — CRUISE NO: 1

Name: ..... — Sheet No:.... / No. of sheets.....

Vessel Name: R/V Provider — OBSERVER POSITN: PRT

Date: 25./4/88 — Time: Start 14.52 hrs, Finish 15.52 hrs

Transect No: ...23.... — SPEED: 8 /Knots

Wind over: bow stern (port) starboard — Sun positioned: infront (behind) overhead

Vessel travelling: into waves away from waves // to waves; ~~diagonally into waves~~ diagonally away from waves

Hirundichthys affinis

Time (mins)	Number observed <5	5-9	10-14	15-19	20-24	25-29	>30	Comments
5			12				12	3/2/1/1/4/1/1/
10						27	27	2/1/1/2/3/1/1/1/1/10/
15		8					8	1/1/1/2/1/1/1/1/
20							35	3/1/4/4/3/8/7/5
25					20		20	1/3/2/1/1/1/4/1/1/1
30		7					7	1/1/1/1/2/1/
35	3						3	1/1/1/
40	0						0	.
45	3						3	1/1/1/
50	3					(124)	3	1/1
55					24		24	1/1/1/1/1/20/
60		6					6	1/3/1/1/

Cypselurus cyanopterus

Time (mins)	Number observed <5	5-9	10-14	15-19	20-24	25-29	>30	Comments
5	0							
10	0							
15	0							
20	0							
25	0							
30	0						0	
35	0							
40	0							
45	0							
50	0							
55	0							
60	0							

Parexocoetus brachypterus

Time (mins)	Number observed <5	5-9	10-14	15-19	20-24	25-29	>30	Comments
5					21		21	6/1/2/2/1/1
10	2						2	1/1/
15	0						0	
20						26	26	1/8/1/1/10/6/
25			13				13	1/1/1/7/1/3/
30					21		21	1/15/2/1/1/
35	1						1	1
40				17			17	7/6/4/
45							32	5/2/10/5/
50					(189)		52	4/10/8/8/23/1/
55	0						0	
60	4						4	1/3

Unidentified

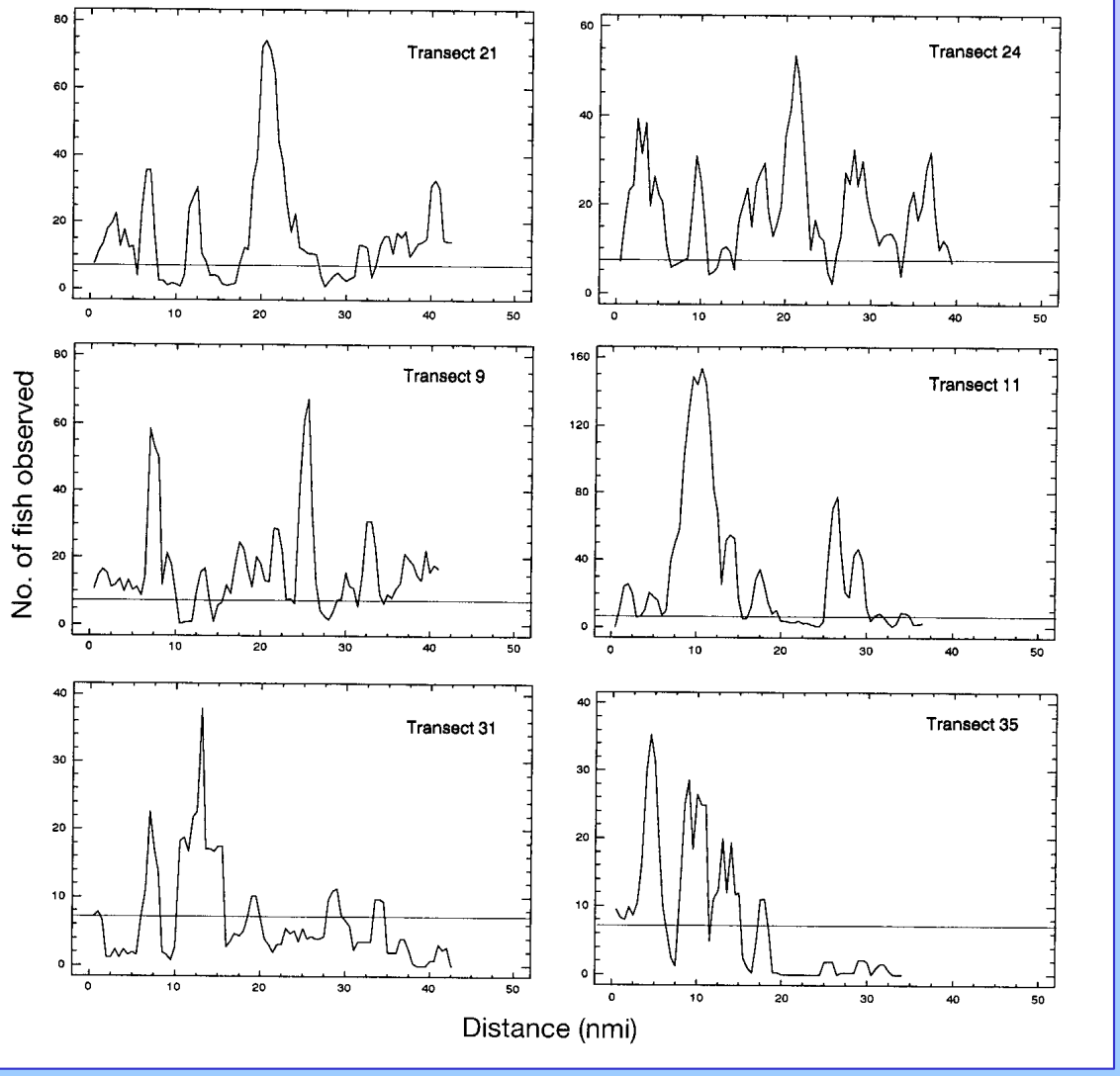
Time (mins)	Number observed <5	5-9	10-14	15-19	20-24	25-29	>30	Comments
5	0						0	
10	0						0	
15	2						2	2
20	0						0	
25	1						1	1
30	0						0	
35	0			3			0	
40	0						0	
45	0						0	
50	0						0	
55	0						0	
60	0						0	

- Any small ones were flying fish or parexocoetus.

Visual Survey

Distribution and size of flyingfish patches

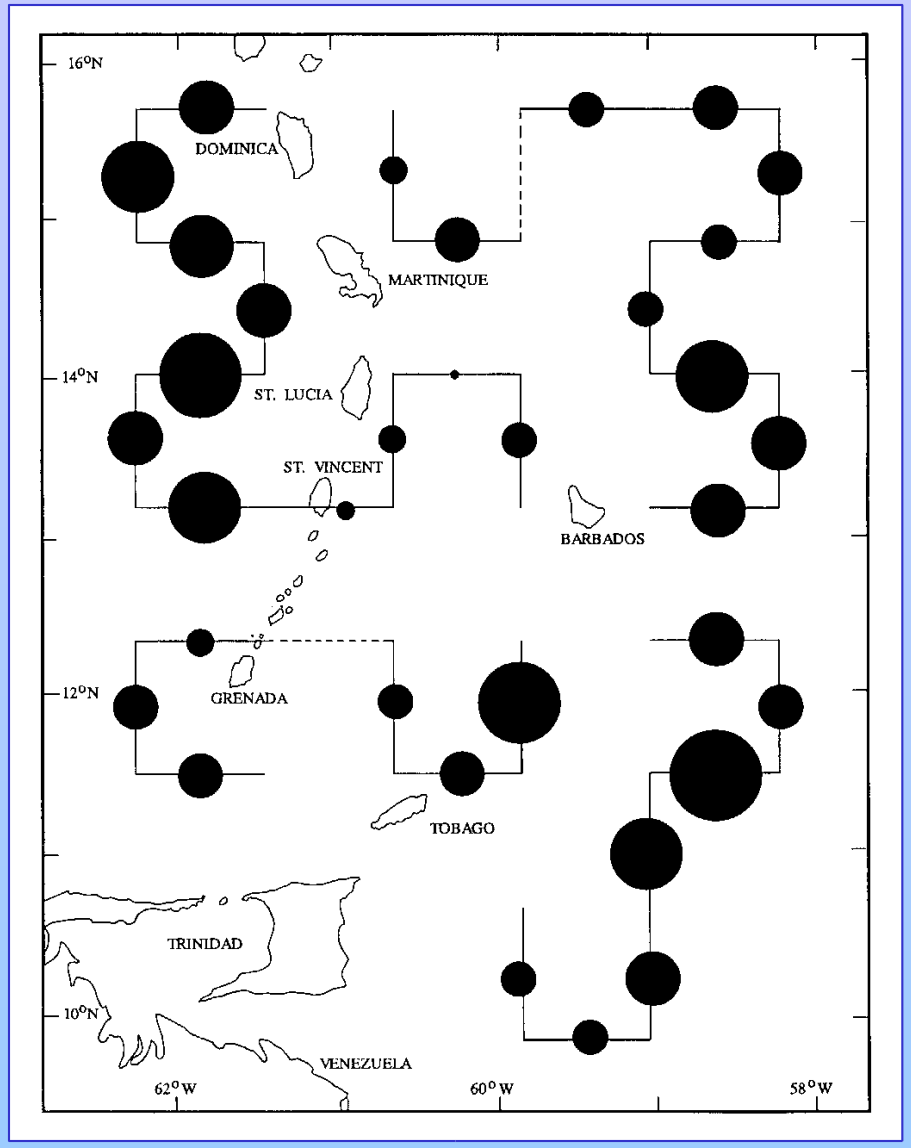
Image removed



From: Oxenford et al. 1995a

Visual Survey

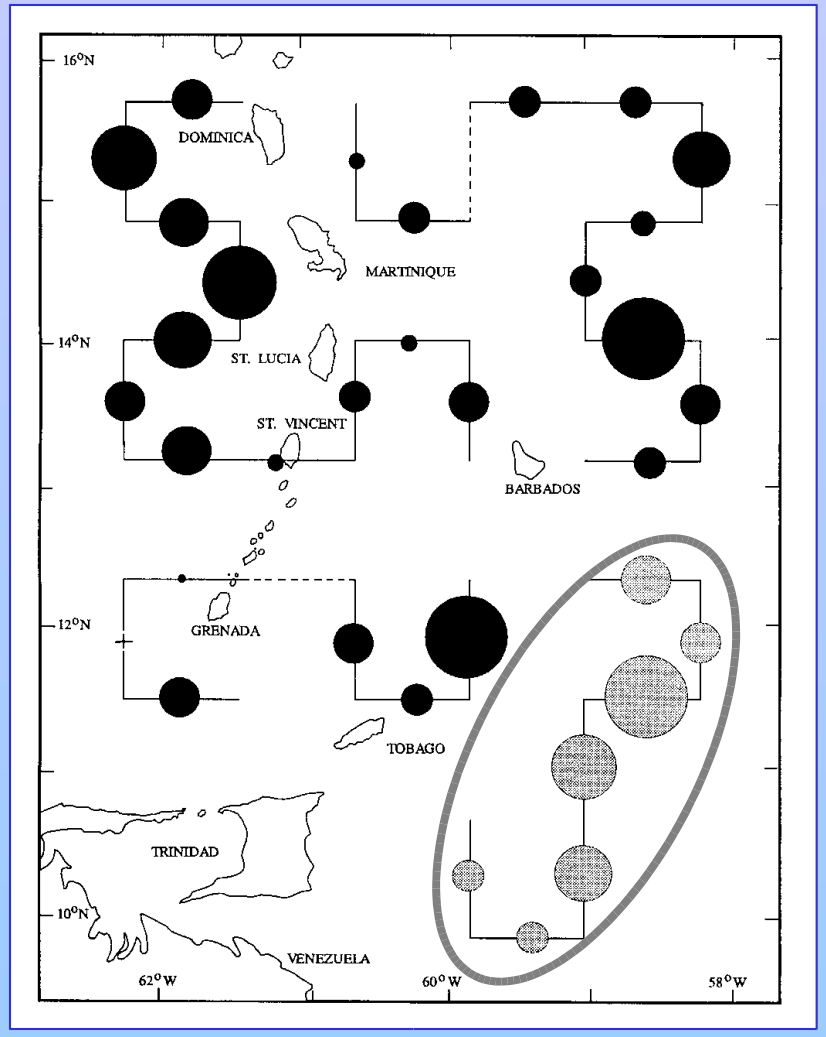
Relative abundance of all flyingfishes across the eastern Caribbean



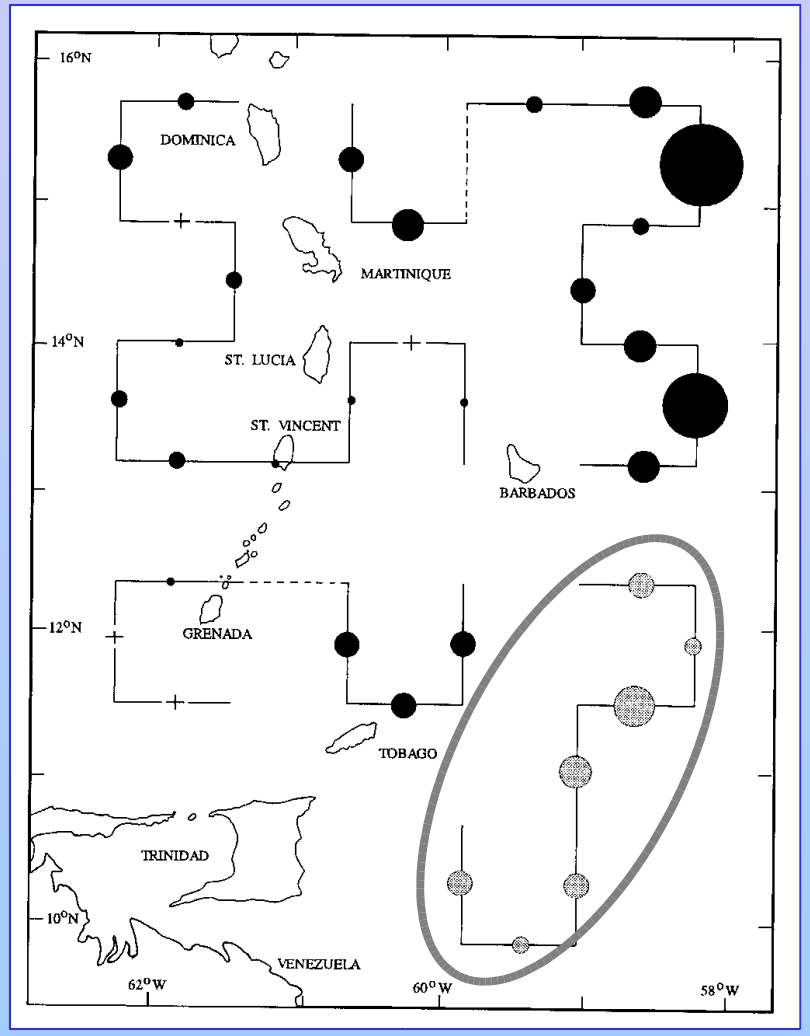
From: Oxenford et al. 1995a

Visual Survey

Parexocoetus brachypterus



From: Oxenford et al. 1995a



Cheilopogon cypselurus

Visual Survey

Note:

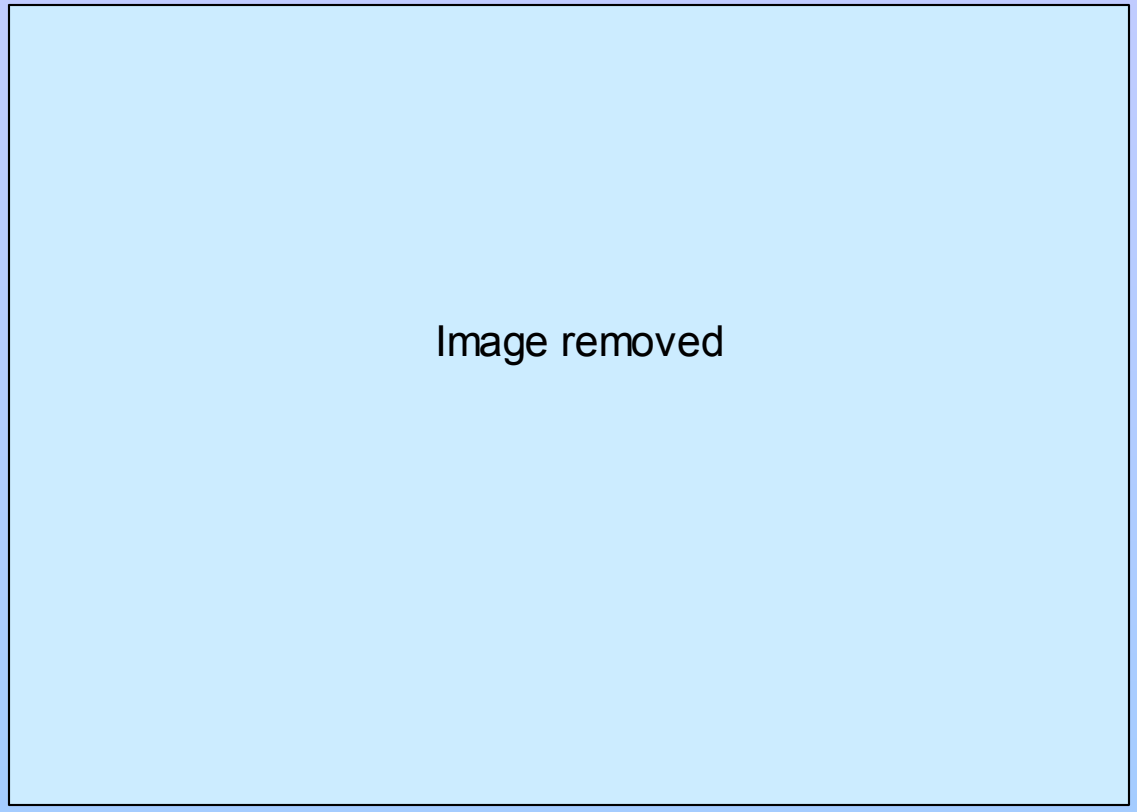
- Assumes a constant proportion of the school flies
- Close correlation with other indices (dipnet data)

Conclusions

- Provide reliable data on relative abundance
- Easy and relatively inexpensive
- Suitable for individual species
- Objectivity could be improved with additional instrumental recording (e.g. video)

Night-Lighting and Dipnetting

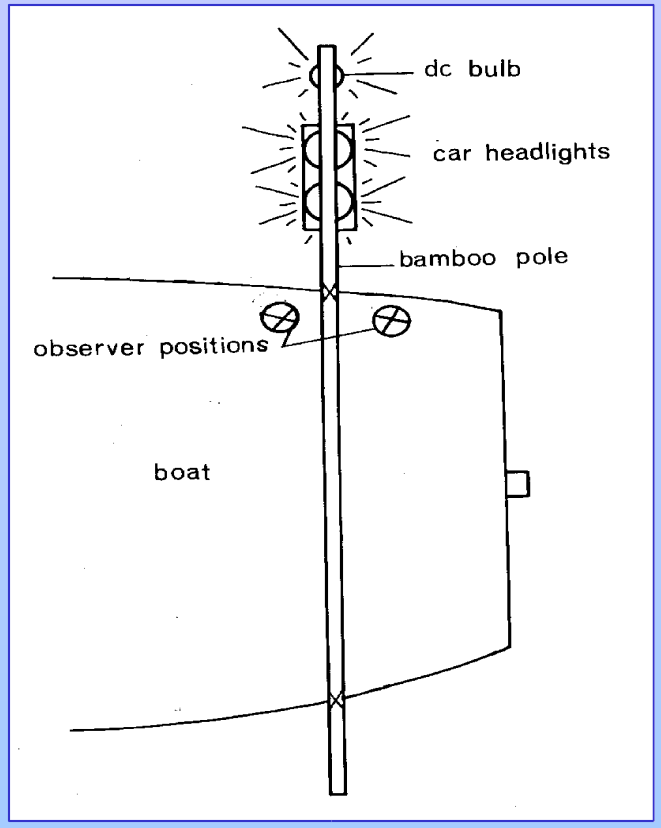
Adults and juveniles



Traditional flyingfish fishing in Tokelau

Night-Lighting and Dipnetting

- 200 watt spot lamps
- 5 mm mesh dipnet
- 4 replicate stations
- 40 mins each

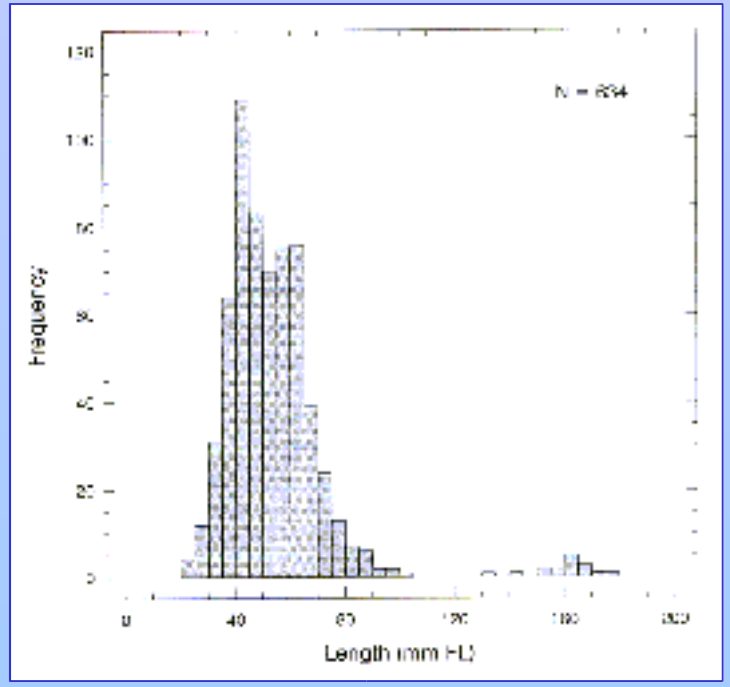


From: Lao 1989

Arrangement of nightlights on small fishing vessel

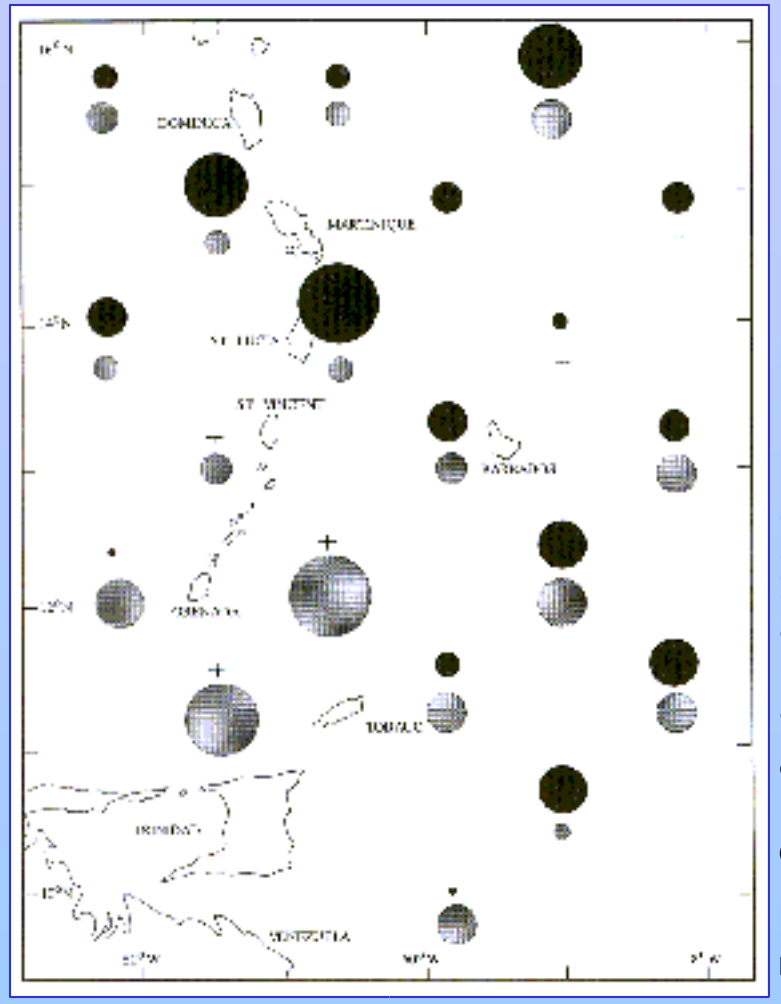
Night-Lighting and Dipnetting

- Partitioning by species



From: Oxenford et al. 1995b

Exocoetus volitans



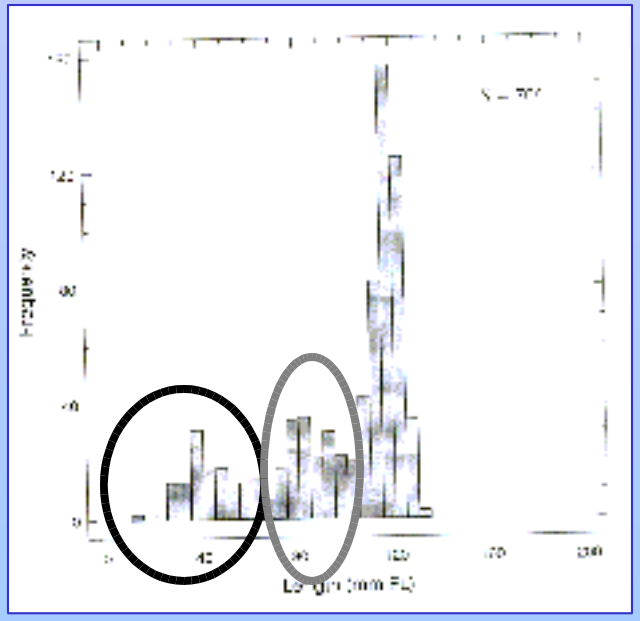
From: Oxenford et al. 1995b

Hirundichthys affinis

Exocoetus volitans

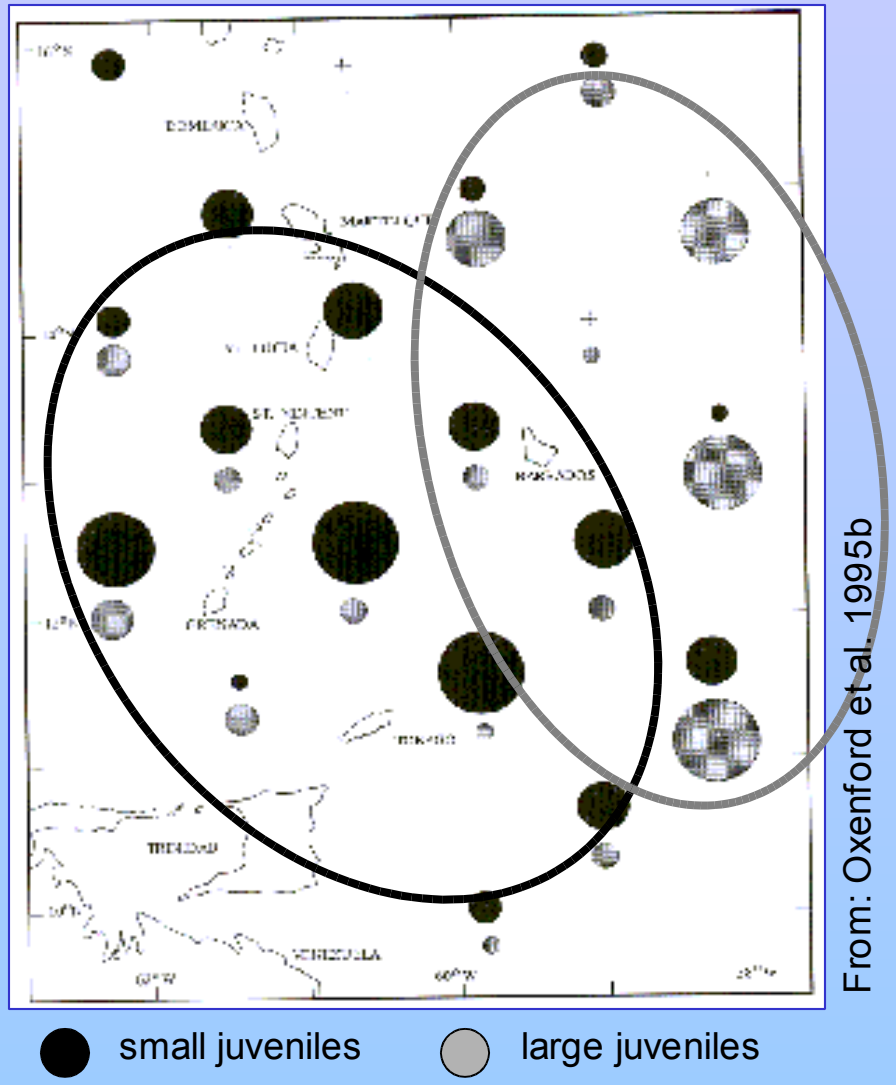
Night-Lighting and Dipnetting

- Partitioning by size



From: Oxenford et al. 1995b

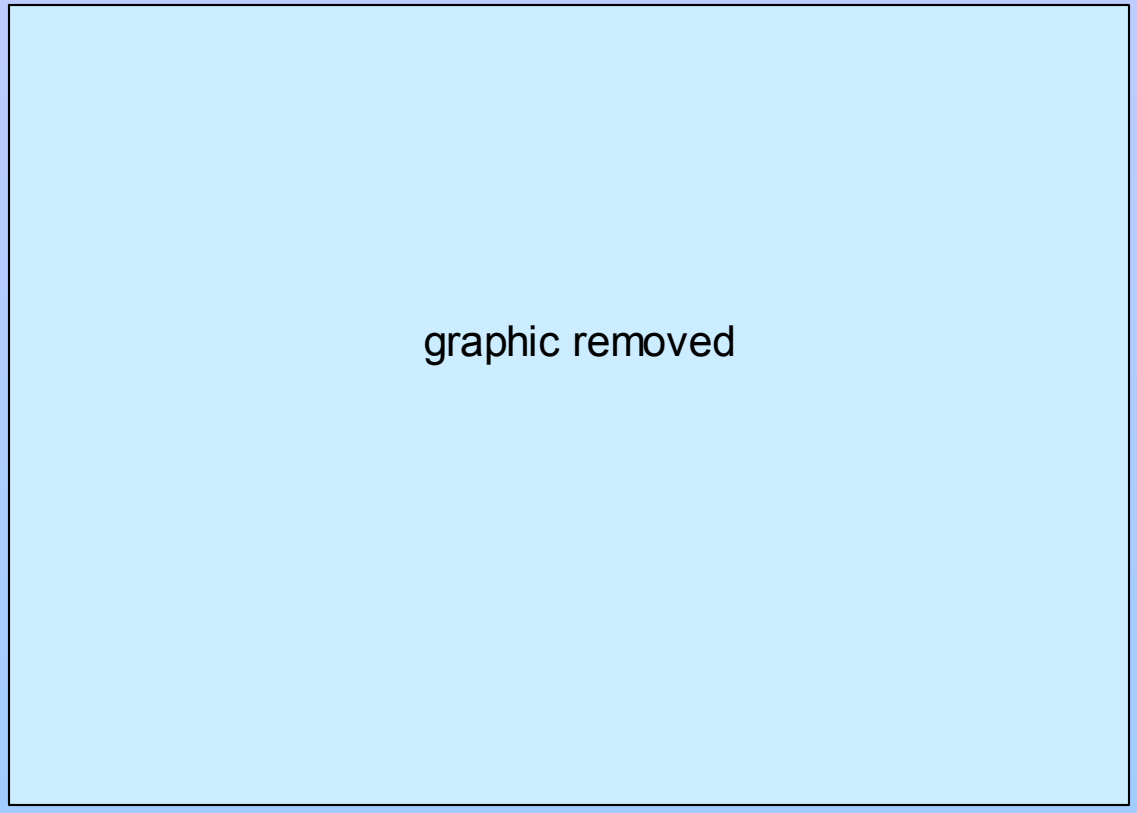
Parexocoetus brachypterus



From: Oxenford et al. 1995b

Night-Lighting and Dipnetting

Comparing distribution of four-winged flyingfishes among years



From: Pitman et al. 2002

Predator Gut Contents: Adults and juveniles

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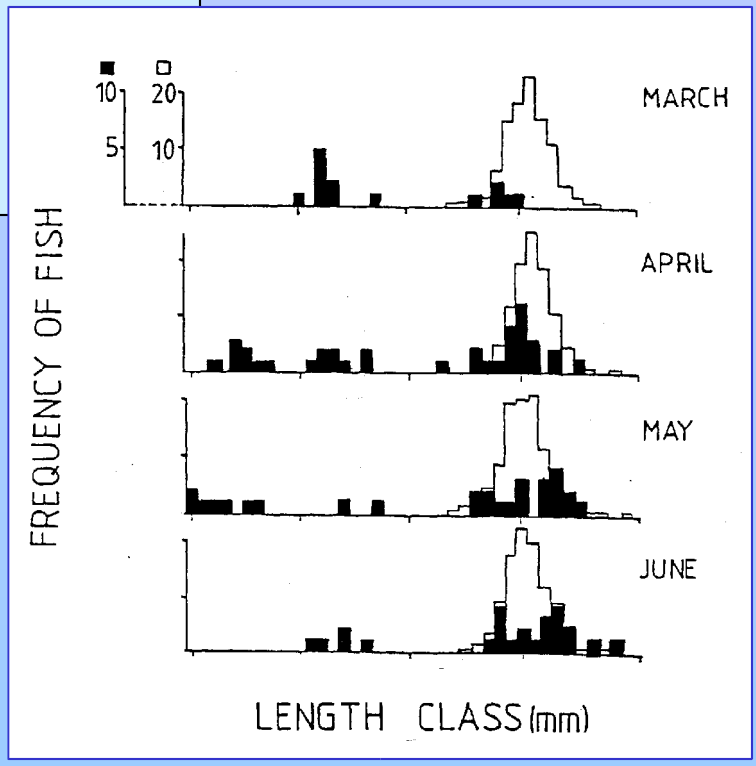
From: Storey 1983



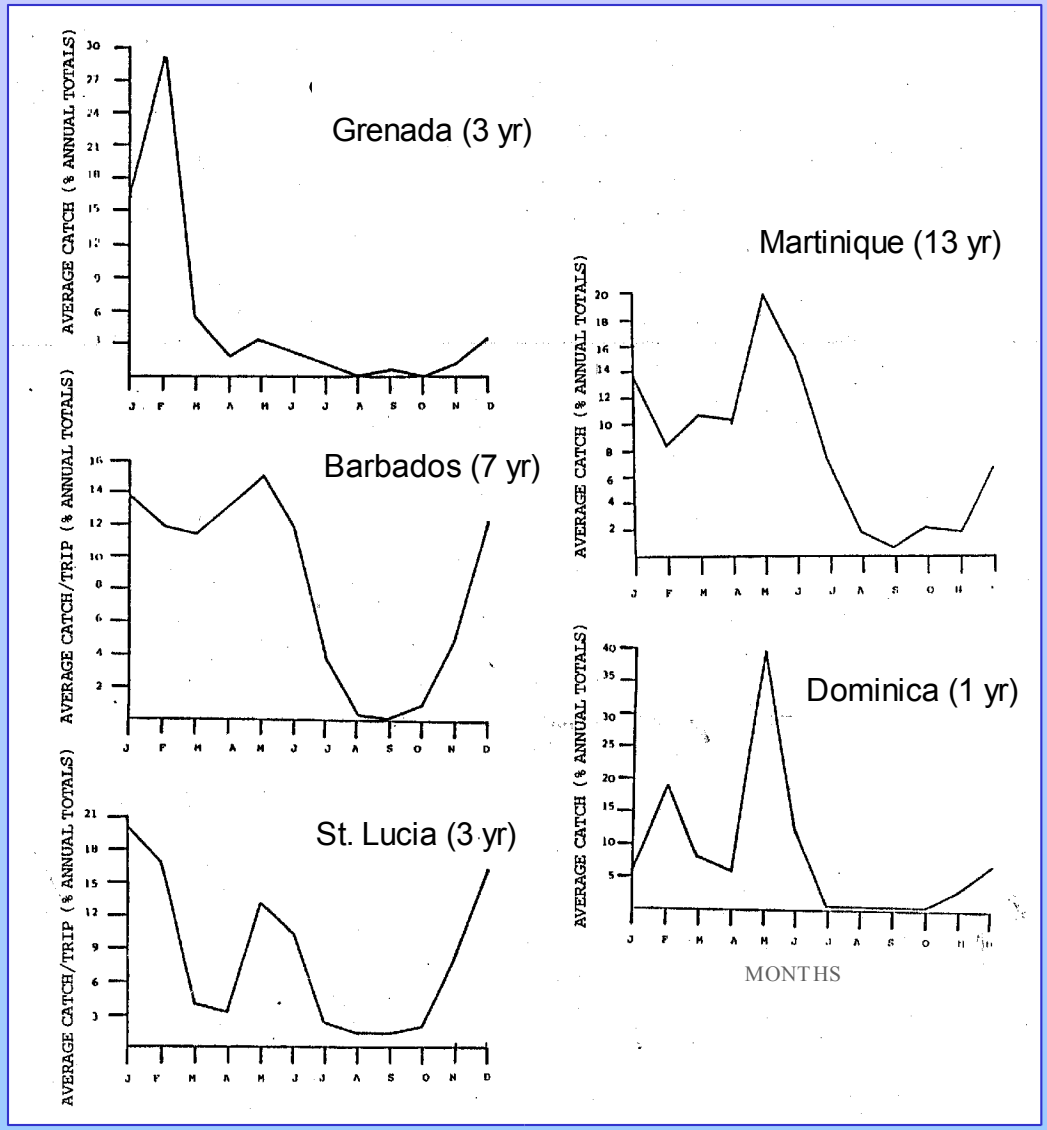
Monthly size frequency of *Hirundichthys affinis* sampled by the fishery (gillnet and hooks) and by dolphinfish predators

- ■ from dolphinfish
- □ from fishery

Fishery Dependent Catch Data: Adults

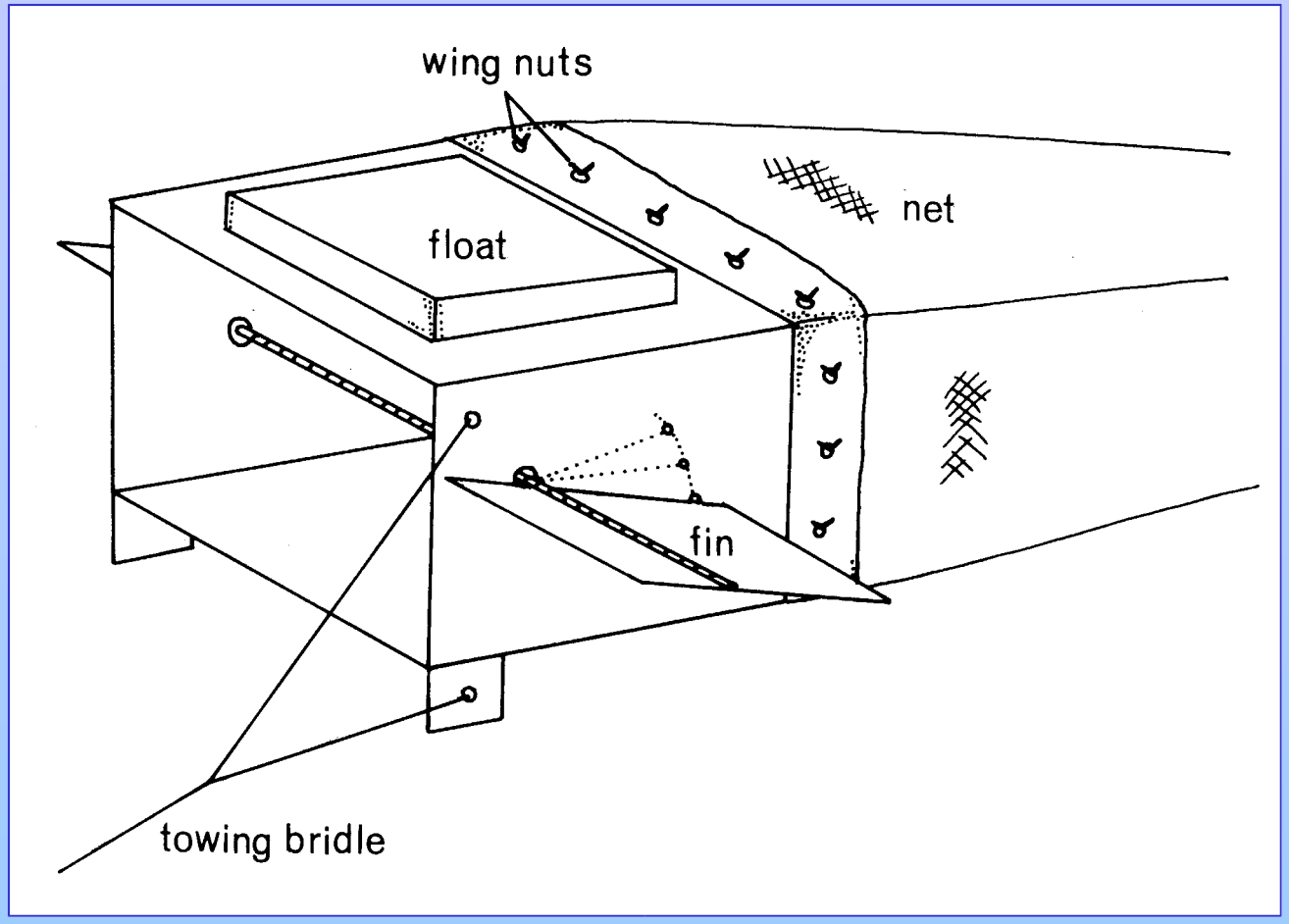
Dominica canoe

Barbados day launch



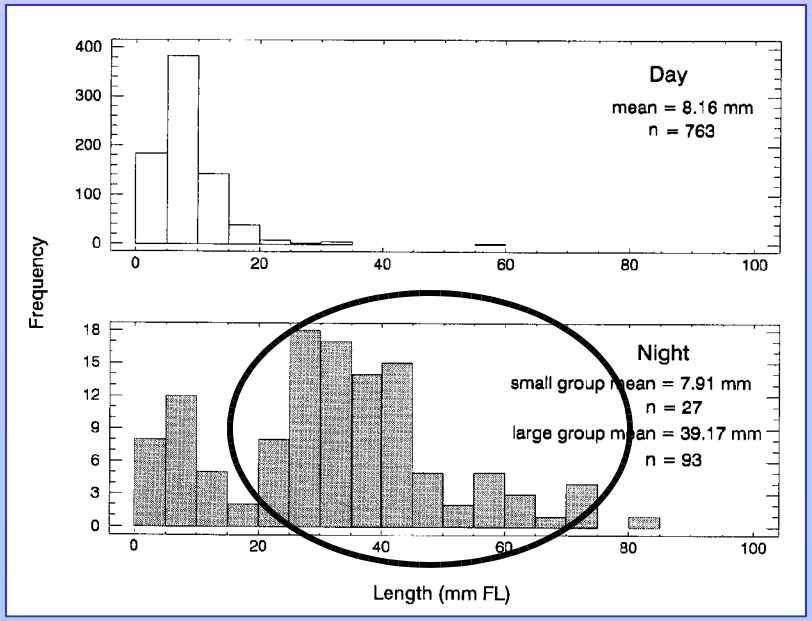
From: Hunte 1987

Neuston Net Tows: Eggs and larvae



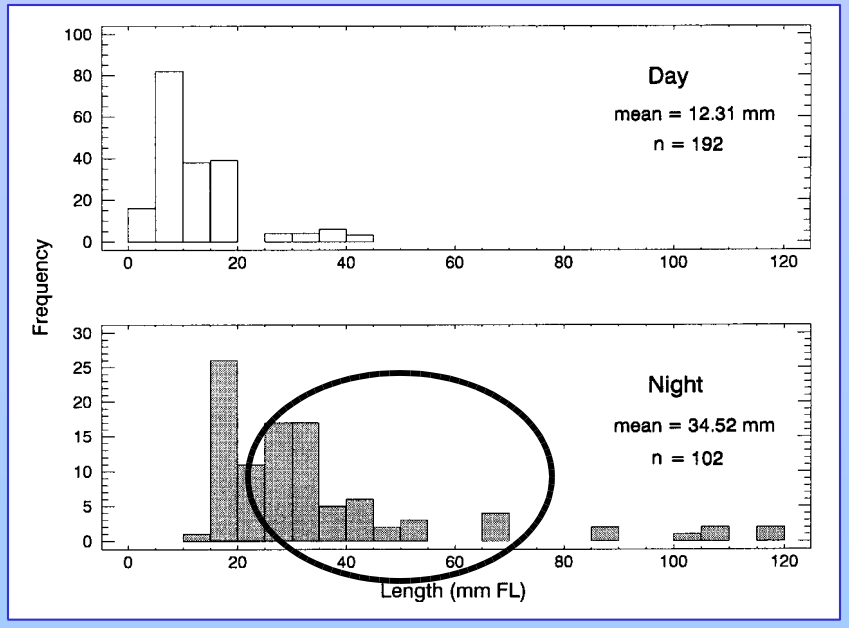
From: Oxenford et al 1986

Neuston Net Tows: Eggs and larvae



Exocoetus volitans

From: Hunte et al 1995



Parexocoetus brachypterus

Day collections

- Larvae more abundant
- only small larvae captured

Adult Movements: Tagging *Hirundichthys affinis*

Off Barbados

- Mulloney 1961 (n = 762)
- Lewis 1964 (n = 1,288)

Off Brazil

- Barroso 1967 (n = 552)

Results

- Local recapture of 1 – 6.4%
- Time-at-large up to 50 days

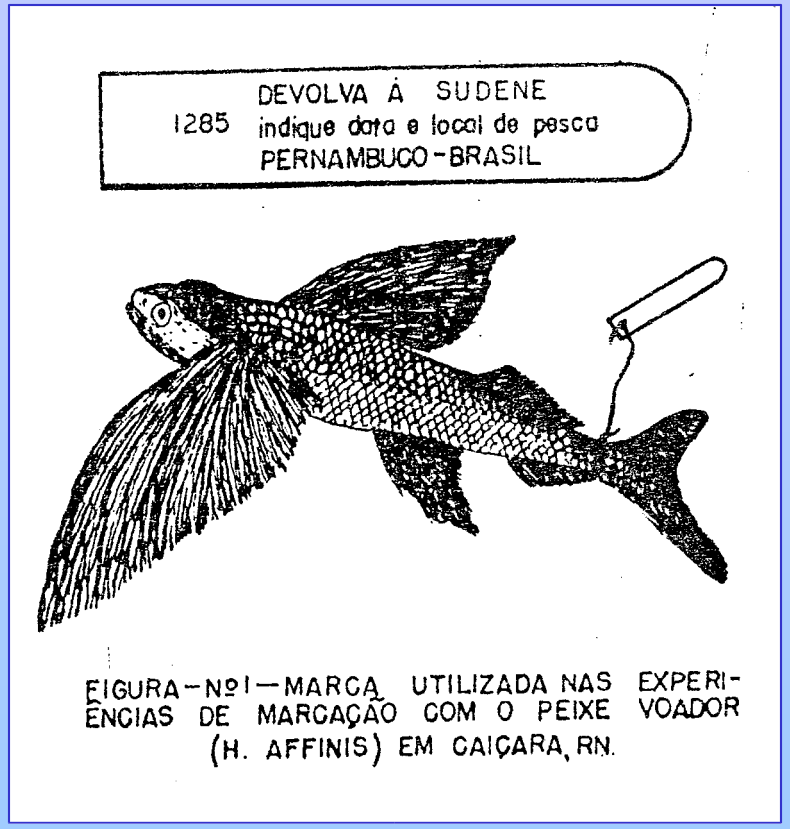
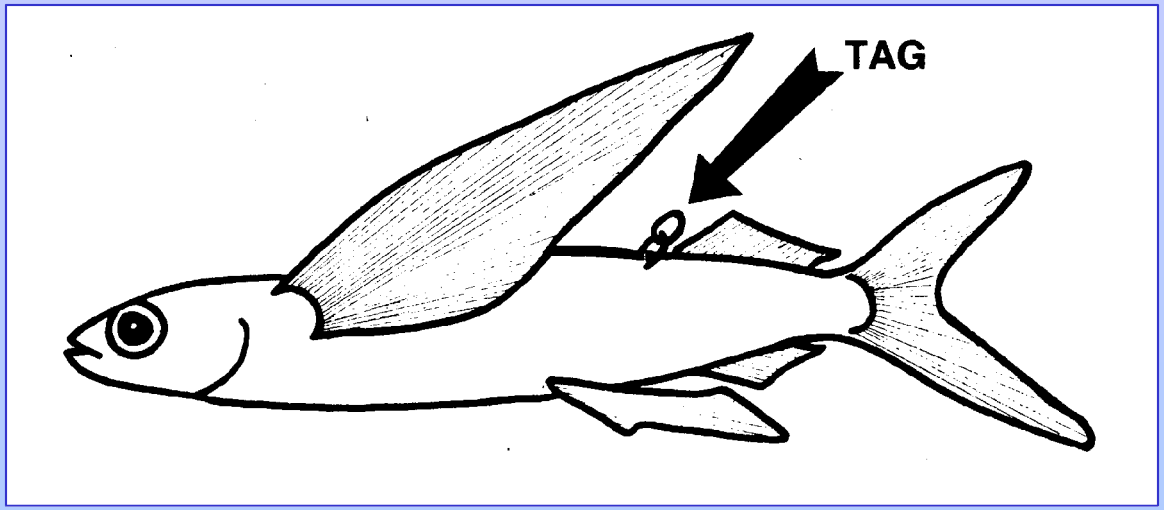


FIGURA-Nº1-MARCA UTILIZADA NAS EXPERIÊNCIAS DE MARCAÇÃO COM O PEIXE VOADOR (H. AFFINIS) EM CAIÇARA, RN.

From: Barroso 1967

Adult Movements: Tagging



- 7,019 flyingfish tagged
- Floy fingerling tags
- Hand-stitched in 30 sec
- Captured by dipnet and barbless hook
- Tagged and released across the eastern Caribbean
- 1988 and 1989 fishing seasons

Photo by H. Oxenford

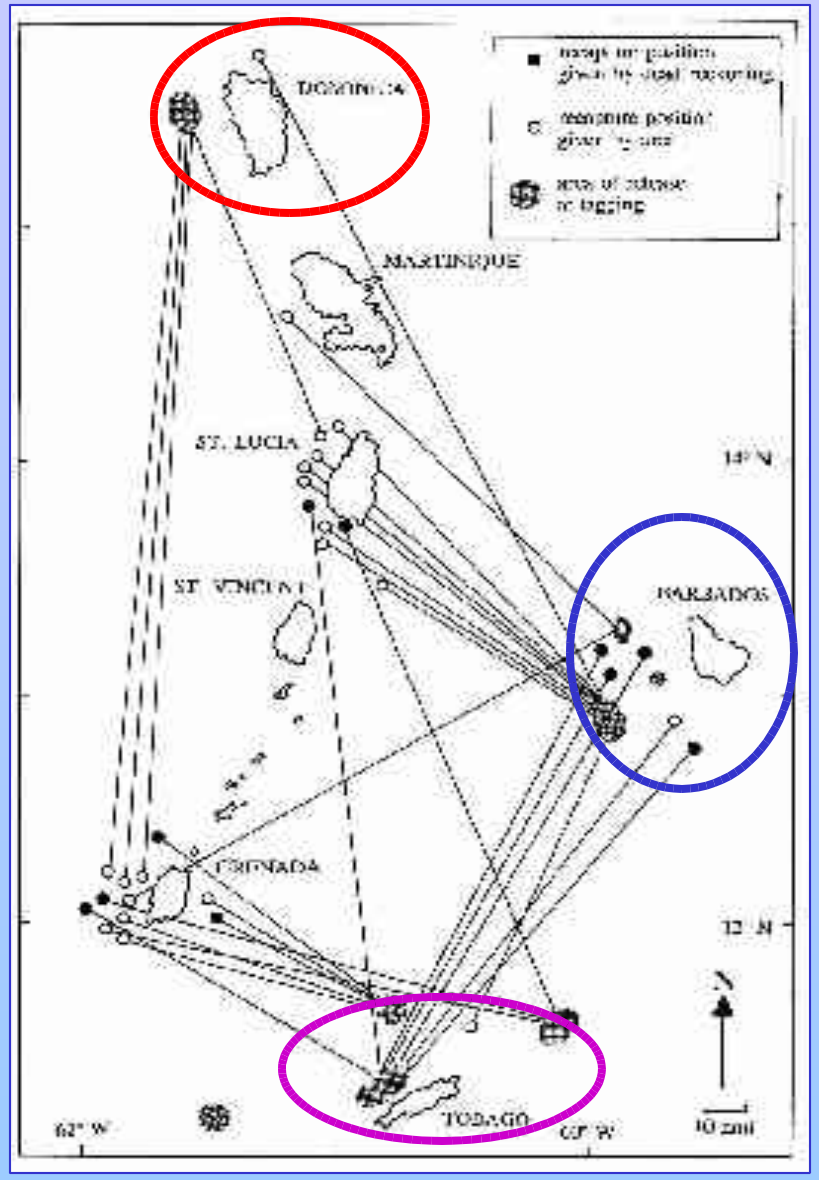
Adult Movements: Tagging

Public awareness campaign

Adult Movements: Tagging

Results

- 4.5% recaptured
- Mean time-at-large: 3 weeks, maximum:121 days
- Greatest recorded displacement: 200 nmi
- Fastest speed > 16 nmi/day
- 10% recaptures showed transboundary movement
- Transboundary movements same for males and females
- Greater movement by maturing fish than running ripe or spent fish
- No tag returns in following season

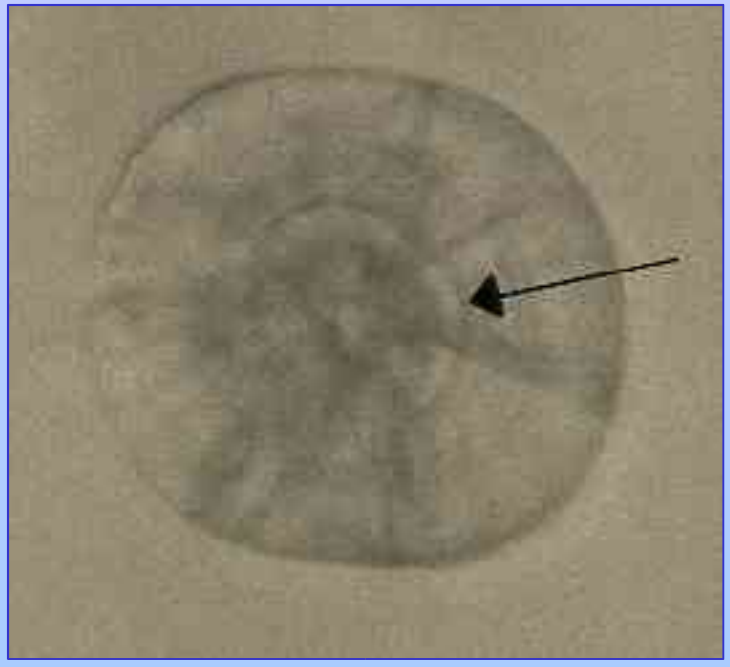


From: Oxenford 1994

Age Determination: Adults and juveniles

Otolith growth checks

- Otoliths must be ground and polished
- Viewed under 500 x
- Good agreement between readers
- Presumed daily rings clearly visible in lapilli of juveniles and adults
- Rings cannot be counted beyond 120

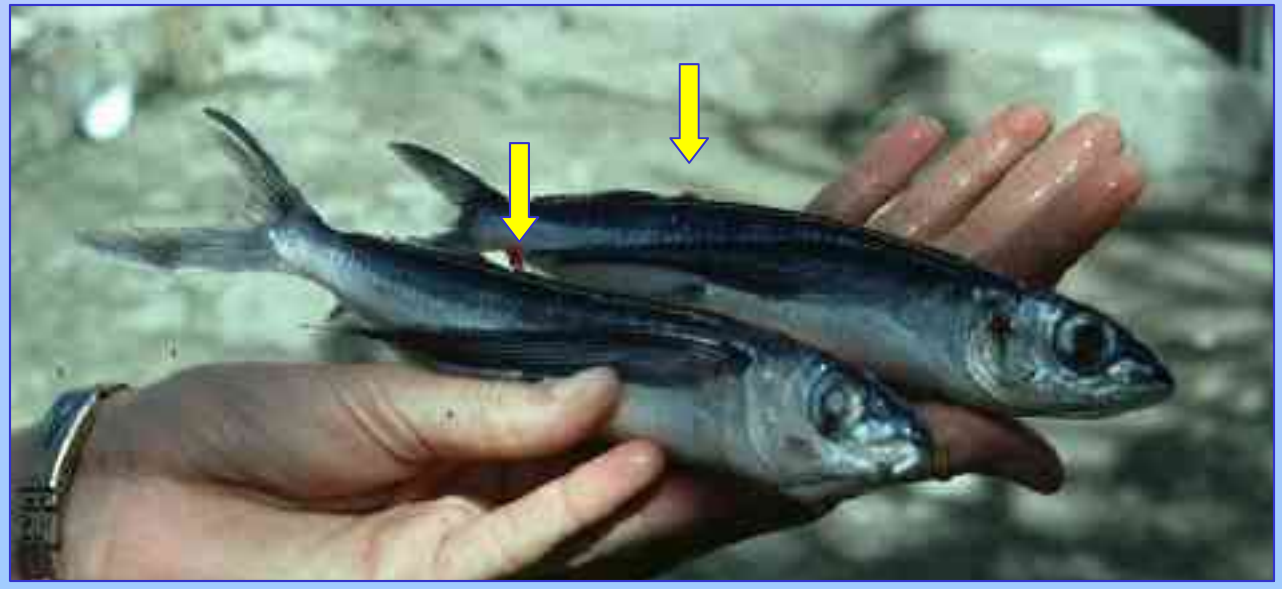


Lapillus otolith from *Hirundichthys affinis*

Age Determination

Validating daily rings

- Marking captive adults with OTC
- Marking, tagging and releasing (n = 946)



Tagged fish marked with OTC

Age Determination

Validating daily rings

Laboratory rearing

- Hatched in 3-6 days
- Fed on brine shrimp

Collecting eggs of *Hirundichthys affinis*

Otoliths in newly hatched *H.affinis* larva

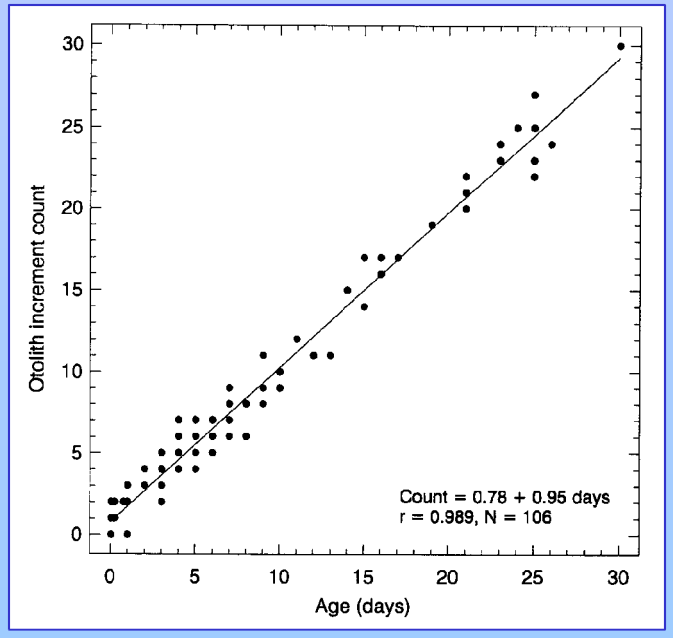
Flyingfish larvae

Age Determination

Validating daily rings

Laboratory rearing

- Sacrificed every day for counting rings
- Maintained in laboratory for 52 days
- Rings and days strongly correlated



From: Oxenford 1994

Otoliths growth checks vs known age

Laboratory reared larvae of *Hirundichthys affinis*

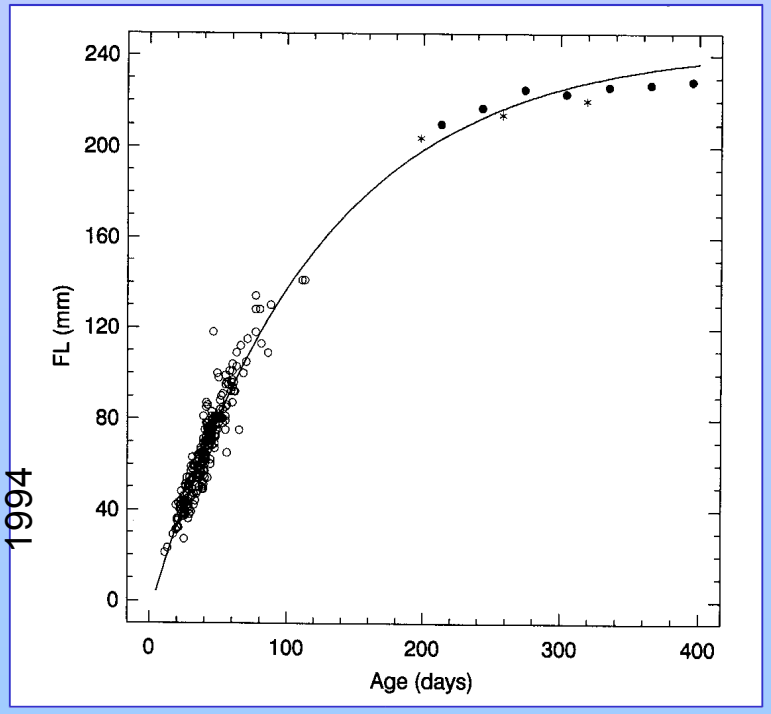
Age Determination: Further validation

Modal progression

- Fishery independent sampling

Radio chemical dating

- Th-228/Ra-228 radio isotopic pair



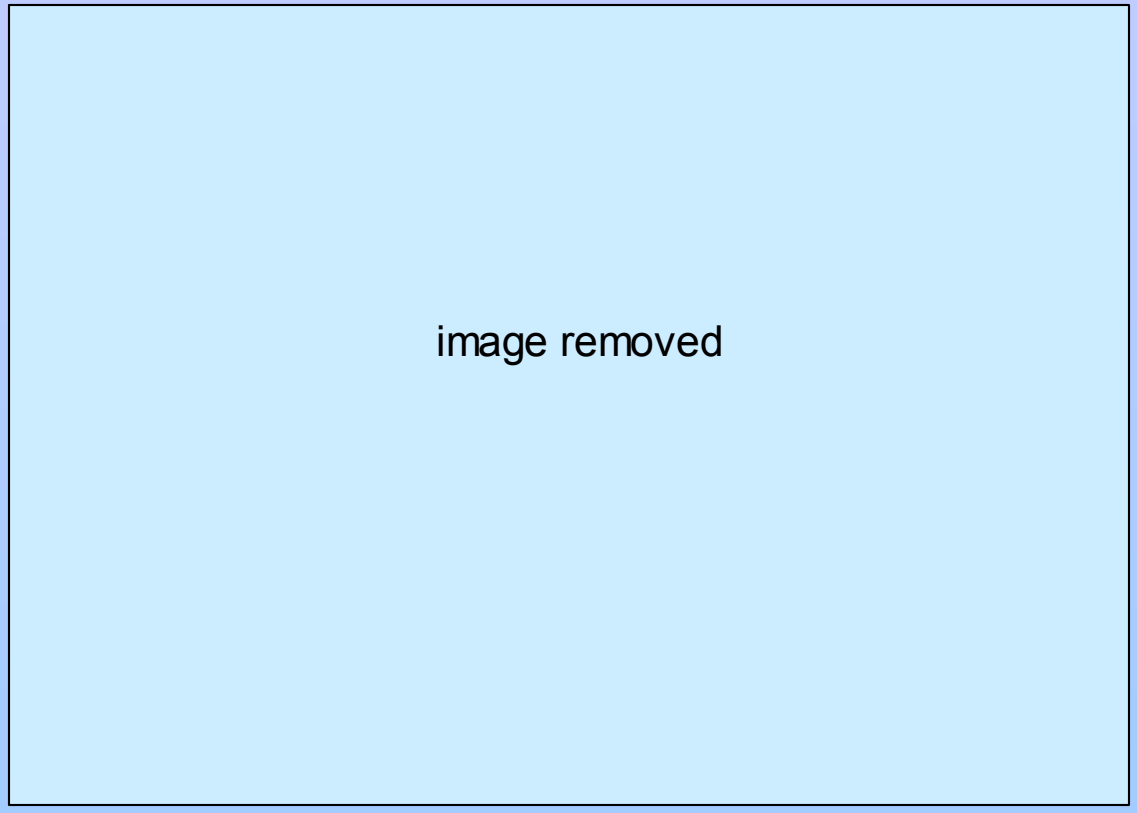
From: Oxenford 1994

Von Bertalanffy growth curve for *Hirundichthys affinis*

Conclusions

- Otoliths show daily rings suitable for aging juveniles
- Larvae easy to hatch in laboratory
- Juvenile growth is fast (1.4 mm/day)
- Growth rate slows markedly after sexual maturity
- Radiochemical dating feasible but expensive
- Fishing gear very size selective

Reproductive Characteristics:
Spawning behaviour



Flyingfish spawning on surface substrate (screeler)

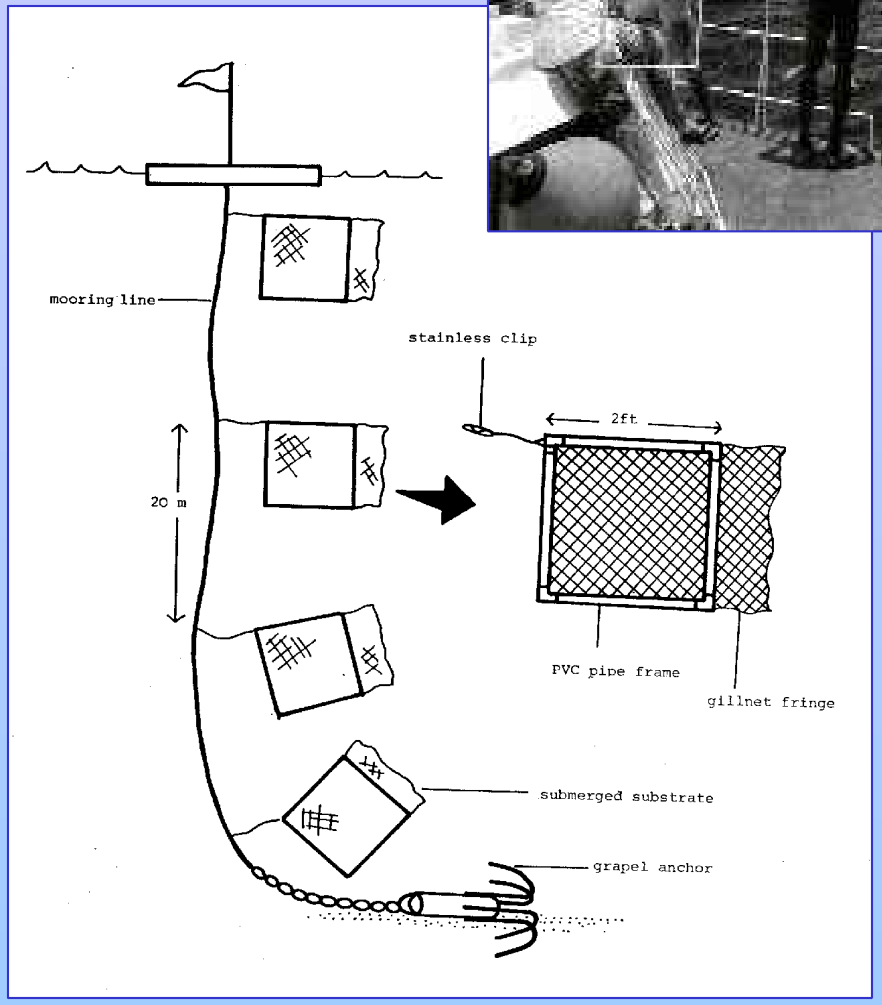
Spawning Behaviour

The mystery?

- Scarcity of spawning substrata (flotsam)
- Scarcity of eggs
- Newly hatched larvae swim upwards
- Anecdotal evidence from fishers

The test

- Provided substrates at different depths
- Provided surface substrates for sinking



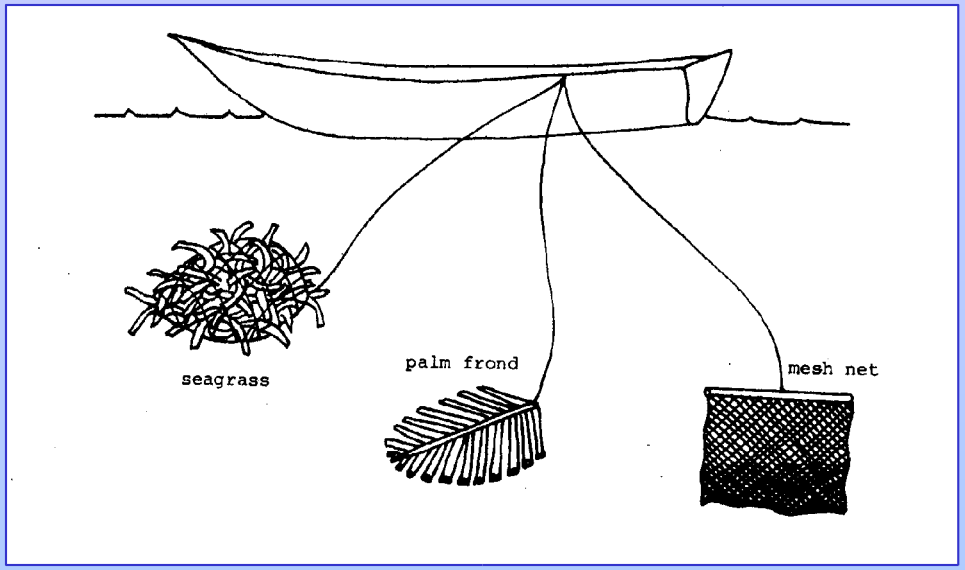
From: Oxenford et al. 1996

Experimental spawning substrata moorings

Spawning Behaviour

Results

- Flyingfish did spawn on substrata at 20 m depth
- Strong preference for surface



From: Oxenford et al. 1996

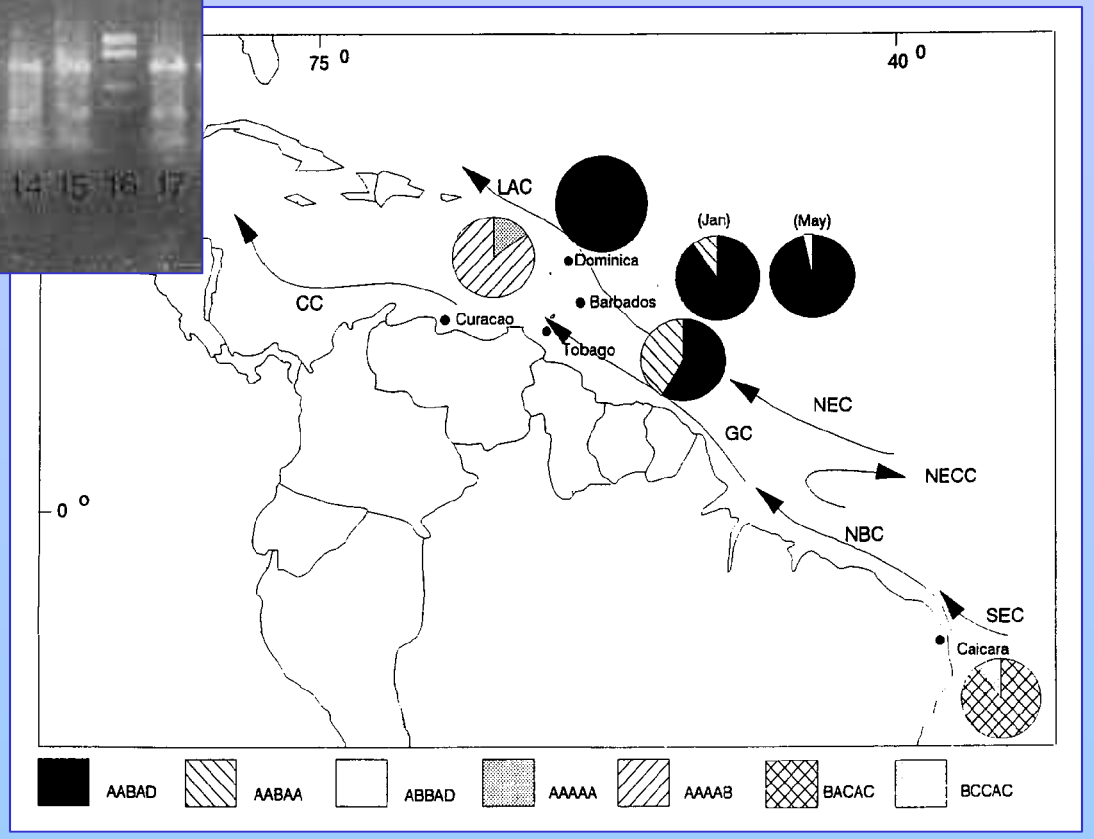
Results

- Flyingfish spawned on all 3 substrata
- Experiment inconclusive as insufficient time

Population Genetics

Mitotypes for mtDNA of *Hirundichthys affinis*

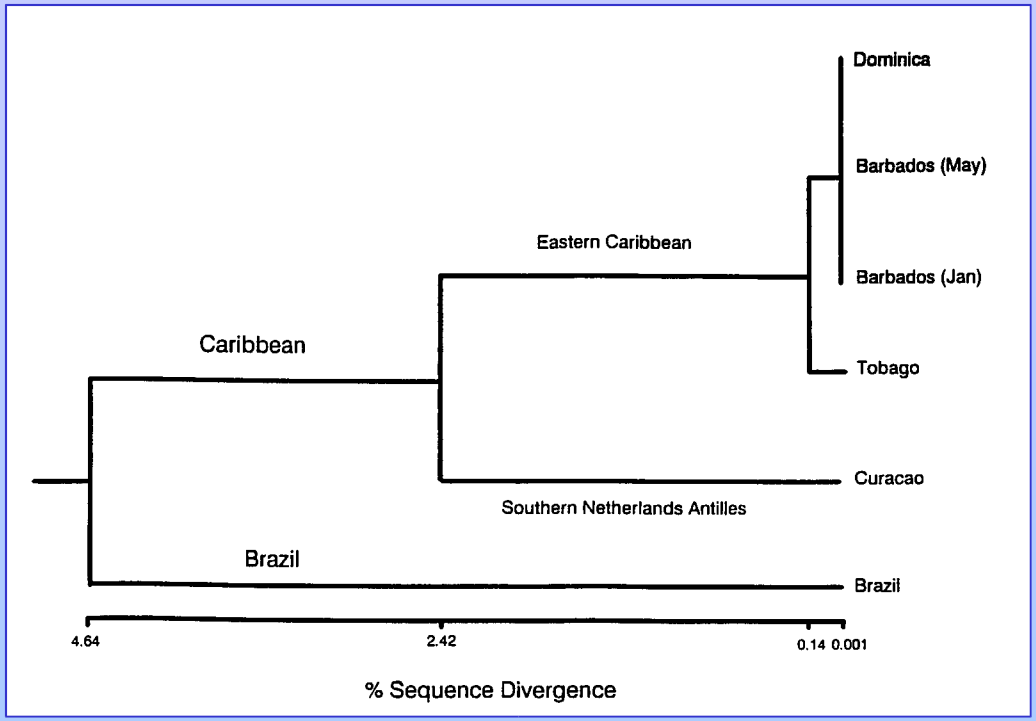
- 360 fish
- mtDNA RFLPs
- gDNA RAPDs



Frequency of composite mitotypes of *H. affinis*

From: Gomes et al. 1999

Population Genetics



From: Gomes et al. 1999

- Consistent results for RFLPs and RAPDs
- Clear separation of populations

- 3 distinct unit stocks
- Shared management in eastern Caribbean