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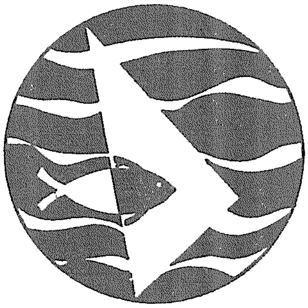

SYNOPSIS OF BIOLOGICAL DATA ON SCALLOPS

Chlamys (Aequipecten) opercularis **(Linnaeus)**
Argopecten irradians **(Lamarck)**
Argopecten gibbus **(Linnaeus)**

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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(*Chlamys* (*Aequipecten*) *opercularis* (Linnaeus)
Argopecten *irradians* (Lamarck)
Argopecten *gibbus* (Linnaeus))

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PREPARATION OF THIS SYNOPSIS

This synopsis is concerned with the biology and exploitation of three species of pectinid mollusc in the North Atlantic. The inclusion of the three species in the same synopsis is justified by their close similarity, not only in biological but also in economic and industrial terms, and by the relatively small amount of data available on them.

The author wishes to acknowledge the advice and information received from Mr. G. Pickett (Fisheries Laboratory, Burnham-on-Crouch) and Dr. J. Mason (Fisheries Laboratory, Aberdeen). The author would also like to thank Mr. M. Castagna of the Virginia Institute of Marine Science, and Dr. H. Porter of the Institute of Marine Sciences, University of North Carolina, for sending me shells of *A. irradians* and *A. gibbus* respectively.

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CONTENTS

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* As no information was available to the author, these items have been omitted from the text

1 IDENTITY

1.1 Nomenclature

1.11 Valid name

The following are the valid names of each of the three species:

Chlamys (*Aequipecten*) *opercularis* (Linnaeus). The author has been unable to trace the original publication of the combination *Chlamys opercularis*. However, *Aequipecten* was first suggested as a new subgenus of *Pecten opercularis* (an earlier, invalid name for *Chlamys opercularis*) by Fischer, P.H., 1886, Manuel de conchyliologie, Paris, 1 369 p. (For further discussion of the confused situation relating to the nomenclature of this species see Section 1.21).

Argopecten irradians (Lamarck) Waller, T.R., 1969, The evolution of the *Argopecten gibbus* stock (Mollusca: Bivalvia), with emphasis on the Tertiary and Quaternary species of eastern North America. *Paleontol.Soc.Mem.*, (3):125 p. Also *J.Paleontol.*, (43) (Suppl. to No.5).

Argopecten gibbus (Linnaeus) Waller, T.R., 1969, Ibid.

1.12 Objective synonomy

- Original invalid names

C. opercularis was first named as *Ostrea opercularis* by Linnaeus (1758).

A. irradians was first named as *Pecten irradians* by Lamarck (1819).

A. gibbus was first named as *Ostrea gibba* by Linnaeus (1758).

- Junior objective synonyms

No information on the junior objective synonomy of *C. opercularis* was available to the author.

A. irradians
≡ *Aequipecten irradians irradians* (Lamarck) Clarke (1965, p. 176)

A. gibbus
≡ *Aequipecten gibbus* (Linnaeus) Dodge (1952, p. 182)
≡ *Aequipecten* (*Plagioctenium*) *gibbus* (L.) Abbot (1954, p. 368)
≡ *Aequipecten* (*Argopecten*) *gibbus* (L.) Warmke and Abbot (1961, p. 170).

1.2 Taxonomy

1.21 Affinities

- Suprageneric

The classification here adopted for groups down to "order" is that used by Morton and Yonge (1964). "Superfamily" and "family" are those used by Moore (1969), thus:

Phylum Mollusca
Class Bivalvia
Subclass Lamellibranchiata
Order Anisomyaria
Superfamily Pectinacea
Family Pectinidae

- Generic

To quote Waller (1969, p. 36): "... broad usage of the name *Chlamys* has lead to a world-wide genus containing a tremendous amount of morphological variation, a profusion of subgeneric names, and a cumbersome nomenclature involving "sections" and species-groups."

As a result of this some authors use the name *Chlamys* as the generic name, qualifying species descriptions with the use of subgenera, as in *Chlamys* (*Aequipecten*) *opercularis*, while others use the term *Chlamys* as a group description and elevate the various subgenera to full generic rank. It is not the task of the present author to argue for, or against, the use of *Aequipecten* in a full generic sense in the case of *Chlamys* (*Aequipecten*) *opercularis*. Instead an attempt is made to clarify the distinctions between species bearing the name *Chlamys* in the group (or generic) sense, the name *Chlamys* in the generic (or subgeneric) sense and the name *Aequipecten* in the generic (or subgeneric) sense.

The term *Chlamys* was first proposed by Röding, P.F. (1798) Museum Boltenianum (2):p. 161 with *Pecten islandicus*[1] (Müller) as the type species by subsequent designation (Herrmannsen, 1847). The following description of the *Chlamys* group was provided by Moore (1969) who used Röding's original term as a group description to be further divided into genera:

> "Higher than long or rounded, commonly somewhat oblique; L V usually more convex but in some species valves nearly equally convex; auricles clearly delimited, usually large; byssal notch large; ctenolium usually present; sculpture of radial (usually stronger) and concentric elements, with scalelike spines commonly developed at their junctions, especially on L V but some

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[1] These are the originally published combinations of generic and trivial names; they are not necessarily valid at the present time

shells nearly smooth; interspaces of many forms with intercalaries in adult; margin usually scalloped; cardinal crura variable in number and size."

Moore (1969) also used the term Chlamys in describing a genus with type species Pecten islandicus, and having the following modifications on the group:

"Usually higher than long, anterior auricle longer than posterior one; sculpture of numerous, generally grooved or striated and spinose, radial ribs; inner margin commonly with rounded, grooved, weak riblets; cardinal crura weak or nearly obsolete."

Moore described Aequipecten as a genus with a type species Ostrea opercularis[1] Linnaeus (1758) (designated by Fischer, 1886, see Section 1.11), differing from the Chlamys genus in the following respects:

"... more rounded outline, nearly equal auricles, smaller byssal notch, fewer, not usually bifurcating radial ribs, and flattened, marginally pointed internal riblets near margin; pair of cardinal crura and auricular denticles (or weak auricular crura) present."

According to Waller (1969) the genus Argopecten was first proposed by Monterosato, T.A. di (1889) Coquilles marines Marocaines: Jour.Conchyliologie, (37) p. 20 as a subgenus of Pecten. The type species by subsequent designation (Monterosato 1889, p. 193) is Pecten solidulus, Reeve 1853 (junior subjective synonym of Pecten circularis[1], Sowerby 1835).

The generic concept of Argopecten adopted here is that followed by Waller (1969). The diagnostic features of the genus as described by Waller are:

"well-demarcated disk flanks, free margins of posterior auricles distinctly sigmoidal in plane of commissure with posterior sinus generally well-developed, and a deep byssal notch with ctenolium present throughout most of ontogeny."

Full generic synonomies for Aequipecten, Argopecten and Chlamys were given by Moore (1969).

- Specific

- Type specimens

The type specimen of Chlamys (Aequipecten) opercularis is a right valve named Ostrea opercularis by C. von Linnaeus (1758) Systema naturae per regna tria naturae...editio decima, reformata: Stockholm, Regnum animale, 1 823 p., and recorded as found in French waters (Moore, 1969).

The type specimen of A. gibbus is a single valve in the collection of the Linnean Society of London, 10th - edition specimen No. 172 from "American Seas" named Ostrea opercularis by Linnaeus (1758) (Waller, 1969).

The type specimen of A. irradians is an articulated shell, Museum d'Histoire Naturelle, Geneva, from an unknown locality and named Pecten irradians[1] by J.B.P.A. de M. de Lamarck (1819) Histoire naturelle des animaux sans vertèbres, Paris, 6(1):343 p. (Waller, 1969).

- Diagnosis

The main diagnostic features of the three species, together with those of the subspecies of A. irradians are presented in Table I.

- Subjective synonymy

Up-to-date information on the subjective synonymy of C. opercularis was not available to the author. However, the reader is referred to the exhaustive list of synonyms provided by Forbes and Hanley (1853, Vol. 2, p. 299).

A. irradians
≘ Pecten borealis Say 1822, J.Acad.Nat.Sci.Phila., 1(2):259 (Clarke, 1965)

A. gibbus
≡ Pecten (Chlamys) liocymatus Dall 1925, p. 119 (syntypes, 2 right valves, USNM (Z) 62290, from 34 fathoms, 39 miles off Cape Hatteras, North Carolina) (Waller, 1969)
≡ Chlamys (Plagioctenium) gibbus (Linnaeus) Rowland 1938, p. 44 pl. 4 fig. 21 (photograph not Ostrea gibba Linnaeus) (Waller, 1969)
≡ Pecten (Plagioctenium) gibbus portusregii Grau 1952b, p. 69, new name for P. (P.) gibbus carolinensis Grau 1952a, p. 17 pl. i figs. 2-5, 7, non carolinensis Conrad 1875 (holotype of portusregii, an articulated shell, USNM (Z) 605016, from depth of 80 ft; 2 miles off Port Royal, South Carolina) (Waller, 1969)

(See Dall 1898, p. 745 for further synonomy.)

- Artificial key

Due to the number of species included in the world-wide genus Chlamys the author has found it impossible to produce an artificial key for this group. Instead, it should be pointed out that Chlamys (Aequipecten) opercularis is the only member of the subgenus Aequipecten, this group having been established with reference to a type specimen Ostrea opercularis which is in fact a monotype. It is, therefore, suggested that the diagnostic features of the Aequipecten subgenus should be sufficient for identification of the species.

TABLE I

Diagnostic features used to distinguish between
C. opercularis, *A. gibbus*, *A. i. irradians*, *A. i. concentricus* and *A. i. amplicostatus*

	C. opercularis	*A. gibbus*	*A. i. irradians*	*A. i. concentricus*	*A. i. amplicostatus*
Valve/valve inflation	least gibbose of all three species	more gibbose than *A. i. irradians*, less than *A. i. concentricus*	most compressed of the three subspecies	more gibbose than *A. i. irradians*, shell thicker than *A. i. irradians*	more gibbose than *A. i. concentricus*, shell thicker than *A. i. concentricus*
Interspecific (relative) valve inflation	distinctly left-convex	equiconvex to slightly left-convex	moderately right-convex	distinctly right-convex	right convex
Disk outline	roughly equilateral	roughly equilateral to slightly produced posteriorly	roughly equilateral	roughly equilateral appearing somewhat opisthocline	equilateral, commonly appearing opisthocline
Disk gapes	very wide	absent or very narrow	narrow to moderate width	very narrow to rather wide, posterior gape commonly absent	narrow or absent
Number of ribs	19–22	17–23	15–20	15–22	13–17
Size of adult (shell height)	60–90 mm	50–80 mm	60–90 mm	55–90 mm	60–90 mm

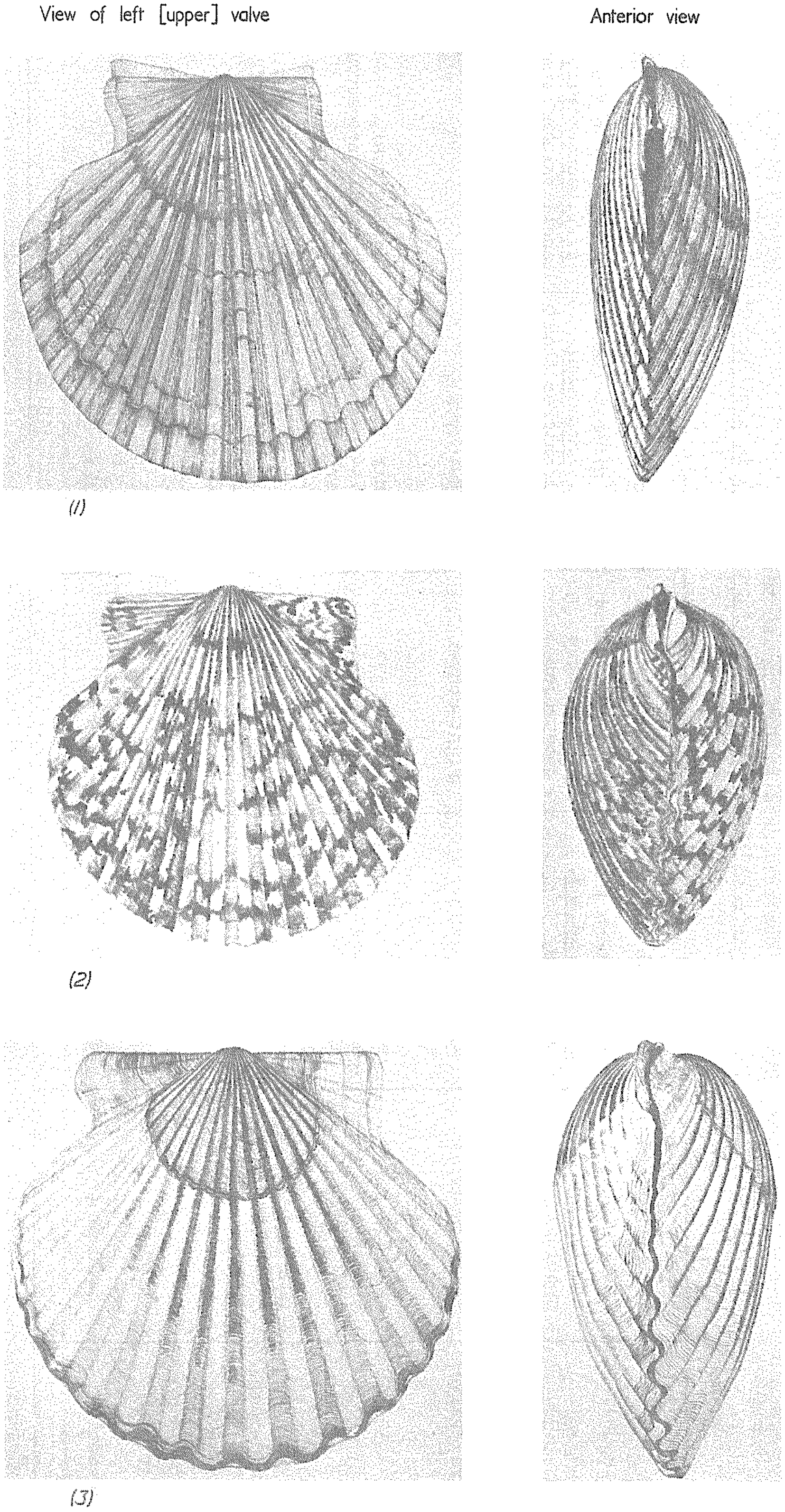

Fig. 1 The external morphology of C. opercularis (1), A. gibbus (2), and A. irradians (3).

- Key to the species of the *Argopecten* genus

A Present in northeast American and central-east American coastal waters C
B Present in southwest, central-west and northwest American coastal waters ....D
C Shell distinctly right-convex ....*A. irradians*
Shell equiconvex or slightly left- or right-convex CC
CC Shell equiconvex to slightly left-convex; disk flanks costate to non-costate; mottling dominant over light background; adult shell height 50-80 mm......*A. gibbus*
Shell equiconvex to slightly right-convex; disk flanks distinctly costate; white background areas of shell generally dominant over mottling; height of adult usually 40-50 mm.............*A. nucleus* (Born)
D Present in American Pacific coastal waters from California to Peru; equiconvex to right-convex........*A. circularis* (Sowerby)
Present in Pacific coastal waters from Nicaragua to Chile; distictly left-convex; adult shell height commonly 60-90 mm, sometimes greater than 140 mm ....*A. purpuratus* (Lamarck)

1.22 Taxonomic status

All three species are morphospecies and none have been established as a result of either breeding experiments, cytomorphology or comparative serology. They are clearly morphologically distinct (Waller, 1969) and furthermore *A. irradians* and *A. gibbus* are very distinctly separated in terms of habitat (see Section 4.6). *A. irradians* does, however, possess three subspecific forms which are discussed in the following section.

1.23 Subspecies

The recognized existing subspecies of *A. irradians* are:

(i) *Argopecten irradians irradians* (Lamarck), first referred to as *Aequipecten irradians irradians* by Clarke (1965) who designated one of Lamarck's original *P. irradians* type specimens (see Section 1.21) as lectotype and defined the type locality as Waquoit Bay, seven miles northeast of Falmouth, Massachusetts.

(ii) *Argopecten irradians concentricus* (Say), first named as a subspecies of *A. irradians* by Clarke (1965) who named it *Aequipecten irradians concentricus* thus replacing the original combination of *Pecten concentricus* Say (1822). It appears that Say's original type specimens have been lost (Clarke, 1965) and Clarke designated a neotype corresponding as closely as possible to Say's original description and locality. This specimen bears catalogue no. 56295 in the collection of the Academy of Natural Sciences, Philadelphia. The type locality is Atlantic City, New Jersey.

(iii) *Argopecten irradians amplicostatus* (Dall), first named as *Pecten gibbus amplicostatus* by Dall (1898). Waller (1969) subsequently designated the lectotype as an articulated shell USNM (Z) 106990, from Texas (specimen illustrated by Dall 1902, pl. 32 fig. 9 and by Clarke 1965, pl. 4 figs. 9-12). Dodge (1952) named this specimen *Aequipecten irradians amplicostatus* and Clarke (1965, p. 171) argued that it should be given full specific rank as *Aequipecten amplicostatus*. Waller (1969) opposed this, arguing for the retention of the subspecific rank under the generic term *Argopecten*.

1.24 Standard common names

Eire	:	Queens
France	:	Vanneaux
Spain	:	Zamburina
U.K.	:	Queens, queenies

1.3 Morphology

1.31 External morphology

The general scallop shape is well known and has formed the basis of emblems and motifs for many centuries. The external morphology of the three species is illustrated in Fig. 1.

The following description of *Chlamys opercularis* is based largely on that given by Tebble (1966).

The shell is solid, equilateral and roughly circular in outline except for the "ears"; the ears (or auricles) are almost equal; the byssal notch in the right anterior ear is small and has small "teeth", the animal lies on the right valve which is slightly convex, the left (upper) valve is markedly convex; specimens have been found measuring up to 105 mm in length[2] but normally the largest ones are about 90 mm long (see Section 4.13). The shells are very variable in colour (e.g., red, pink, brown, yellow, orange and purple shells are all commonly found) and exhibit a variety of colour patterns, often being mottled or blotched. The shells are plicated with usually 19-22 rounded, radiating ribs; they also exhibit rows of fine transverse corrugations or lamellae which are at times laid down in very close succession to form distinct rings; the ears also have fine ribs and

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[2] Length is taken as the anterior-posterior measurement of the shell and height (sometimes referred to as breadth) as the dorso-ventral measurement from the umbo to the shell margin

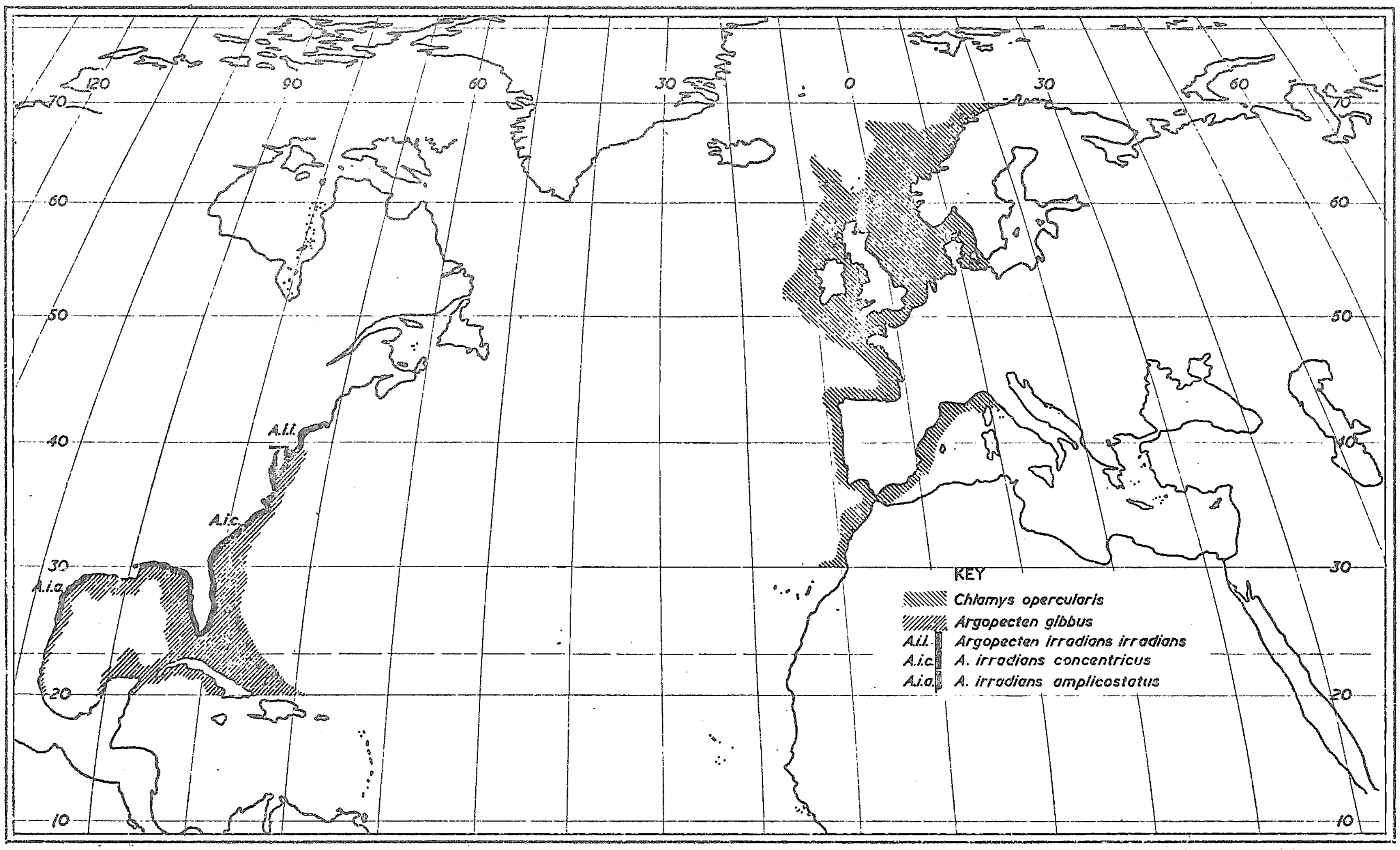

Fig. 2 Approximate world distribution of C. opercularis, A. gibbus and A. irradians.

concentric corrugations. The shell margin is strongly crenulate and the two valves fit closely together along the ventral edge. However, the valves do not come together completely along the anterior and posterior edges as there are large gapes between the margins just below the ears ("disk gapes"; Waller, 1969) and also between the edges of the ears (auricular gapes).

The morphology of bay and calico scallops differs from *C. opercularis* primarily in the features listed in Table I.

Waller (1969) has described the colour of *A. gibbus* as follows:

"Colour of left valve variable, generally with dusky or brilliant red or maroon mottling background; hues of vivid orange, yellow or violet not uncommon; commonly uniformly coloured rather than variegated. Right valve more lightly pigmented except in umbonal region and commonly lightly mottled or with dark spots or incomplete bands of same colour as on left valve".

According to Waller (1969) the colour of *A. i. irradians* is "very variable, that of left valve ranging from pastel orange, brown, yellow or almost white to very dark brown or black; right valve commonly as darkly pigmented as left". He described *A. i. concentricus* as follows:

"Colour of left valves generally dark and drab grey, brown or black, sometimes reddish, in a uniform, vaguely mottled, or vaguely concentrically banded pattern. Right valves generally dusky yellowish white except at the umbones, rarely with faint, irregular patches of same colour as on left valve".

Waller maintained that the colour of *A. i. amplicostatus* is similar to that of *A. i. concentricus*.

1.32 Cytomorphology

The only reference in the literature to chromosome number is that of Beaumont and Gruffydd (1974) who found that *C. opercularis* possesses 13 pairs of chromosomes.

2 DISTRIBUTION

2.1 Total area

The total distribution of the three species is shown in Fig. 2.

The queen scallop, *Chlamys opercularis*, is widely distributed on the European continental shelf, having an approximate latitudinal range of 30°N to 70°N (Aravindakshan, 1955; Ursin, 1956). The calico scallop, *Argopecten gibbus*, is restricted to the continental shelf of the western North Atlantic and Gulf of Mexico between *ca* 35°N and 20°N (Waller, 1969) although small populations have recently been found as far north as Delaware Bay (*ca* 39°N) (Waller, 1969, quotes A.S. Merrill, personal communication 1965). The bay scallop, *Argopecten irradians*, in the form of its three subspecies is also distributed along the continental shelf of the western North Atlantic and Gulf of Mexico but its range extends rather further to the north than that of *A. gibbus* (*ca* 26°N 97°W to 42°N 70°W). *A. irradians irradians* is found between 42°N and 39-40°N where it apparently intergrades with *A. i. concentricus* (Clarke, 1965). The range of the latter extends southward from this point, around the coast of Florida and into the Gulf of Mexico, where the most reliable westerly record of its presence is around the Chandeleur Islands (29°N 88°W) (Waller, 1969). *A. i. amplicostatus* is distributed along the southern and eastern coasts of the U.S.A. bordering the Gulf of Mexico and present records range from Galveston, Texas (29°N 95°W) to the Laguna Madre, southern Texas (26°N 97°W) (Waller, 1969).

Because their distribution is essentially coastal, association with natural ocean regions may not be of great significance. Suffice to say that the N.E. Atlantic species *C. opercularis* has been found in Faroese waters (Ursin, 1956) and around the coasts of Norway (area 5.2.3) and is abundant around the coasts of the British Isles (5.2.4) (Aravindakshan, 1955). Also it is to be found on the continental shelf as far south as the Azores (5.3.3, 5.4.2) and extends into the Mediterranean and Adriatic Seas (5.5.1) (Lamy, 1929). *A. gibbus* is found on the northern side of the Greater Antilles (5.6.2), throughout the Gulf of Mexico (5.6.1) and up the eastern coast to slightly north of Cape Hatteras, North Carolina (5.3.1, 5.3.2) (Allen and Costello, 1972). *A. i. irradians* is found between the north shore of Cape Cod and New Jersey (5.2.1 and 5.3.2), *A. i. concentricus* from New Jersey round into the Gulf of Mexico (5.3.2, 5.3.1 and 5.6.1), and *A. i. amplicostatus* in the Gulf of Mexico only (area 5.6.1) (Waller, 1969).

2.2 Differential distribution

2.21 Spawn, larvae and juveniles

- Spawn

The eggs of *C. opercularis* are probably demersal (see Section 3.17) and, therefore, owing to the relatively static nature of the parent stock, are likely to be distributed in the same area, although no precise information is available on this point. There is no information in the literature regarding the distribution of spawn of either *A. irradians* or *A. gibbus*.

- Larvae

In the laboratory the larval period of *A. gibbus* and *A. irradians* is about two weeks (see Section 3.22) and since the larvae are pelagic, distribution is likely to depend on the current systems in the area of the stock. The larval period of queen scallops is unknown but the larvae are also planktonic (Fullarton, 1890; Rolfe, 1973) so that distribution is again determined by currents, although insufficient data are available for assessment of such distribution.

- Juveniles

There appear to be no major differences in distribution between juveniles and adults, only differences in habitat selection which are discussed in Section 3.22.

2.3 Determinants of distribution changes

There is little evidence of regular changes in the distribution of the adults of either queen, calico or bay scallops.

Ursin (1956) suggested that the mean depth at which queen scallops are found in the southern Kattegat (area 5.2.4/5.2.5) has decreased in recent years from about 29 m in 1883-86 to about 24 m in 1950-53. He attributed this to an increased influx of saline Atlantic water into the Kattegat resulting in a shoreward shift of the distributional salinity limit (*ca* 30 °/oo, see Section 4.6).

Roe, Cummins and Bullis (1971) reported a slight seasonal change in the depth distribution of calico scallops off the east coast of Florida. They noted that in winter scallops are in slightly deeper water than in summer although the difference is less noticeable north of Cape Kennedy than south of it. Calico scallops are also particularly noted for abrupt yearly changes in the precise location of fishable stocks (Allen and Costello, 1972). It is possible that such changes are the result of the movement of large numbers of individuals from one area to another but Allen and Costello (1972) believed that they are probably determined by environmental conditions which control setting and survival of larval scallops.

3 BIONOMICS AND LIFE HISTORY

3.1 Reproduction

3.11 Sexuality

Each species is hermaphrodite (Amirthalingham, 1928; Loosanoff and Davis, 1963; Costello *et al.*, 1973; for *C. opercularis*, *A. irradians* and *A. gibbus* respectively). *C. opercularis* and *A. gibbus* are essentially protandrous, releasing male gametes before female (Aravindakshan, 1955; Allen and Costello, 1972). Loosanoff and Davis (1963) reported that in the laboratory *A. irradians* is usually protandrous but that there may be considerable variation amongst individuals.

3.12 Maturity

C. opercularis spawns for the first time at or slightly later than the end of its first year of life (Aravindakshan, 1955; Bhatnagar, 1972). However, since growth rate varies from area to area (Section 3.43) size at first spawning also varies. Thus Aravindakshan (1955) reported that *C. opercularis* from around the Isle of Man spawn at an average size of 22 mm, whereas Bhatnagar (1972) referring to queens in the size group 41-45 mm taken off eastern Eire in 1970, stated that 80 percent of gonads "were in advanced stages of development which indicates that some queens mature sexually very early in life. All these fish had one growth ring on the shell and belonged to the 1969 year class".

The bay scallop also spawns after one year (Gutsell, 1930; Marshall, 1960) and it seems likely that the calico scallop does so as well, first spawning being dependent upon age rather than size (Roe, Cummins and Bullis, 1971).

3.14 Fertilization

In all three species the sex products are liberated into the sea and fertilization takes place externally (Rolfe, 1973; Castagna and Duggan, 1971; Allen and Costello, 1972). Self-fertilization is probably avoided by protandry (see Section 3.11). This may be of considerable importance since Castagna (1974) reporting on the culture of bay scallops stated that "Larvae from self-fertilized eggs usually appeared normal in the F_1 generation. Subsequent generations often had larval deformities and poor survival". Experience with artificial culture techniques (see Section 3.16) has shown that, in the case of bay scallops, an excessively high sperm density may lead to larval deformities probably due to polyspermy (Castagna, 1974).

3.15 Gonads

The general pattern of gonad morphology and maturation is similar in each of the species. The shape and position of the organ can be seen in Fig. 3. In all cases the proximal, whitish part adjacent to the foot is the testis and the distal, darker coloured part is the ovary. When spent, the testis is very flaccid and translucent; when ripe, it is cream-coloured and turgid. The colour of the ovary in each of the species is slightly different. In *C. opercularis* the collapsed, underdeveloped ovary exhibits a light brown colour, but as it develops it passes through stages of orange and red and, when ripe, is a rich

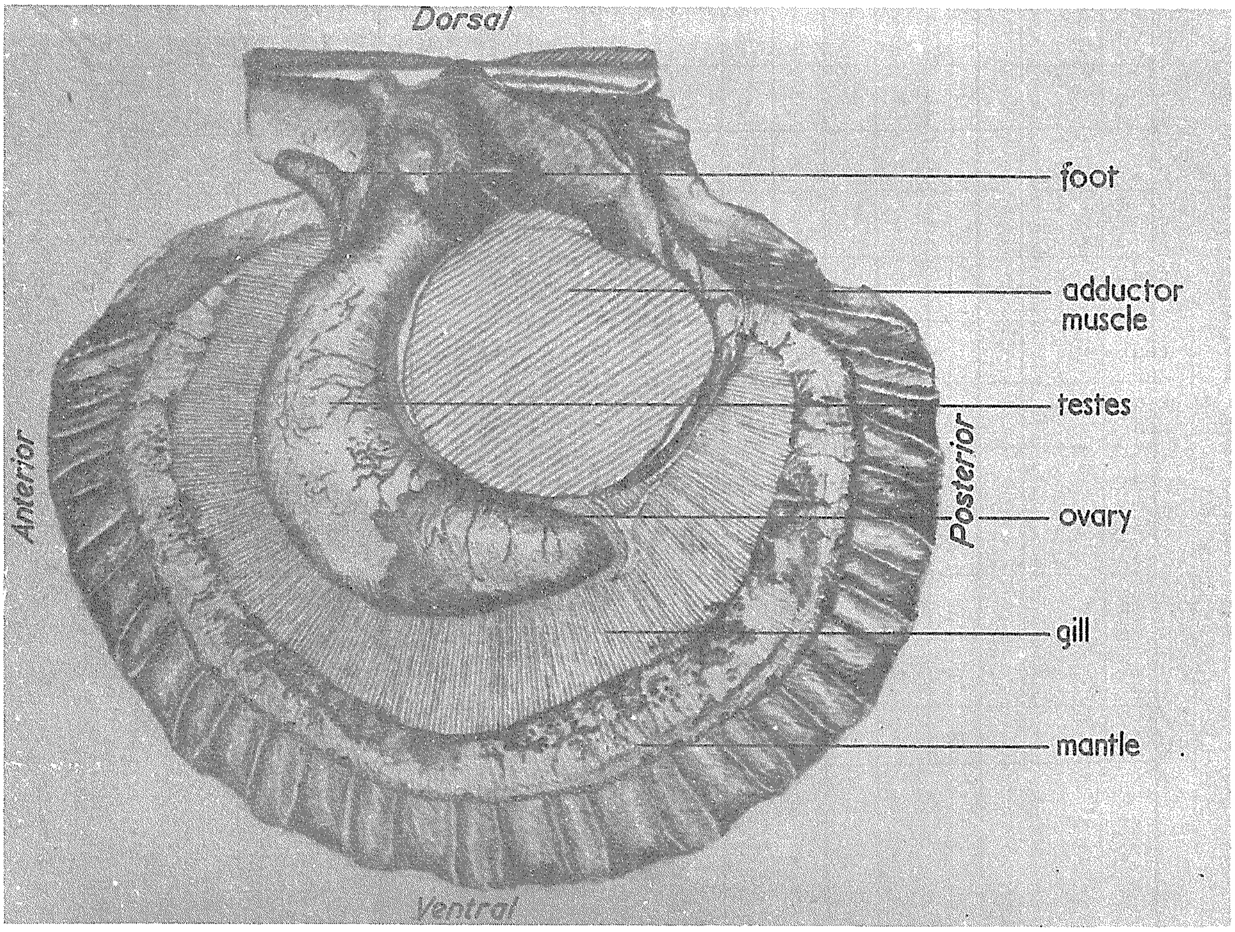

Fig. 3 The internal structure of C. opercularis.

vermillion (Amirthalingham, 1928). The ovary of A. gibbus is whitish-yellow when resting, becomes yellow-orange while maturing and is a bright reddish-orange when ripe (Roe, Cummins and Bullis, 1971). The ovary of the bay scallop is also reddish-orange when ripe, although a black-pigmented epithelium sometimes obscures the initial colour change during ripening (Castagna and Duggan, 1971).

3.16 Spawning

In each species the time of spawning varies from place to place. The spawning times are summarized in Table II. Attempts to relate the spawning of C. opercularis to temperature regimes or temperature changes have been rather inconclusive. Amirthalingham (1928) found that queens from the Plymouth area spawn when temperature is both rising and falling but not when it is above 11°C. Ursin (1956) suggested that queens from the Kattegat and Sound of Ven probably have a spawning season lasting from July to early October when temperatures are rising from 7°C to 11°C and he also stated that populations in Faroese waters spawn in June and July at temperatures between 7.6°C and 8.9°C. Aravindakshan (1955) quoted the water temperature at 19 fath around the Isle of Man during each of the spawning periods as 9.0–8.4°C (Jan./Feb.), 10.8–11.2°C (June) and 13.0–13.2°C (Aug.) in 1954, and 8.8–8.0°C, 10.0–11.1°C and 14.4–14.3°C for similar periods in 1955.

Gutsell (1930) pointed out that bay scallops from the most northern part of their range (e.g., Massachusetts) spawn in early summer when temperatures are still rising while those from around Beaufort, N.C., spawn when temperatures are dropping from a maximum of around 30°C. Similarly Sastry (1963) suggested that the major spawning period for bay scallops from Florida begins when the temperature is declining after the summer peak. This may possibly represent a subspecific difference between A. i. irradians in the north and A. i. concentricus in the south.

TABLE II

The occurrence of larvae and condition of the gonads as an indication of spawning season in <u>C. opercularis</u>, <u>A. gibbus</u> and <u>A. irradians</u>

	J	F	M	A	M	J	J	A	S	O	N	D
<u>C. opercularis</u>												
Isle of Man (Aravindakshan, 1955) 0 and 1 groups	R	R				R		R	R			
2 + groups								R	R			
Plymouth (Amirthalingham, 1928)	R	R	R	R	R	R						
(Pickett, personal communication)	+	+	+	+	+	+	+	+	+	+	+	+
Eastern Eire, Kish and Bray Banks (Bhatnagar, 1972)											R	R
Firth of Forth (Fullarton, 1889)			r	r	r	R	R	R	r	r		
(Dakin, 1909)	r	r	r	r	r	r	R	R	r	r	r	r
Faroese waters (Ursin, 1956)						R+	R+					
<u>A. irradians</u>												
Massachusetts (Belding, 1910)						R						
Wickford, Rhode Island (Risser, 1901)						R						
Niantic River, Connecticut (Cooper and Marshall, 1963)						R	R					
Beaufort, N.C. (Gutsell, 1930)	+							+	+	+	+	+
(Sastry, 1966)									R	R	R	
Alligator Harbour, Florida (Sastry, 1963)								R	R	R	R	R
<u>A. gibbus</u>												
East Florida, Off Cape Kennedy (Roe, Cummins and Bullis, 1971)	+	+	R	R	R	R	+	+	+	+	+	+
North Carolina (Kirby-Smith, 1970)					R	R						
Gulf of Mexico (Allen and Costello, 1972)			R	R	R	R	R	R				
(Pequegnat and Pequegnat, 1968)	+	+	+	+	+	+	+		+	+	+	+

\+ - occurrence of juveniles, <10 mm in height
R - occurrence of ripe/running adults
r - few ripe adults

Spawning has been induced in both A. irradians and A. gibbus using mainly controlled temperature techniques. Loosanoff and Davis (1963) maintained bay scallops in running water at 20°C for 23 days, after which the specimens responded readily to a temperature of 30°C and spawned profusely. Castagna and Duggan (1971) stimulated bay scallops to spawn by raising the water temperature from ambient to 27-30°C. Costello et al. (1973) placed calico scallops in dishes of sea water, the temperature of which was then gradually raised from 20°C to 25°C. Sperms were then stripped from a mature scallop and added to the experimental animals, with the result that the first individual spawned 78 minutes after the water temperature had reached 25°C and six additional scallops spawned at various intervals in the next hour.

3.17 Spawn

The unfertilized eggs of C. opercularis are about 70 µm in diameter (Aravindakshan, 1955; Fullarton, 1890). When liberated artificially the eggs are more or less polyhedral in shape, but if liberated naturally when they are fully ripe they soon become spherical; the vitelline membrane is clearly visible and the diameter of the nucleus/is about 1/3 that of the ovum (Fullarton, 1890).

The sperm has an ovate head, somewhat drawn out at the apex. The head is about 1.5 µm long and the tail 50 µm (Aravindakshan, 1955).

The eggs of A. irradians and A. gibbus are very similar in size to those of C. opercularis, though according to Costello et al. (1973) they tend to be asymmetrical. Loosanoff and Davis (1963) maintained that the eggs of the bay scallop are 55-65 µm in diameter and Costello et al. (1973) found that unfertilized eggs of A. gibbus average 60 µm diameter.

Fullarton (1890) reported that in his aquaria the fertilized ova of C. opercularis settled to the bottom until cilia had been developed and movement could be achieved, thus queen scallop eggs are probably demersal.

3.2 Pre-adult phase

3.21 Embryonic phase

The early embryology of the three species is essentially the same and, according to the accounts of Fullarton (1890) for C. opercularis, Costello et al. (1973) for A. gibbus, and Sastry (1965) and Gutsell (1930) for A. irradians, the early cleavage pattern is as follows:

Oocyte maturation is completed after the entrance of the sperm so that two polar bodies[3/] are budded off before the first cleavage proper, which results in the formation of two unequal blastomeres - the micromere and the macromere. The micromere divides very rapidly and the macromere is partially enveloped by the micromeres before it starts dividing. As is typical in mollusc eggs which have the "mosaic" type of development, the micromeres envelop the macromeres to form the ectoderm, and a solid stereoblastula results. Gastrulation is thus achieved by epiboly; a blastopore is present. The ciliated gastrula gradually transforms into the top-shaped trochophore which is here deemed to mark the end of embryonic development.

Embryonic development of A. irradians and A. gibbus has been closely observed in the laboratory and the approximate times taken to reach certain stages are given in Table III. Increased temperature probably speeds the development of the eggs but there may be a lower temperature limit below which early cleavages do not occur (Sastry, 1966). Sastry has found this limit to be between 15°C and 20°C for fertilized bay scallop eggs.

3.22 Larval phase

There are two references in the literature to larval size of C. opercularis. Jørgensen (1946) stated that the planktonic stage of the queen scallop measures 250-260 µm in length. Rees (1950) recorded a larva of C. opercularis 280 µm in length (Pectinid C, later identified by Rees (1954) as C. opercularis).

Both A. irradians and A. gibbus have been maintained under laboratory conditions until set. A summary of the larval development of A. i. concentricus at 24 ± 1°C and salinity 30‰ is presented below (from Sastry, 1965).

The trochophore stage, attained about 24 hours after fertilization, secretes a shell and is gradually transformed into a veliger larva which, when the shell is fully formed about 48 hours after fertilization, averages 101 µm. At this stage food is collected by the cilia of the velum. By the third day of the veliger (average length 122 µm) slight growth of the umbones may be noted and the veliger continues to develop as the shell morphology changes from the straight-hinged shell to the curved umbones of the prodissoconch shell. At this point the internal organs and mouth are rotated through 90° and the foot develops noticeably. Then follows a short period of crawling before metamorphosis of the pediveliger larva and subsequent attachment, which takes place around the 13th day at an average length of 190 µm. Settlement and metamorphosis mark the disappearance of the velum, enlargement of the foot, development of gill filaments and secretion of the dissoconch shell.

[3/] Fullarton (1890) observed only one polar body after fertilization of C. opercularis eggs

TABLE III

The embryonic development of *A. irradians* and *A. gibbus* maintained in the laboratory

	Time taken to reach each stage (hours)					
	Temperature during development (°C)	1st cleavage	Blastula	Gastrula	Trochophore	Veliger (straight hinge stage)
A. irradians						
Sastry (1965)	24 ± 1	1	5¼	9	24	48
Gutsell (1930)	25				24–48	42–48
Castagna and Duggan (1971)	20–28					18–28
Belding (1910)	–			10	12–14	17–40
A. gibbus						
Costello *et al.* (1973)	23 ± 2	1			24	48

In the laboratory the size of *A. irradians* at settlement is around 190 µm (Sastry, 1965; Loosanoff and Davis, 1963; Costello *et al.*, 1973). Time of settlement is usually around 14 days after fertilization in laboratory cultures (Sastry, 1965; Loosanoff and Davis, 1963) though Castagna and Duggan (1971) found that settlement time ranged from 10 to 19 days with most occurring from 10 to 14 days, and that height at set was in the range 148–216 µm (temperature range 20–28°C). Costello *et al.* (1973) found that in the laboratory situation at 23 ± 2°C *A. gibbus* had a larval period averaging 16 days and a size at set of between 235 and 270 µm.

The rate of development, however, depends largely on food supply as well as temperature, and starved larvae will never metamorphose. Loosanoff and Davis (1963) maintained *A. irradians* larvae at room temperature, feeding them on mixed plankton cultures which were composed of either *Chlorella*-like forms (unicellular green algae) or a mixture of naked flagellates such as *Isochrysis galbana* and *Monochrysis lutheri*. They grew well on either diet but those fed on naked flagellates grew better, with a growth rate averaging up to 10 µm/day. Sastry (1965) using the same *I. galbana*/*M. lutheri* mixture at a concentration made up to 10 000 algal cells/ml every two days, obtained a similar growth rate for the veliger shell (6.5 µm/day) which he described as "very slow". Castagna and Duggan (1971) also used unicellular cultures of naked flagellates (*M. lutheri* and *Dunaliella tertiolecta*) as well as the diatom *Phaeodactylum tricornutum*, for feeding bay scallops and larvae under culture. These authors first kept eggs at densities of 17–34/ml but the density was decreased as the larvae grew so that when they were starting to settle the density was *ca* 4/ml. Costello *et al.* (1973) fed their *A. gibbus* larvae on *Monochrysis lutheri* at an initial density of 60 000 algal cells/ml. This value was adjusted as the larvae grew so that all the food was utilized. The larvae grew at a rate of about 12.3 µm/day, attaining the size at settlement (235–270 µm) in about 16 days.

Little is known of the preferred substratum for settlement of the larvae of these species. Spat of *C. opercularis* from the Plymouth area in the English Channel are found attached in large numbers to hydroids and bryozoans (Walne and Wood, 1974). Very young queens are also found attached to *Laminaria* sp., a brown seaweed (Aravindakshan, 1955; Mason, personal communication).

Ingersoll (1886) stated that *A. irradians* larvae settle on "stones, sea weeds, and other firm supports from the sheltered tide pools to considerable depths". Marshall (1960) found that in the Niantic River, Connecticut "In natural setting scallops attached in quantities to most anything, including frayed manila rope....". He also found good sets on the upper surface of oyster shells suspended in the river, irrespective of whether the rough or the smooth shell surface was oriented upward. Furthermore Marshall noted that *A. irradians* settle heavily on the "small branching algae" abundant in the river and suggested that this serves as a substitute for eel grass which was largely destroyed along the eastern seaboard in the early thirties (see Section 4.22).

Young calico scallops have been found attached to the shell remains of dead calico scallops off the east Florida coast (Allen and Costello, 1972) and also on live adult calico scallops (Wells, Wells and Gray, 1964).

3.23 Adolescent phase

Sastry (1965), studying the bay scallop, found that after settlement the dissoconch shell increased in length very rapidly (0.070 mm/day) so that by the 29th day after fertilization ribs had begun to appear. [The dissoconch is the thin, fragile post-larval shell formed after settlement and sharply demarcated from the thicker and more homogeneous larval shell or prodissoconch (Sastry, 1965)] Rapid growth (0.079 mm/day) continued through the plicated stage so that by the 37th day the adult shell form of the pre-adult had been attained at a size of 1.804 mm. Growth of the pre-adult up to the 108th day was considerably slower (0.021 mm/day).

Other workers culturing bay scallops have provided some data on mortality during the early post-settlement period. High post-set mortality often occurs with pelecypods (Loosanoff and Davis, 1963), and Castagna and Duggan (1971) found that up to the time when the bay scallops kept in outdoor tanks were 2 mm in height mortalities often reduced the number by 50–80 percent. Matthiessen and Toner (1966), culturing bay scallops in Massachusetts, found little mortality associated with metamorphosis and estimated that of the 14–28 percent mortality occurring at this time about 5 percent could be attributed to tray cleaning.

3.3 Adult phase

3.31 Longevity

Owing to uncertainties regarding the significance of growth rings in *C. opercularis* (see Section 4.12) it is difficult to assess the life-span of this species. However, it seems likely that the life expectancy of a queen scallop is somewhere in the region of 6 years (Rolfe, 1973).

Both *A. irradians* and *A. gibbus* appear to have a much shorter life-span than this. The average life expectancy of the bay scallop is probably between 1½ and 2 years (Gutsell, 1930). Roe, Cummins and Bullis (1971) concluded that the maximum age of the calico scallop averages 18–20 months and does not exceed 24 months.

3.32 Hardiness

The inability of *C. opercularis* to close its shell completely means that out of water it rapidly becomes dehydrated and in the summer it will die in a few hours. In the sea it may possibly suffer damage if exposed to low temperatures for long spells. Dakin (1909) reported that long continued cold weather resulted in large numbers of queens in the Firth of Forth dying in 1895.

The susceptibility of queens to very cold weather was confirmed by Ursin (1956) who pointed out that the species was completely absent from dredge hauls made by Danish research vessels in the central North Sea in 1947–48 although they were present in samples taken in 1932–39, 1946 and 1950–54. He stated that during the winter of 1947 the queen stock in the central North Sea was exposed to temperatures between 2°C and 3°C and probably locally to less than 2°C, compared with the minimum of 4°C which is normally tolerated by the stock. From this he inferred that "without much doubt the stock in the central North Sea became reduced or perhaps completely exterminated owing to the unusual cooling of the water". Pickett (personal communication) maintains that adult queens may be transported relatively long distances in water that is simply charged with oxygen at the beginning of the journey and that individuals thus collected survive for many months in indoor aquaria. Furthermore very young queens (average size 6 mm) can be kept alive for at least 20 hours in a seawater-oxygen environment even during transportation in the summer, provided the containers they are in are surrounded with ice (present author).

Because of their association with shallow water areas (Section 4.6) bay scallops may suffer considerable exposure to freshets and low temperatures. Gutsell (1930) stated that heavy freshets may be very destructive and that severe cold weather, especially accompanied by low ebb tides, sometimes does much damage to bay scallop populations. However, Marshall (1960) maintained that out of water *A. irradians* is quite resistant to temperatures well below freezing and that until the temperature drops below 20°F (-6.6°C) the bay scallop may survive for longer than 2 hours in air. Experiments by Sastry (1966) indicated that bay scallops in spawning condition are those least likely to survive adverse conditions. He kept specimens of *A. irradians* at various temperatures without food and found that at all temperatures (10°C to 30°C) animals in spawning condition yielded the poorest survival rates.

There is no information on the hardiness of calico scallops although Vernberg and Vernberg (1970) noted that specimens from the northern end of their range, off North Carolina, did not survive 48-hour exposure to laboratory water temperatures of 10°C.

3.33 Competitors

As the precise source of food for the scallops is not absolutely certain (see Section 3.42) it is difficult to assess possible competitors in this respect. If they do feed mostly on phytoplankton then their main competitors for food will be the zooplankton that also harvests the phytoplankton. Possibly the epifauna found encrusting the upper valve of many of the older individual scallops also compete for their food as, in all probability, do some of the commensals inhabiting the mantle cavity (see Section 3.35).

Competitors for space include any other benthic species likely to live a sedentary existence on substratum that may also be suitable for the scallops. Important among such competitors are other bivalve molluscs. *Pecten maximus* (L.) for instance is often dredged up with *C. opercularis*. Askew, Dunn and Reay (1974) found that some areas of the sea bottom near a fished bed of queen scallops off Guernsey in the English Channel were covered in ophiuroids and these may also be major competitors for space.

3.34 Predators

Little information is available concerning specific predators of *C. opercularis*, but Fullarton (1889) stated that hermit crabs prey on them and that he had seen "cases where these soft-bodied crustaceans left their shell and clung on by their claws to and began to devour the body of the living scallop". Certainly young scallops must be very susceptible to the crushing claws of crabs. Marshall (1960) named the green crab "*Carcinides maenas*" as the worst predator of the bay scallop, feeding almost entirely on the flats where the bay scallop lives. Nevertheless, in deeper water the principal natural enemies of all three scallops are probably the asteroid starfish, particularly *Asterias* and *Marthasterias* spp. Gutsell (1930) stated that starfish annually destroy large numbers of bay scallops in North Carolina but is not known to be a menace in any particular locality. Marshall (1960) found a distributional effect in starfish predation of *A. irradians* in that the predators were most prevalent in the "deeper" water (more than 8 ft) with only one or two on the flats area.

The oyster drill *Urosalpinx cinerea* has also been named as a predator of *A. irradians* (Marshall, 1960) but Gutsell (1930) maintained that there is little evidence of destruction by this form. Wells, Wells and Gray (1964) regarded juveniles of the gastropod *Murex fulvescens*, recorded from calico scallops, as a possible predatory counterpart of *Urosalpinx cinerea*. Struhsaker (1969) suggested that the thorny stingray *Dasyatis centoura* is a possible predator of *A. gibbus*, while Roe, Cummins and Bullis (1971) place puffer fish (Sphoeroides) in their list of definite predators of this species.

One predator definitely associated with the shallow water habitat of *A. irradians* is the herring gull, which according to Gutsell (1930) destroys many large bay scallops by catching them at low tide and dropping them on the beach.

3.35 Parasites, diseases, injuries and abnormalities

The pests reported as occurring in or on *C. opercularis*, *A. irradians* and *A. gibbus* are listed in Table IV. The term "pests" includes organisms forming several types of host-symbiont relationship with the scallop.

As can be seen from Table IV the gastropod *Odostomia* spp. are to be found on all three scallops. According to Wells, Wells and Gray (1964) *O. seminuda* penetrates the mantle edge of the calico scallop with a stylet and then sucks up body fluids by means of a buccal pump. These authors found one to four specimens of *O. seminuda* on most calico scallops, usually on the margin or dorsal wings of the shell and particularly on the posterior wing near the siphons. The tiny pea crab *Pinnotheres maculatus* is found in the mantle cavity of *A. irradians* and *A. gibbus* (Cheng, 1967; Wells, Wells and Gray, 1964). Kruczynski (1972) produced evidence that this commensal may cause stunting of growth in *A. irradians*. He found that infected scallops are consistently slightly smaller in height than non-infected scallops, that the mean dry weight per shell height is significantly lower ($P<0.05$) in infected individuals, and that the mean growth of small (43–46 mm) and medium-sized (50–52 mm) infected scallops is significantly lower ($P<0.05$) than that of non-infected ones. The height differences ranged from 47 mm against 49 mm for a sample collected in June 1968 and 56 mm against 61 mm for a sample collected in October 1968. The dry weight per shell height difference for a sample collected in September 1968 was a mean of approximately 24 mg per mm for infected animals against a mean of approximately 31 mg per mm for non-infected ones. Kruczynski (1973) found that the incidence of infection of bay scallops from Bogue Sound, North Carolina, with ovigerous females ranges from 4 percent between September and November to 10 percent between June and August. Sastry and Menzel (1962) found that in a population of bay scallops in Alligator Harbor, Florida the percentage infected with adult females ranges from 13 to 36 percent.

The annelids tabulated are both to be found in the epifauna of *A. gibbus* (Wells, Wells and Gray, 1964). *Polydora* penetrates the shell, where

TABLE IV

Pests recorded from C. opercularis, A. gibbus and A. irradians

Specific Name	Classification	Host	Mode of Parasitism	Reference
Odostomia scalaris	Mollusca (Gastropoda)	C. opercularis	Ectoparasite	Ankel and Christensen (1963)
Odostomia eulinoides	as above	C. opercularis	as above	Cheng (1967)
Odostomia seminuda	as above	A. gibbus A. irradians	as above	Wells, Wells and Gray (1964) Cheng (1967)
Pinnotheres maculatus	Crustacea (Decapoda)	A. gibbus A. irradians	Commensal	Wells, Wells and Gray (1964) Cheng (1967)
Pontonia margarita	as above	A. gibbus	as above	Wells, Wells and Gray (1964)
Modiocola sp.	Crustacea (Copepoda)	C. opercularis	as above	Reddiah (1959)
Porrocaecum pectinis	Nematoda	A. gibbus	Endoparasite (?)	Hutton (1964); Cummins (1971)
Polydora websteri	Annelida (Spionida) (Polychaeta)	A. gibbus	Epizoon/Commensal (?)	Wells, Wells and Gray (1964)
Ceratonereis tridentata	Annelida (Polychaeta)	A. gibbus	Facultative endoparasite (?)	Wells, Wells and Gray (1964)

its presence stimulates the host to secrete extra layers of shell over it; presumably it feeds independently of its host. *Ceratonereis*, on the other hand, is found not only in the epifauna but also between shell and mantle in blisters. Although most blisters communicate with the exterior many communicate with the mantle cavity through a perforation in the mantle which often occurs in conjunction with a malformation of the gill or gonadal mass. It is thus possible that this species steals food from *A. gibbus* and may be considered a facultative parasite (Wells, Wells and Gray, 1964).

The immediate effect of these pests probably will be to weaken the scallop, thus making it prey to disease. Indeed Sinderman (1971) reported that "barnacles, tube worms and corals can reduce survival of calico scallops". Fouling by barnacles may prevent complete closure of valves of *A. gibbus* so that predators can be admitted more easily (Allen and Costello, 1972). Wells, Wells and Gray (1964) suggested that the epigrowth on calico scallops might impair mobility and thus reduce the animal's ability to escape from predators. However, in this respect it should be noted that Wiborg (1963) found that the heaviest epigrowth on *Chlamys islandica*, exceeding the weight of the animal itself, did not prevent the shell from opening, even in air. As mentioned in Section 3.33 the epizoons may compete with the scallop for food.

3.4 Nutrition and growth

3.41 Feeding

The scallops are filter feeders, pumping water through the mantle cavity and retaining food particles on the gills. However, they are not capable of retaining all particles irrespective of size. Vahl (1972) found that *Chlamys opercularis* shows a retention efficiency of 80-100 percent for particles larger than 7 µm diameter but below this size retention efficiency decreases and reaches zero for particles 1-2 µm in diameter. Similarly, Chipman and Hopkins (1954) reported that *A. irradians* retains *Chlamydomonas* sp. (7 µm long) and *Nitzschia closterium* (56 µm long) equally well.

My observations on *C. opercularis* and those of Kirby-Smith (1970) on *A. irradians* and *A. gibbus* indicated that pumping is continuous. However, Kirby-Smith (1970) suggested that *A. irradians* may be able to control the rate and duration of feeding in response to changes in phytoplankton concentration even while remaining open and pumping continuously. This may be achieved by alteration of the porosity of the filibranch structure or possibly by alteration in the secretion of mucus.

Filtration rate appears to be related to size, and assuming that the relationship can be described by $F = KW^b$ where F = filtration rate, W = weight and K and b are constants, Kirby-Smith (1970) found a "b" value of -0.58 for *A. irradians* filtering *Nitzschia* sp., while McLusky (1973) found b = -0.1828 for *C. opercularis* filtering *Dunaliella euchlora*. Actual filtration rates for some experimental situations are shown in Table V.

3.42 Food

A few workers have examined the stomach contents of these pelecypods. Aravindakshan (1955) inspected the stomach contents of specimens of *C. opercularis* about 75 mm long. He found them to be composed of dinoflagellates, diatoms, small,

TABLE V

Filtration rates observed in the laboratory

Species	Temperature °C	Size (length) range of specimens (mm)	Filtration rate l/hour/g wt of tissue[a/]	Reference
C. opercularis	11-13	18.6-76.3	1.2-3.4	Vahl (1972
C. opercularis	5 10 20	-	1.64 4.00 5.50	McLusky (1973)
A. irradians	21.9-25.8 but during any one observation variation averaged 0.5°C and only twice exceeded 1°C	38-44 47-48 54-56 64-65	0.99 0.93 0.79 0.71	Chipman and Hopkins (1954)
A. irradians	20	-	0.285	Kirby-Smith (1970)
A. gibbus	20	-	0.295	

a/ Wet weight except for McLusky's data which are in dry weight whole or broken bits of crustacean larvae, particles of sand and "a fair amount of unrecognisable detritus". Because the rectal contents frequently consisted of large numbers of apparently undigested diatoms, Aravindakshan inferred that the main sources of nutrition were probably detritus, dinoflagellates, eggs, sperms, and spores of algae. Hunt (1925) found that in general the abundance of plankton organisms in the water was reflected in the stomach contents of the queen scallops that he examined and that in winter detritus constituted a considerable part of these contents. Ithas been suggested, however, that benthic forms probably contribute more to the feeding of bay scallops than do characteristically planktonic forms (Davis and Marshall, 1961). This hypothesis was based on an analysis of the gut contents of A. irradians, which showed predominantly benthic diatoms present.

In the laboratory, larvae of both A. irradians and A. gibbus have been successfully maintained on unicellular algal cultures of flagellates and/or diatoms (see Section 3.22).

3.43 Growth rate

The queen scallop, C. opercularis, exhibits a pattern of growth which basically conforms to that predicted by the von Bertalanffy growth equation:

$$\frac{dl}{dt} = K\,(L_{\infty} - l)$$

where $\frac{dl}{dt}$ is the rate of increase in length, L_{∞} is the length at which growth theoretically ceases, l is the initial (variable) length and K is the growth constant, i.e., the rate at which L_{∞} is approached. Thus the rate of growth of the individual decreases from a maximum at spatfall to zero when the maximum size is reached some time before death. Fig. 4 is a plot of the absolute growth curve for C. opercularis from Millport, Scotland (data from Aravindakshan, 1955). The relative growth curve (initial length vs length one year later) for the Millport queens is plotted

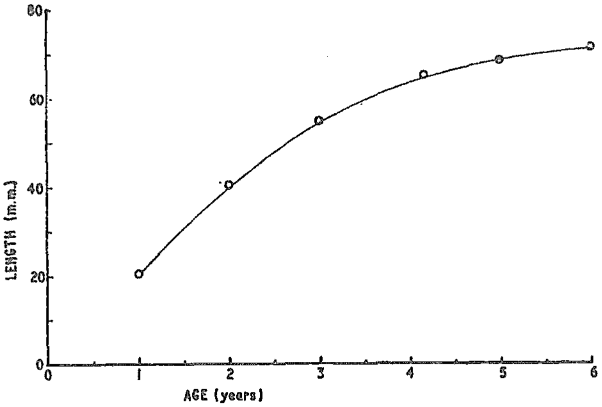

Fig. 4 Absolute growth curve for C. opercularis from Millport, Scotland. (From Aravindakshan, 1955)

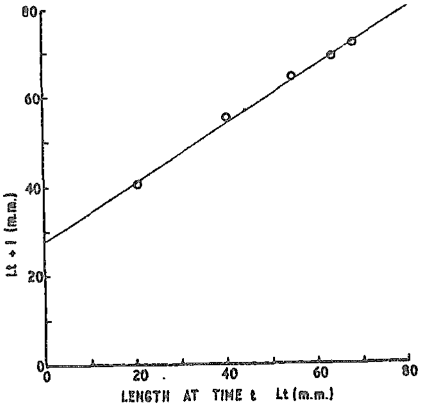

Fig. 5 Relative growth curve for C. opercularis from Millport, Scotland. (From Aravindakshan, 1955)

TABLE VI

Growth constants of queen scallops from populations around the British Isles and in nearby waters

Locality	Growth constant (K)	Theoretical maximum Length L_∞ (mm)	Reference
Port Erin, Isle of Man	0.6802	76.72	Aravindakshan, 1955
Millport, W. Scotland	0.5503	75.52	Aravindakshan, 1955
Aberdeen, E. Scotland	0.7510	73.51	Aravindakshan, 1955
S.E. Irish Sea (i) 10 miles south of Kilmore Quay, Eire	0.4786	74.10	Lee, 1973
(ii) 11 miles south of Carnsore Point, Eire	0.5335	70.61	Lee, 1973
Kish Bank, Irish Sea	0.7409	74.79	Rolfe, 1973
*Guernsey, Channel Islands	1.100	60.31	Askew, Dunn and Reay, 1974
Southern Kattegat and Danish Sound	0.6364	73.08	Ursin, 1956
North Sea	0.6502	78.00	Ursin, 1956
Faroese waters	0.5445	69.95	Ursin, 1956

*Data for these areas refer to height measurements so that the growth constants for height and figures for H_∞ are presented.

in Fig. 5. This is a straight-line curve with a slope of e^{-K} and its intersection with the zero growth line $L_{t+1} = L_t$ gives the value of L_∞.

Some of the K values for queen scallops from different areas around the coast of Britain are presented in Table VI. These values have been calculated using the data provided in the original texts.

Seasonal growth rates of C. opercularis are not well documented. Aravindakshan (1955) observed that growth of adult queens virtually stops from January to March, but growth of juveniles continues throughout the first two years of life although it is retarded during the winter.

Ursin (1956), referring to queens from the Kattegat and Sound of Ven, stated that these show cessation of growth when temperature first decreases in October–November. Then follows a period of rapid growth which starts in January and has not come to an end when the minimum temperature occurs in April. Ursin maintained that sexual activity is not responsible for these growth variations because they occur when the gonads are reduced and apparently inactive.

The bay and calico scallop share essentially the same growth pattern for their short life-span. It is not clear whether their overall growth conforms to the von Bertalanffy model. Certainly seasonal fluctuations would mask such a relationship if it were present. In fact it seems likely that these scallops continue growing steadily until spawning has been completed. This is generally followed by a short period of senescence, then death, although some may survive to a second spawning (Gutsell, 1930; Roe, Cummins and Bullis, 1971).

Maximum growth rates of bay and calico scallops occur over a period of 4–5 months during the warmest part of the year and vary between about 5.8 and 8 mm per month for A. irradians (Risser, 1901; Gutsell, 1928; Sastry, 1966; Castagna and Duggan, 1971), and is about 8 mm per month for A. gibbus (Duggan, 1973). However, the growth rates of bay scallops often show considerable divergence from a simple relation with temperature.

For instance Gutsell (1928) found that the onset of rapid growth in bay scallops from North Carolina could occur as early as February with temperatures as low as 3°C; furthermore, growth virtually ceased after October, even though temperatures were still well above 20°C.

These anomalies may be explained, at least in part, by spawning activities. The North Carolina bay scallop populations spawn in late summer and autumn, and data obtained by Sastry (1966) indicated that growth in weight in these scallops continues during August and September while linear growth is declining, yet ceases abruptly at about the end of September after spawning. Similarly A. irradians from Rhode Island studied by Risser (1901) showed zero growth during June, which was the month in which most of the population spawned.

Duggan (1973) investigated the effects of depth and population density on bay scallops suspended in trays. He found that scallops suspended at the surface, 1 m below the surface, 2 m above the bottom ($2\frac{1}{2}$ m depth at low tide) and 1 m above bottom in Finney Creek, Wachapreague, Virginia, showed approximately equal growth rates from June to October 1971 (from $41\frac{1}{2}$ mm to 45 mm in height). From May to September 1971 scallops kept at densities of 100, 75, 50 and 25 individuals/ft^2 (1 075, 806, 537 and 269/m^2 respectively) showed approximately equal growth until they reached 27-28 mm. Above this size growth decreased with increasing population density so that those at 100/ft^2 reached a final mean size of ca 40 mm, those at 75/ft^2 reached 43 mm, those at 50/ft^2 reached ca 47 mm and those at 25/ft^2 reached 49 mm in the duration of the experiment.

Kirby-Smith (1972) presented evidence that a fast water-flow rate adversely affects the growth of bay scallops. Thus over a period of 21 days at 27°C specimens subjected to a flow rate of 12.4 cm/sec showed zero growth, those experiencing a 3-4 cm/sec flow grew slightly (ca 0.5 mm) while maximum growth of 4 mm was observed at both 0.75 and 0.21 cm/sec. Measurements of water oxygen tension indicated that only at the slowest current speed does a significant fraction of the water flowing past the animal actually go through the mantle cavity. Furthermore, Kirby-Smith also demonstrated phytoplankton removal to be most efficient at slow current speed. Thus it appears that in A. irradians rapid current flow adversely affects growth rate by decreasing the efficiency of the filtration system.

Kirby-Smith and Barber (1974), again working with A. irradians, suggested that the relationship between bay scallop growth rate and phytoplankton concentration can be described by the equation:

$$V = \frac{Vm\ (S-a)}{(C-a) + (S-a)}$$

where V = growth rate, Vm = maximum growth rate (saturation), S = optimum phytoplankton concentration, C = value of S at $\frac{Vm}{2}$, a = value of S at which V = 0. In this system there is a different value of S at each temperature. Kirby-Smith and Barber found that at 22°C maximum growth is achieved at a chlorophyll "a" concentration of 1.2 µg/l, while at 28°C maximum growth rate is not achieved even at the highest phytoplankton concentration (2.4 µg chlorophyll "a"/l).

Standardized condition index data were provided for the bay scallop by Cooper and Marshall (1963) using $K = \frac{V}{L^N}$.

(where K = coefficient of condition, V = muscle volume, L = shell height[4/] and N = slope of log muscle volume/log shell height). These authors compared the condition of bay scallops from different environments in the Niantic River, Connecticut, and found that from age 7 months to age 20 months:

$$\text{Log } K = 0.06197\ t - 0.06203$$

where t = age in months. Furthermore, K values in June and July were significantly lower (K = ca 3) than those predicted by regression (K = 4-5), and this may have been due to the development of the reproductive products, which occurs at about this time in this area.

A simple measure of condition frequently used in the industry is the meat count per unit weight. Thus when the shellfish are in poor condition the meat count is very high. In the Guernsey queen fishery this period of poor condition occurred in the autumn when meat counts rose to 142 per lb (315 per kg) compared with 94 per lb (208 per kg) in May (Askew, Dunn and Reay, 1974). The precise reasons for these changes in condition are uncertain but they are thought to be related to spawning.

3.44 Metabolism

Data on the oxygen consumption of C. opercularis was provided by McLusky (1973). He found that the relationship between size and metabolism can be described by:

$$\ln y = a + b \ln x$$

where y = ml O_2 consumed/g dry wt of flesh/h
x = dry wt of flesh (g)

and that the mean value for "b" at 5°C, 10°C and 15°C is -0.3466.

[4/] Shell height was measured as distance from hinge to ventral edge of shell along a straight line tangent to the outer curvature of the shell

Oxygen consumption in relation to temperature depends, in addition, on the time of acclimation to a particular temperature. McLusky found that for animals acclimated for a minimum of 5 weeks (after which time the author claimed they were fully acclimated) oxygen consumption for a 1 g animal at 5°C was 0.1091 ml/h and for a 1 g animal at 10°C it was 0.2293 ml/h. Animals acclimated for a minimum of 1 week showed corresponding rates of 0.2134 ml O_2/h and 0.3860 ml O_2/h.

Vahl (1972) measured the oxygen consumption of six queen scallops at 11-13°C and found that values ranged from 0.0267 to 0.0367 ml O_2/g wet wt/h.

The only information on metabolic rate of bay scallops is that provided by Van Dam (1954), who found their oxygen consumption to be ca 0.07 ml/g wet wt/h at 20°C.

3.5 Behaviour

3.51 Migrations and local movements

All three species are capable of swimming, though it appears that adult calico scallops are not very active (Allen and Costello, 1972; Mellon, 1969). Both queen and bay scallops do, however, swim well (Rees, 1957; Gutsell, 1930). In both species normal swimming is achieved by clapping the shell valves together rapidly, expelling jets of water near the hinge so that the animal moves in the direction of the gape.

There are conflicting reports regarding the ability to migrate over large distances. Rolfe (1973) maintained that there is "mounting evidence to suggest that the sudden disappearance of queens from areas where previously good catches were obtained could be due to a mass migration as the result of swimming activity assisted by tidal currents". Some support is given to this theory by fishermen who report that queens are more liable to "disappear" from gravelly ground than from softer bottoms; this may be partly due to the stronger currents found in gravelly areas (Rolfe, 1973). Fullarton (1889) believed that the swimming power of queens is limited and doubted whether "some more quickly creeping molluscan forms may not, at the end of a day's journey, show as good a record in the distance attained from the morning's starting point".

Moore and Marshall (1967) noted that A. irradians swims two or more feet off the bottom and that this activity is greatest in the warmer months. Their observations indicated that slight directedness in movement can be accounted for by tidal transport. Gutsell (1930) considered that after an early stage of growth extensive shifting of bay scallops is unusual if, indeed, it occurs at all.

3.52 Schooling (= aggregations)

Commercial densities of queen and calico scallops are usually localized, suggesting the existence of some sort of gregarious behaviour, possibly simply a common response to an environmental stimulus. Videotapes of the sea bed on the Cape Kennedy calico scallop grounds have shown that A. gibbus lay on the bed at the bottom of furrows which run in a northwest ⟷ southeast direction (Anon, 1970). Further evidence for the existence of local aggregations of A. gibbus is the low catch rates achieved by some tows even on commercial beds.

There is one report of schooling exhibited by A. irradians while swimming; Ingersoll (1886) quoted a fisherman from Say Harbor, Rhode Island, as stating that "if possible, when driven before a storm they (bay scallops) will work to windward" and also that he (the fisherman) had seen them swimming in shoals 10 ft (3.05 m) deep.

3.53 Responses to stimuli

There are few data on the response of any scallops to environmental stimuli. Since the animals seem to spend all their time pumping water through the mantle cavity such response is largely limited to either closure of the shell or swimming. The present author found that when kept in outdoor tanks with a once-through seawater system young Chlamys opercularis will move to positions in the tank where current flow is greatest and secure themselves by byssal attachment in these areas. It is also possible that the reaction of queens to fishing gear (see below) is a reaction to a pressure wave set up by the headline of the gear (Rolfe, 1973).

Chemical sensitivity in the bay scallop has been investigated by Gutsell (1930). He introduced an extract of a starfish into the water next to the "guard tentacles" borne on the third fold of the mantle and "repeatedly and unfailingly" the tentacles were sharply withdrawn and the shell violently closed.

Although scallops are equipped with a large number of ocelli around the end of the mantle image vision is apparently very poor (Gutsell, 1930). They do, however, respond to change in illumination; for example, decreases, such as a shadow cast on the eyes, normally causes quick complete or partial closure of queens (present author). Also, movements within a few feet of bay scallops elicit a similar response (Gutsell, 1930).

The reaction of C. opercularis to fishing gear has been observed from small submersible craft and also by divers. Rolfe (1973) reported that in Scottish waters observations from a submersible showed queens rising and escaping in front of a beam trawl, although divers maintained that the gear was avoided less when the submersible was absent, but in Lyme Bay fewer than 10 percent of the queens in the path of a lightweight dredge, with only 6 in (15.24 cm) effective headline height, were seen to escape and most of these went to one side rather than over the top. It is possible that queens are alerted by heavy gear, especially on the hard ground (Rolfe, 1973).

4 POPULATION

4.1 Structure

4.12 Age composition

There are few data relating to the age composition of C. opercularis populations. Aravindakshan (1955) sampled a population of queens off the Isle of Man, using a scallop dredge lined with shrimp netting. The data he obtained are presented in Table VII. Ursin (1956) provided age composition data on populations of C. opercularis from Faroese waters (taken in June 1954 using a trawl with a 9 mm mesh cod end) and from southern Kattegat and the Sound of Ven (taken in October 1953 using a trawl with a 15 mm mesh cod end). These data are also presented in Table VII.

Age composition data relating to commercial catches of queens are also available but, as with whole population data, they naturally vary from stock to stock and from year to year. Examples of the age composition of catches taken by commercial gear used on a research cruise and by a commercial fishing fleet are given in Table VIII.

However, some doubt exists as to the validity of age composition data where ageing has been carried out by counting the "growth rings" on the shells. It has been assumed that ring formation occurs once a year when growth slows (or stops) during the coldest months, but Aravindakshan (1955) working on queen scallops from the Isle of Man found that in 0 and 1 groups an annual ring is formed in September, when spawning occurs. Adults, on the other hand, were found to lay a true growth ring as a result of the sudden resumption of growth after the winter months and not during the final spawning for the year in August/September. The situation is further confused by the fact that on some beds (e.g., the Kish Bank) the rings are very clearly defined whereas on others (e.g., the south Devon beds) they are extremely variable (Pickett, personal communication). Thus estimates of age composition of queen scallop populations, and indeed of growth rates, based on ring measurements must be treated with caution.

The age compositions of bay and calico scallop populations, like those of queen scallops, depend heavily on year class strength. However, because of the short life-span of A. gibbus and A. irradians age composition data generally show the presence of only two year classes in the population. Thus while absolute abundance measures on the younger year class may provide valuable information on the likely

TABLE VII

Age composition of populations of C. opercularis

	Isle of Man[a/] (Feb. 1955) (from Aravindakshan, 1955)		S. Kattegat and Sound of Ven (Oct. 1953) (from Ursin, 1956)		Faroes (June 1954) (from Ursin, 1956)	
Age group	No.	%	No.	%	No.	%
0					21	3.9
1			136	12.8	190	35.1
2	110	41.6	445	41.9	154	28.4
3	63	23.9	300	28.3	65	11.9
4	30	11.4	86	8.1	91	16.8
5	33	12.5	56	5.3	18	3.3
6	28	10.6	30	2.8	2	0.4
7			6	0.6	1	0.2
8			2	0.2		

a/ 0 and 1 group data omitted for reasons given in the following section (4.1.3)

TABLE VIII

Age composition of the commercial catches of C. opercularis taken by Lee (1973) and Bhatnagar (1972) in waters southeast and east of Eire

Year Class	Lee (1973)[a/] Area I % of catch	 Area II % of catch	Bhatnagar (1972)[b/] Kish and Bray Banks % of catch
0	-	-	-
1	-	-	15.6
2	-	-	11.9
3	8.9	8.8	42.9
4	37.2	36.2	26.5
5	38.6	38.8	2.6
6	12.1	14.3	0.5
7	3.2	22.0	

[a/] Lee's samples were taken in August 1972 from about 10 miles south of Kilmore Quay, Eire (Area I) and from about 11 miles south of Carnsore Point, Eire (Area II)

[b/] Bhatnagar's data were obtained from samples of the catch landed in Eire in October, November and December 1970 by vessels fishing the Kish and Bray Banks, Irish Sea

success of the fishery in the coming year, the nature of the fisheries is such that relative age composition data are not very important and hence largely unavailable.

Age at first capture of bay and calico scallops is about 1 year (after the first spawning which takes place at the end of the first year).

The age of C. opercularis at first capture varies from area to area according to growth rate. Askew, Dunn and Reay (1974) found that for the Guernsey stock it is approximately 3.3 years while Ursin (1956) stated that in the southern Kattegat queens first enter the catches at about two years of age. The age of queens at maturity is uncertain. Aravindakshan (1955) stated that queens from the Isle of Man area may spawn in their first year.

4.13 Size composition

Aravindakshan (1955) and Ursin (1956) provided size composition data on the same populations of C. opercularis for which they supplied age composition data (see previous section). The information gathered by Aravindakshan (1955) is presented in Table IX and Fig. 6, but it should be pointed out that the 0 and 1 groups sampled were supplemented from other collections made during the month and it seems likely that only the 2+ to 6+ groups are truly representative of their relative proportions in the population. Data provided by Ursin (1956) are presented in Table X.

Fig. 6 demonstrates that the 0+ and 1+ groups are not unimodal - probably a result of the three spawnings in one year. But during the spring and summer preceding the formation of the second ring, growth is very rapid and earlier size differences are largely obliterated. Similarly Ursin (1956) noted a bimodality in the size frequency distribution of 1-ringed and 2-ringed specimens of C. opercularis from Faroese waters.

Bhatnagar (1972) took samples of the catch of queens from vessels working the Kish and Bray Banks in the Irish Sea from October to December 1970 and obtained the size composition data shown in Table XI. He also found evidence of a seasonal change in size composition of the catch; in July and August there were no "small" (41-55 mm) queens in his samples but in October "small" queens constituting 4-10 percent of the total appeared in the catches, indicating the entry of another year class into the fishery.

Size composition data for bay and calico scallop populations are rare in the literature. Gutsell (1930) produced details of the size frequency distribution of a population of A. irradians from the Newport River estuary, North Carolina. These data, presented in Table XII and Fig. 7 demonstrated that a similar phenomenon

TABLE IX

The size (height) composition of each year group in a population of *C. opercularis* near the Isle of Man (from Aravindakshan, 1955)

Size group (mm)	No.	Percentage of each size group within each age group													
		0+		1+		2+		3+		4+		5+		6+	
		No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
10–11	10	10	34.5												
12–13	5	5	17.0												
14–15	2	2	7.0												
16–17	3	3	10.0												
18–19	5	5	1.7												
20–21	4	4	14.0												
22–23	8			8	18.0										
24–25	8			8	18.0										
26–27	4			4	9.0										
28–29	1			1	2.0										
30–31	1			1	2.0										
32–33	6			6	13.0										
34–35	5			5	11.0										
36–37	3			3	6.5										
38–39	7			7	15.5										
40–41	2			2	4.5										
42–43	–														
44–45	–														
46–47	–														
48–49	3					3	2.5								
50–51	12					12	11.0								
52–53	39					39	35.0								
54–55	21					21	19.0								
56–57	22					22	20.0								
58–59	11					10	9.0	1	1.5						
60–61	7					2	2.0	5	8.0						
62–63	23					1	1.0	21	38.0	1	3.3				
64–65	33							28	44.0	5	16.6				
66–67	18							6	9.5	11	36.6	1	3.0		
68–69	15							1	1.5	9	30.0	4	12.1	1	3.5
70–71	10							1	1.5	2	6.6	4	12.1	1	3.5
72–73	14									1	3.3	8	24.2	5	17.8
74–75	16									1	3.3	6	18.1	9	32.1
76–77	10											6	18.1	4	14.2
78–79	6											2	6.0	4	14.2
80–81	4											2	6.0	2	7.1
82–83	–													–	–
84–85	2													2	7.1

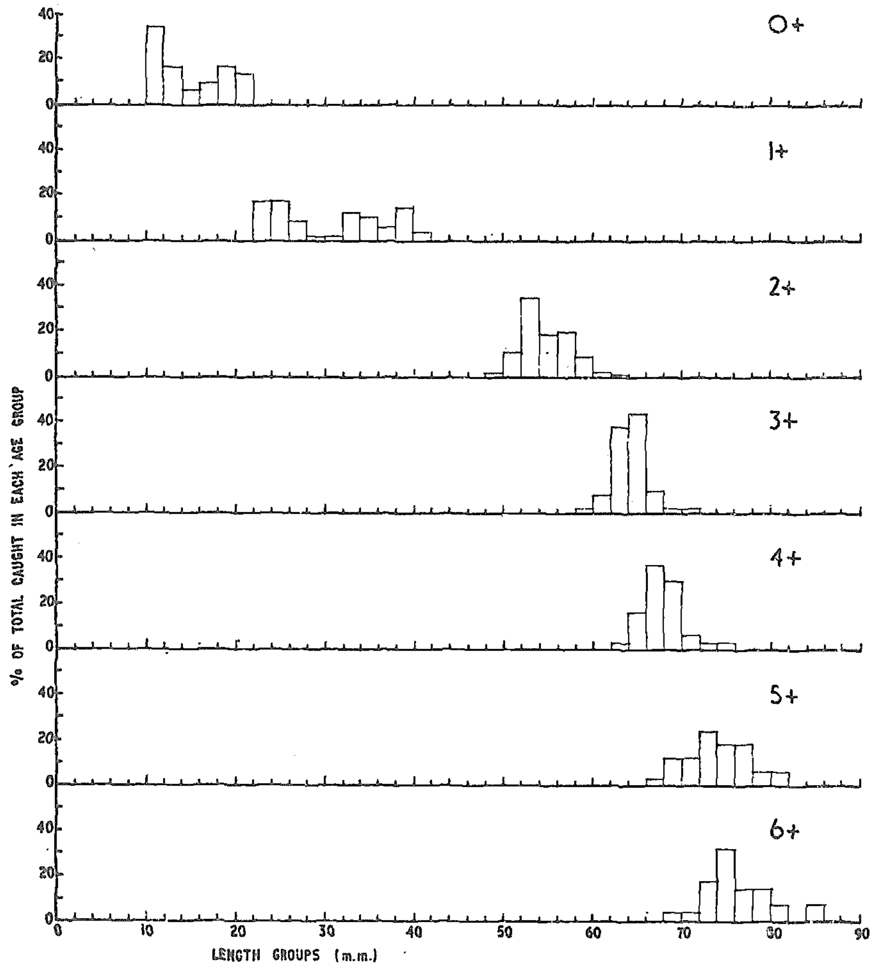

Fig. 6 Size composition of each age group in a population of *C. opercularis* from the Isle of Man area. (From Aravindakshan, 1955)

occurs as amongst the queen scallop population, namely the lack of distinct modality in younger age groups. At the beginning of the year, in January, two year classes were present - one consisting of a large number of small individuals with a considerable size range, the other of large scallops of a compact size group with a well-defined modal peak at 75-79 mm length. As the season progressed the larger group was first fished out, then the smaller individuals, which in May range from 10 to 50 mm in length, rapidly formed a more compact group so that by July a single, unimodal year class was present.

Roe, Cummins and Bullis (1971) collected samples of calico scallops from the east Florida grounds between August 1967 and December 1968. They used a standard 8 ft (2.44 m) scallop dredge with 2 in (50.8 mm) bag rings and 2½ in (63.5 mm) mesh nylon liners so that the data they obtained represent size composition of the catch. These data are presented in Table XIII and Fig. 8 which demonstrate a bimodal distribution from June until October owing to the presence of two year classes, the younger having been spawned in early summer. By December only one mode exists and the year classes are inseparable. This situation remains until April, during which time the older year class presumably disappears.

The size of *C. opercularis* at maturity is uncertain. Aravindakshan (1955) maintained that in queens from around the Isle of Man gamete development starts, on average, when the animal is about 15 mm in size and the first spawning

TABLE X

Size composition of *C. opercularis* populations (from Ursin, 1956)

Length group (mm)	Locality S. Kattegat and Sound of Ven (Oct. 1953) No.	 %	 Faroes (June 1954) No.	 %
1-10	2	0.2	9	1.6
11-20	-	-	24	4.4
21-30	8	0.6	129	23.8
31-40	163	12.9	68	12.5
41-50	293	23.2	133	24.5
51-60	469	37.2	124	22.9
61-70	282	22.3	54	10.0
71-80	45	3.6	1	0.2

TABLE XI

Size (length) distribution of the catch of *C. opercularis* taken by vessels fishing the Bray and Kish Banks, Irish Sea, Oct.-Dec. 1970 (from Bhatnagar, 1972)

Size Group (mm)	Age Group (year) 1+ No.	 %	 2+ No.	 %	 3+ No.	 %	 4+ No.	 %	 5+ No.	 %	 6+ No.	 %	 All groups No.	 %
41-45	5	3.5											5	0.5
46-50	36	25.3	2	1.9									38	4.2
51-55	78	54.9	1	0.9									79	8.7
56-60	19	13.4	2	1.9									21	2.3
61-65	4	4.0	9	8.4	2	0.5							15	1.6
66-70			42	39.2	12	3.1	1	0.4					55	6.0
71-75			46	13.0	87	22.2	12	5.0					145	15.9
76-80			4	3.7	190	48.6	69	28.6					263	28.9
81-85			1	0.9	85	21.7	119	49.4	13	54.2			218	23.9
86-90					14	3.6	29	12.0	8	33.3	4	80.0	55	6.0
91-95					1	0.2	11	4.6	3	12.5	1	20.0	16	1.6

TABLE XII

Size (length) composition of a population of A. irradians from Pivers Island, Newport River, North Carolina, sampled at monthly intervals (from Gutsell, 1930)

Size group (mm)	Jan.		Feb.		Mar.		Apr.		May		June		July		Aug.		Sept.		Oct.		Nov.		Dec.	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0–4.5	313	61.7	290	56.6	27	11.3	4	2.3			1	0.6	3	2.0	71	31.0	174	50.0	290	67.1	387	69.9	142	41.9
5–9.5	56	11.0	46	9.0	39	16.3	41	23.6			4	2.4	1	0.7	19	8.3	51	14.6	22	5.1	56	10.1	47	13.9
10–14	13	2.6	18	3.5	13	5.4	28	16.1	2	1.1	1	0.6	1	0.7	14	6.1	26	7.1	26	6.0	4	0.7	19	5.6
15–19	5	1.0	8	1.6	12	5.0	13	7.5	7	4.0					6	2.6	6	1.7	3	0.7	2	0.4	8	2.3
20–24	4	0.8	6	1.2	9	3.8	8	4.6	20	11.6					4	1.7	2	0.6	1	0.2	3	0.5	4	1.2
25–29	6	1.2	8	1.6	14	5.8	2	1.1	17	9.9									1	0.2	2	0.4	1	0.3
30–34	6	1.2	14	2.7	12	5.0	7	4.0	5	2.9													1	0.3
35–39	3	0.6	17	3.3	27	11.3	7	4.0	7	4.0	5	3.0			1	0.4								
40–44	6	1.2	8	1.6	44	18.3	22	12.6	17	9.9	34	20.6												
45–49	3	0.6	10	2.0	26	10.8	17	9.8	20	11.6	19	11.5	3	2.0	1	0.4								
50–54			2	0.4	10	4.2	10	5.7	39	22.7	32	19.4	29	19.5	1	0.4								
55–59					1	0.4	4	2.3	16	9.3	30	18.2	43	28.8	32	14.0	5	1.4	4	0.9	1	0.2	2	0.6
60–64	1	0.2							3	1.7	32	19.4	50	33.6	52	22.7	37	10.6	32	7.4	13	2.3	7	2.1
65–69	2	0.4	2	0.4	1	0.4					3	1.8	12	8.1	18	7.7	39	11.1	40	9.3	43	7.8	35	10.3
70–74	32	6.3	18	3.5	5	2.1			1	0.6			3	2.0	5	2.2	8	2.3	11	2.5	35	6.3	65	19.1
75–79	44	8.7	29	5.7	10	4.2	6	3.4	2	1.2	1	0.6	1	0.7	2	0.9	1	0.3			7	1.3	8	2.3
80–84	18	3.6	31	6.1	9	3.8	4	2.3	10	5.8	2	1.2			2	0.9			2	0.5				
85–89	3	0.6	4	0.8	1	0.4	1	0.6	5	2.9	1	0.6	2	1.3	1	0.4	1	0.3			1	0.2		
90–94	1	0.2	1	0.2					1	0.6			1	0.7										

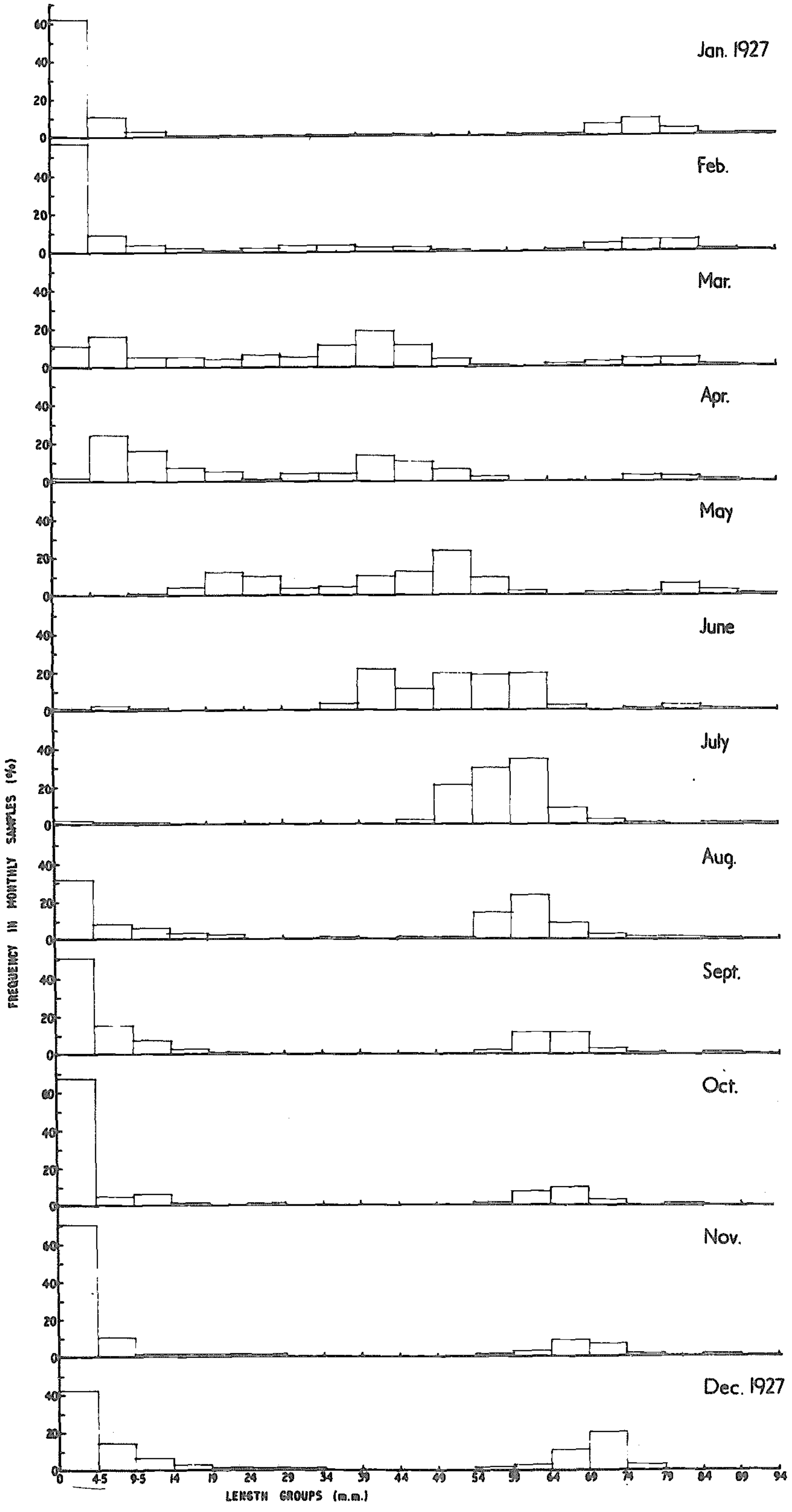

Fig. 7 Size composition of a population of A. irradians. (From data presented in Table XII)

TABLE XIII

Size composition data for A. gibbus taken from a transect across the Cape Kennedy grounds using a commercial dredge (from Roe, Cummins and Bullis, 1971)

Size group (mm)	1967										1968											
	Aug.		Sept.		Oct.		Nov.		Dec.		Feb.		Apr.		June		Aug.		Oct.		Dec.	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
0-9															6	3.3	1	0.2				
10-19	1	3.7	4	2.6											24	13.2	57	10.3	2	1.0		
20-29	1	3.7	4	2.6	1	0.8	1	1.3							4	2.2	163	29.5	61	30.8	125	16.7
30-39	1	3.7	3	2.1			3	3.8			3	0.3					41	7.4	3	1.5	260	34.7
40-49	2	7.4	16	11.0	3	2.5	7	8.8			4	0.4	38	6.2	1	0.5					116	15.5
50-59	11	40.7	58	40.0	72	59.5	23	28.8	38	59.4	295	32.9	185	30.2	44	24.2	41	7.4	8	4.0	103	13.8
60-69	9	33.3	42	29.0	43	35.5	39	48.8	25	39.0	567	63.2	343	55.9	72	39.6	211	38.2	103	52.0	138	18.4
70-79	2	7.4	18	12.4	2	1.6	7	8.8	1	1.6	28	3.1	46	7.5	31	17.0	38	6.9	21	10.6	7	0.9
80-89													1	0.2								

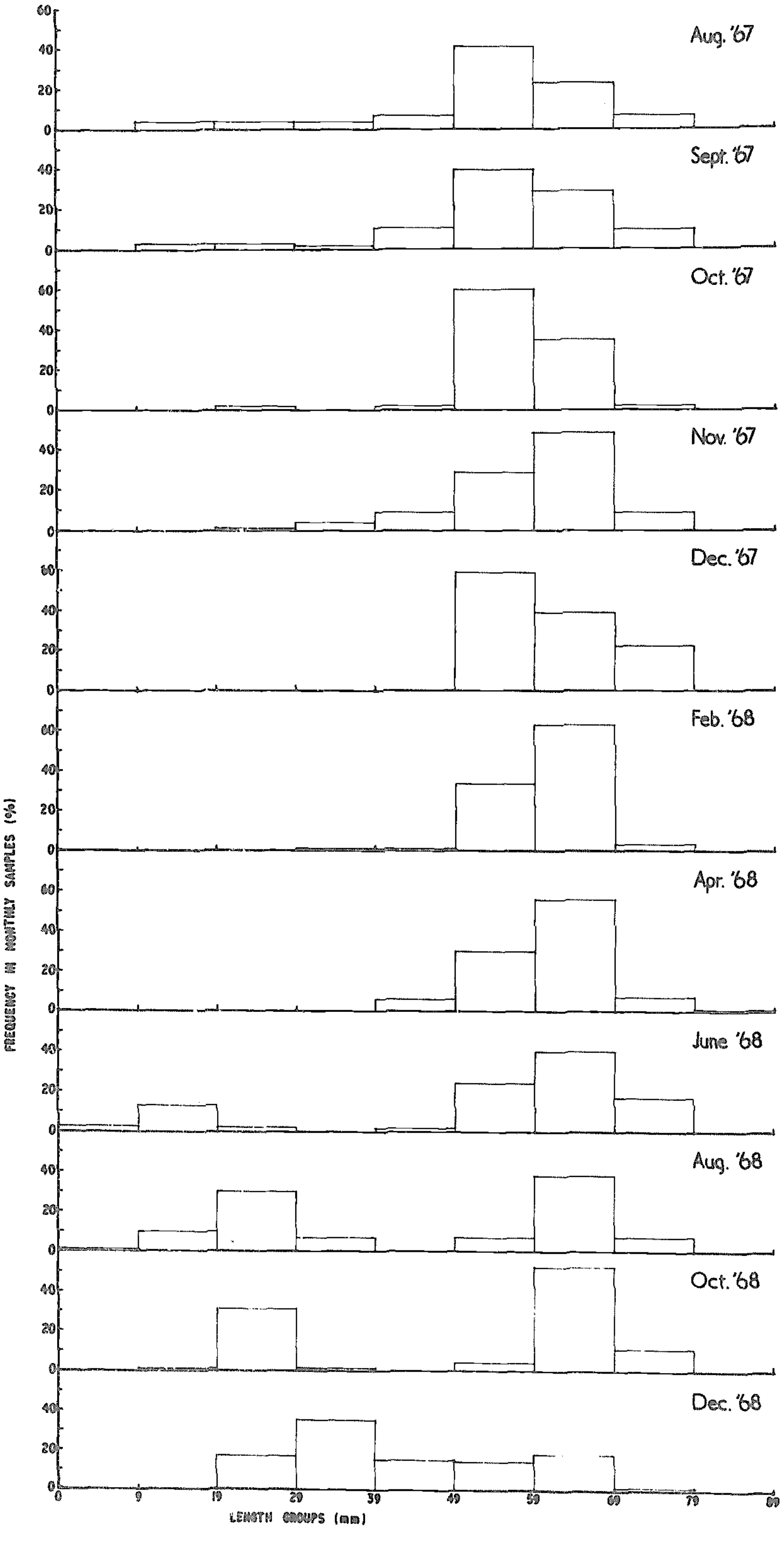

Fig. 8 Size composition of catches of A. gibbus taken from the Cape Kennedy grounds using commercial dredge. (From data presented in Table XIII)

occurs at 22 mm. For bay and calico scallops the size at first spawning is the size at the end of the first year. Thus bay scallops first spawn at a length of 60-69 mm (Gutsell, 1930) and calico scallops spawn at about the same size (Roe, Cummins and Bullis, 1971).

The theoretical maximum sizes (L_∞) of *C. opercularis* have been calculated from various data on growth rates using the expression

$$\frac{dl}{dt} = K(L_\infty - l)$$

and have already been presented in Table VI (see Section 3.43). Although queens in most areas do not usually reach sizes larger than 80-85 mm, Mason (1970) found several individuals in the 105-109 mm group in a population in Scapa Flow, Orkney Islands. The maximum length for the calico scallop is about 80 mm (Roe, Cummins and Bullis, 1971) and that for the bay scallop is about 90 mm (Gutsell, 1930).

Askew, Dunn and Reay (1974) produced a length/weight relationship for *C. opercularis* from the Channel Islands. This relationship alters seasonally because of the loss of condition after spawning. Thus, in May, when gonads are developing and condition is good the relationship takes the form

$$W = 0.164\ L^3 + 2.198$$

where W = wt (g) and L = length (mm). However, in October, after spawning

$$W = 0.113\ L^3 + 3.6$$

4.2 Abundance and density (of population)

4.21 Average abundance

The only reference to population size of *C. opercularis* was made by Askew, Dunn and Reay (1974) who estimated the size of the Guernsey queen stock in 1973 to be about 230 million shellfish. Roe, Cummins and Bullis (1971) estimated the standing crop of *A. gibbus* on the Cape Kennedy beds in 1967-68 to be 3 892 million fish, and they suggested that this was a conservative estimate.

4.22 Changes in abundance

Most information concerning changes in the abundance of queen scallop populations relates to the reported sudden disappearance of large numbers from a particular area and also to the decrease in numbers associated with intensive fishing (Rolfe, 1973). However, Ursin (1956) reported a dramatic change in the abundance of *C. opercularis* in the central North Sea following the very cold winter of 1947 during which, he maintained, large numbers of queens were probably exterminated (see Section 3.22).

Abundance of *A. gibbus* varies both seasonally and annually. Roe, Cummins and Bullis (1971) reported that on the Florida grounds in 1967 and 1968 abundance (as measured by catch rate) was highest from September to December. Cummins (1971) and Lyles (1969) reported abrupt yearly changes in abundance on the North Carolina grounds while Bullis and Ingle (1959) and Hulings (1961) reported similar occurrences in the northeast Gulf of Mexico. The catch rate data provided by Cummins, Rivers and Struhsaker (1962) from exploratory fishing for calico scallops off North Carolina demonstrate the seasonal changes in abundance. They found maximum catch rates altered from 3 bu (1.06 hl)/$\frac{1}{2}$ h drag in December to 16 bu (5.64 hl)/$\frac{1}{2}$ h drag in February, and 19 bu (6.70 hl)/$\frac{1}{2}$ h drag in July.

In the early thirties bay scallop populations in the bays and inlets of the eastern seaboard of the U.S.A. decreased greatly following the destruction of much of the eelgrass (*Zostera* sp.) along the coast by a mycetozoan parasite (Stauffer, 1937; Dreyer and Castle, 1941). Several authors (e.g., Gutsell, 1930; Kirby-Smith, 1970; Thayer and Stuart, 1974) pointed out the close association between bay scallops and eelgrass and it was suggested that the eelgrass is probably a favourite settlement substratum for the bay scallop spat (Gutsell, 1930). However, Marshall (1947, 1960) showed that the population of bay scallops in the Niantic River, Connecticut increased considerably after the disappearance of the eelgrass and he suggested that this was due to the better circulation conditions produced when the *Zostera* was destroyed.

4.23 Average density

Askew, Dunn and Reay (1974) assessed the density of queen scallops on the Guernsey bed. Underwater photography by a remote controlled camera gave an estimate of 5.7 queens/m^2 while tagging returns gave an estimate of 6.1 queens/m^2. On other grounds, e.g., south Devon, queens have been reported lying in layers 2 or more deep (Pickett, personal communication).

Cummins (1971) reported the densities of calico scallops on the Cape Kennedy grounds as averaging 4/ft^2 with some areas exceeding 8/ft^2 (43/m^2 and 86/m^2 respectively).

The densities of *A. irradians* at various sites in the Niantic River, Connecticut have been assessed by Cooper and Marshall (1963) in relation to current speed. Thus in slack water densities were 3-5/m^2, while in tidal currents (4-20 cm/sec) they were 65-75 scallops/m^2. In an area where there was some intermediate current, densities were 11-25 scallops/m^2.

Thayer and Stuart (1974) have monitored the density of bay scallops in an eelgrass bed in the Newport River estuary, North Carolina. In one area density from June to November 1973 averaged $24.8/m^2$ and in December-January, after 6 man-hours of raking between 3 and 17 December, density averaged $16.7/m^2$. In a second area where 2 man-hours of dredging took place in addition to the raking, densities dropped from an average of $19.5/m^2$ in June-November to $3.0/m^2$ in December-January.

4.3 Natality and recruitment

4.33 Recruitment

No information on recruitment to the fishable stocks of any of the species is available. Askew, Dunn and Reay (1974) chose an arbitrary figure of 3 years for the age at which the queens were first recruited to the fishable Guernsey stock. Very few young queens were found on the Guernsey bed and it is possible that recruitment to this particular fishery is achieved by the migration of young queens from the surrounding area where there are known to be adults present in less than commercial quantities.

4.4 Mortality and morbidity

4.41 Mortality rates

Estimates of the instantaneous fishing and natural mortality rates for the queen scallops in the Guernsey stock in 1972 and 1973 were made by Askew, Dunn and Reay (1974). For 1972 these were respectively 0.11 and 1.98, and for 1973 they were 0.37 and 1.65. However, these estimates were made by studying the age composition of the population and do not take into account possible variations in year-class strength. Furthermore, the age composition data were based on the assumption that the rings observed represent annual growth increments.

Roe, Cummins and Bullis (1971) reported that the instantaneous natural mortality coefficient for a single year class in a bed of calico scallops on the Cape Kennedy grounds between February and October 1968 was 0.231 and the monthly mortality for that period was 21 percent. These figures were derived from catch data which indicated that recruitment to the sampled population was completed by February. In fact the catch curve plotted suggests a non-uniform mortality rate, increasing rapidly after June, i.e., after the termination of spawning.

The average monthly mortalities of bay scallops maintained in trays from November 1969 to November 1970 /initial size 10 mm height, initial age 3 months, initial density $44/ft^2$ ($473/m^2$)/ generally remained below 7 percent though mortality rose to a peak of 13 percent in August-September (Castagna and Duggan, 1971). Duggan (1973) investigated the mortality among bay scallops maintained in trays at different water depths and population densities. The experiments were carried out over four months from May-June tc August-September 1971. Initial size was ca 15 mm height. The results are summarized in Table XIV.

In fact in Experiment II mortalities were low at all densities during the first two months but began to increase when the scallops reached about 37.0, 39.0, 43.5 and 46.2 mm at densities of 100, 75, 50 and $25/ft^2$ respectively (1 075, 806, 537 and $269/m^2$ respectively).

4.42 Factors causing or affecting mortality

The precise contribution made by predators and parasites discussed in Sections 3.34 and 3.35 to the mortality rates of the scallops is

TABLE XIV

Mortality of A. irradians in relation to water depth and population density (after Duggan, 1973)

Experiment I		Experiment II	
Depth (m)	Final total mortality (%)	Density (scallops/ft^2)	Final total mortality (%)
Surface	16.5	100	35.0
-	8.0	75	16.0
3-4	4.0	50	6.2
4-5	29.0	25	3.2
Initial density - $40/ft^2$ ($430/m^2$) Bottom depth - 5-6 m			

unknown. However, gulls are said to be especially damaging to bay scallop beds at low tide (Waller, 1969) and starfish probably account for large numbers of the deeper living types, A. gibbus and C. opercularis. Cold is often quoted as a cause of mortality and, in bay scallops, freshets (see Section 3.32). Castagna and Duggan (1971) suggested (a) overcrowding and (b) a general physical decline, as the two conditions likely to be responsible for the increase in mortality from June to September among the bay scallops they maintained in trays. Belding (1910) expressed the opinion that a physical decline of bay scallops begins at 18 months and all but eliminates the year class by the 26th month. The increased mortalities obtained by Duggan (1973) in his culture experiments on bay scallops (see previous section) were probably due to reduction of food supply by cage fouling and to mechanical disturbance.

The effect of the fishing gear on the scallops and its potential for causing mortalities is unknown. In the Plymouth area of Britain queen scallop fishermen often bring up quantities of hydroid to which many young queen spat are attached. It is, therefore, possible that dredging in these areas causes significant mortality among the spat.

4.6 The population in the community and the ecosystem

Queen scallops inhabit mainly open marine waters and do not occur in markedly estuarine areas. Ursin (1956) suggested that the minimum salinity tolerance was 25°/oo for queens in Danish waters and showed that they were not usually found inside the 30°/oo isohaline in this area.

Recorded bottom temperatures in the areas where queens are found range from 2.2°C in the Kattegat to 24°C in the Mediterranean (Ursin, 1956). The ranges of temperatures tolerated differ from stock to stock but there appears to be a definite distinction between the boreal forms living in boreal seas at temperatures not below 2-4°C and not above 16-17°C and the form in the Mediterranean which tolerates almost the full range of 13°C to 26°C (Runnström, 1927). Ursin (1956) suggested that the two stocks might be physiologically distinct.

Jeffreys (1863) reported the depth range of queen scallops as 6-90 fath (11-165 m) although in the Mediterranean the depth range is apparently 1-250 m (Bucquoy, Dautzenberg and Dollfus, 1887, cited by Ursin, 1956). However, the greatest concentrations are found at moderate depths, for example, the densest beds around Port Erin, Isle of Man are in 15-25 fath (27.4-45.7 m) (Aravindakshan, 1955). It seems likely that in the boreal forms the shoreward depth limit is determined largely by temperature tolerances (Ursin, 1956).

Queens are usually found on a sandy-mud bottom, some mud being necessary to bind the sand and keep the bottom firm. Other bottom-types may be utilized provided they are firm. Queens are unlikely to be found on pure sand and they also avoid soft, clayey substrata (Ursin, 1956).

A queen scallop "community" was reported in the Firth of Forth, Scotland (Fullarton, 1889). This author maintained that large numbers of horse mussel, Modiolus modiolus, live in close association with queen scallops in this area and that their presence is highly necessary because their byssus threads bind mussel, shell, stone and sand to form a bed suitable for scallops, otherwise they would be buried in the mud. Ursin (1956) stated that C. opercularis is a current-loving species and as such is usually found in a distinct rheophile fauna which often includes Modiolus together with hydroids, balanids and Ophiothrix (Vevers, 1952).

Calico scallops also inhabit open marine water. They have been reported in depths from less than 2 m to 370 m (Allen and Costello, 1972) but fishable concentrations are usually found between 10 and 40 fath (see Section 5.23). Temperatures in the waters they inhabit range from about 10°C to 33°C (Allen and Costello, 1972). Even in the most northern part of their range, in Raleigh and Onslow Bays, North Carolina the temperature range is 10°C to 25°C (Kirby-Smith, 1970). This is because at the water depth they inhabit they are under the influence of the Gulf Stream, so that even on the sea bed, in winter, temperatures do not drop much below 10°C. The types of substratum on which they are found have been listed by Allen and Costello (1972) as bottoms composed mainly of hard sand, sand and shell, quartz sand, smooth sand-shell-gravel, fairly clean medium-grained quartz sand, and sand and dead shell.

Bay scallops, as their name suggests, generally inhabit shallow, protected bays, inlets and estuaries with only slightly reduced salinities (Kirby-Smith, 1970). Marshall (1960) suggested that estuaries with the following hydrographic features will provide particularly favourable conditions for bay scallop populations: (a) high ratio of tidal volume to river flow so that salinity remains high; (b) a relatively shallow basin with a resulting high ratio of tidal volume to volume at low water; and (c) a circulation that will retain the planktonic larvae in sufficient numbers for reseeding and that will provide an adequate supply of planktonic food, perhaps in part supplied by offshore waters. There is little information on the depth range of bay scallops but Gutsell (1930) found that in the most productive areas around Beaufort, North Carolina, depths were seldom more than 6 ft (1.83 m). The distributional minimum for salinity in this area was 20°/oo and bay scallops were also found in the most saline waters of their range (about 38°/oo). The temperature range to which bay scallops in North Carolina are exposed is 3-6°C in January-February to 30°C or above in July, August and September (Gutsell, 1930; Kirby-Smith, 1970). Bay scallops are generally found on a firm bottom, varying from mud to hard, but not shifting, sand (Gutsell, 1930).

The scallops are primary consumers apparently feeding mainly on phytoplankton, although there is some doubt as to whether pelagic or benthic forms contribute the major part of the diet (see Section 3.42). The deep water forms (queen and calico scallops) are undoubtedly a major food source for starfish, while bay scallops possibly contribute as much to the diet of gulls and shore crabs. Bay scallops, living in the shallower water, are probably the most productive of the three species. According to Marshall (1960) the annual harvest of bay scallops from the Niantic River is 300 lb tissue wet weight/acre (336 kg/ha) which is ten times the production of *Placopecten magellanicus* from the Georges Bank off Newfoundland.

5 EXPLOITATION

5.1 Fishing equipment

5.11 Gears

The following account of gear used in queen fishing is based on information provided by Rolfe (1973).

Queen scallops were first fished using lightweight triangular dredges with toothed bars, but these were really only suitable for small boats on smooth grounds. A dredge of similar design but fitted with a blade bar instead of a toothed bar has done well in Lyme Bay, where the ground is very sandy. For use on rougher, more stony grounds the Blake dredge was designed to catch queens as they swam up from the bottom, disturbed by the approaching gear. This gear is fairly strong [an 8-ft (2.44 m) dredge weighs 3½ cwt (178 kg)] and moves over the ground on two or three runners at the mouth of the bag. The frame has a heavy bar, which acts as a stone guard, welded through the middle, but there is no fixed blade or toothed bar to dig into the ground; a chain ground rope is employed instead. The bag has a belly of steel rings and the top is made of sisal or "courlene" netting. Another type of dredge, the Conolly roller dredge, substitutes rollers for the runners found in the Blake dredge. It is believed to be more efficient than the latter on hard grounds but on soft grounds the rollers are said to sink in. Because of their well developed swimming ability queens are often caught with higher gears - namely beam and otter trawls. Two or three heavy tickler chains are usually used to rouse the shellfish, which then swim up into the path of the trawl. The types of gear used thus depends largely on the condition of the ground.

A typical traditional beam trawl used for queen fishing would be 8 ft (2.44 m) wide with a tubular steel beam 18 in (45.7 cm) above the sea bed. The bag would be of 60 mm mesh courlene netting with a 45 mm mesh cod end. A typical Blake dredge might have 3 runners, a top beam 11 in (28 cm) above the bed and a stone guard 6 in (15 cm) above the bed. The steel rings of the belly would be of 2½ in (63.5 mm) internal diameter and the back would be 45 mm mesh courlene.

In the North Carolina calico scallop fishery the shellfish were first caught with dredges but these were soon replaced by trawls (Rivers, 1962). Dredges and trawls are used on the Florida grounds (Allen and Costello, 1972).

The trawl used on the North Carolina calico scallop beds is built of 2-4 in (5.1-10.2 cm) cotton webbing and hung on 25-28 ft (7.6-8.5 m) of ½-in (12.7 mm) combination rope; it is essentially an otter trawl, and boards weighing 250 lb (118 kg) each (3 x 5½ ft; 0.9 x 1.7 m) are most commonly used, but there is no overhang on the net, the top and bottom sections being identical (Rivers, 1962). As with queen fishing, tickler chains are hung across the mouth of the trawl to raise the scallops. A typical 8-ft (2.44 m) tumbler dredge used in this fishery has a bag constructed entirely of 2-in (50.8 mm) internal diameter steel rings. The bag is 33 rings wide, 20 rings long and 5 rings deep (Cummins, 1971).

The shallow habitat of the bay scallops means that hand rakes as well as dredges are used in the fishery.

- Gear efficiency

Askew, Dunn and Reay (1974) reported a gear efficiency for dredges used on the Guernsey queen bed of about 17 percent, i.e., 17 percent of the queens in the path of the dredge are retained. Walne and Wood (1974) estimated that the efficiency of beam trawls used on the south Devon queen beds may be as high as 40-50 percent and Mason (1970) reported that on a smooth sand bottom in Clunaig Bay, Argyll, Scotland a traditional beam trawl caught four times as many queens per unit of fishing effort (catch/ft/h) as a Manx queen dredge. However, the efficiency of the gear does depend on the type of ground. This is well illustrated by the situation in the calico scallop fishery where, on the hard sand bottom of the North Carolina beds, a 25-ft (7.6 m) scallop trawl will consistently outfish a dredge by as much as 6:1 (Rivers, 1962). Rivers (1962a) reported that on the softer beds of the Cape Kennedy grounds dredges generally outfish trawls, although a subsequent investigation (Anon, 1967) showed that on the Florida grounds catch rates using the North Carolina scallop trawl [a 35-ft

(10.7 m) trawl/ exceed those of the smaller dredges /presumably dredges of 8 ft (2.4 m) or less/. Bullis and Cummins (1961) reported that the tumbler dredge is more efficient than the Georges Bank dredge on the Florida grounds.

Dredges used in the bay scallop fishery are more efficient than rakes but there is evidence that they may so damage the eelgrass beds and the substratum as to be responsible for a drop in the success of the spatfall and hence the fishery in subsequent years (Thayer and Stuart, 1974).

5.12 Boats

Queen scallops are fished mainly by side trawlers more than 50 ft (15.2 m) long equipped with dredging gear.

On the Cape Kennedy grounds the types of vessel fishing for calico scallops have included shrimp trawlers, New England scallopers, Chesapeake Bay dredgers and factory type scallopers (Cummins and Rivers, 1970; Cummins, 1971). The factory type vessels effect complete or partial processing at sea and are more than 80 ft (24.4 m) long.

Because of the shallow water habitat, boats used in the bay scallop fishery are necessarily small. At one time very small dredges were operated from row-boats but now small motorized craft up to 35 ft (10.7 m) long are most often used.

5.2 Fishing areas

5.21 General geographic distribution

The most important fished stocks of C. opercularis occur round the coast of the British Isles - notably around the Shetland and Orkney Islands, in the Firth of Clyde and Irish Sea and off the south Devon coast. Fig. 9 shows the major fished stocks of queens around the British coasts. Queens are also fished locally around the coasts of Spain (Gulland, 1970; FAO, 1973) and France (Duclerc and Fauvel, 1968) in the Mediterranean, and also in the Danish Sound and in Faroese waters (Ursin, 1956; ICES, 1974).

There are three important calico scallop grounds off the south and east coasts of the U.S.A. The smaller of the grounds on the east coast is situated off the coast of North Carolina in Raleigh Bay and Onslow Bay. The area runs approximately parallel to the coast and forms two lobes on either side of Cape Lookout, as shown in Fig. 10. The largest area containing commercial concentrations of calico scallops is a wedge-shaped ground off the east coast of Florida. The apex of the wedge is at approximately 27°N 80°W and the base extends from about 31°N 80°15'W to 31°N 80°35'W. The third commercially fished area is situated around Cape San Blas, Florida, in the Gulf of Mexico. It extends from about 84°W to 88°W; the northern limit of the ground approximately follows the 11 fath (20.1 m) line and it has an average width of approximately 40' of latitude (Cummins, 1971).

The bay scallop is fished from New England to the Gulf of Mexico (Gulland, 1970) and is an important article of commerce in Massachusetts, Rhode Island, New York, New Jersey, Virginia, North Carolina and Florida (Thayer and Stuart, 1974).

5.22 Geographic ranges

Most of the queen scallop fishing grounds occur very near the coast. In fact, as seen in Fig. 9, in the Shetlands, Orkneys, Firth of Clyde, and Isle of Man and Solway Firth areas they extend almost up to the coastline. The Kish Bank, Cardigan Bay, south Devon and Lyme Bay stocks are about 15 km offshore. Commercial quantities of queens are highly localized and the areas of great abundance seem to change from year to year.

The calico scallop grounds vary from 10-75 km offshore of North Carolina to 8-110 km offshore of Florida and 2½-130 km offshore in the Gulf of Mexico. The Florida east coast scallop grounds have been estimated to cover some 5 760 mi^2 (14 900 km^2) (Drummond, 1969) but in any month only 5-20 percent of the stock is commercially exploitable (Anon, 1968). This pattern is fairly typical of all three grounds and the areas where fishing effort is concentrated tend to alter annually (Allen and Costello, 1972). Roe, Cummins and Bullis (1971) found that calico scallops from off east Florida show a slight seasonal change in depth distribution, scallops being found in slightly deeper water in winter than in summer, though this difference was less noticeable north of Cape Kennedy. Moreover, south of the Cape abundance was highest in 21-23 fath (38.4-42.1 m) whereas north of the Cape abundance was highest in 24-27 fath (43.9-49.4 m). Indeed scallops south of the Cape were generally found in shallower water than those north of the Cape. The reasons for this are unknown. Roe, Cummins and Bullis (1971) suggested the possibility of a different thermal structure and also pointed out that south of the Cape the shelf is narrower and steeper so that available habitat is restricted. Possibly optimum bottom occurs 4-5 fath (7.3-9.1 m) shallower in that area.

Bay scallops, by the nature of their habitat, are not found concentrated on large grounds but are fished from the bays and inlets along the coast.

5.23 Depth ranges

According to Aravindakshan (1955) the densest beds of C. opercularis around the Isle of Man occur

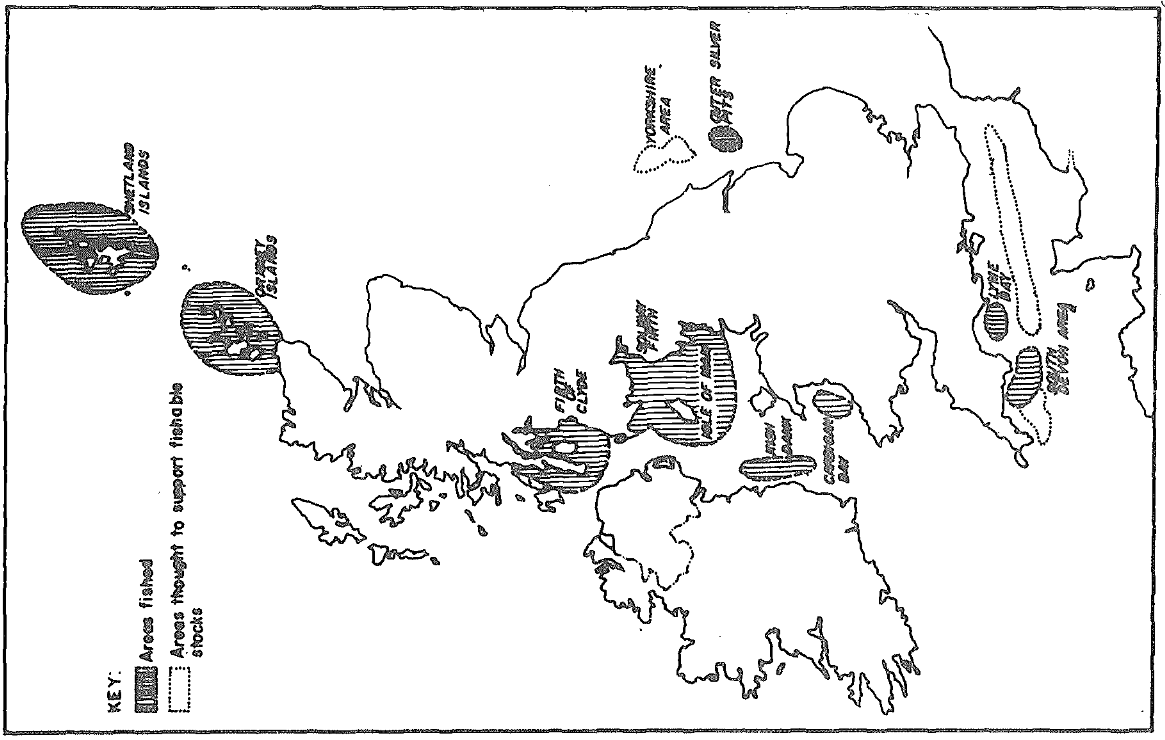

Fig. 9 The distribution of queen scallop fishing grounds around the British Isles. (From Rolfe, 1973).

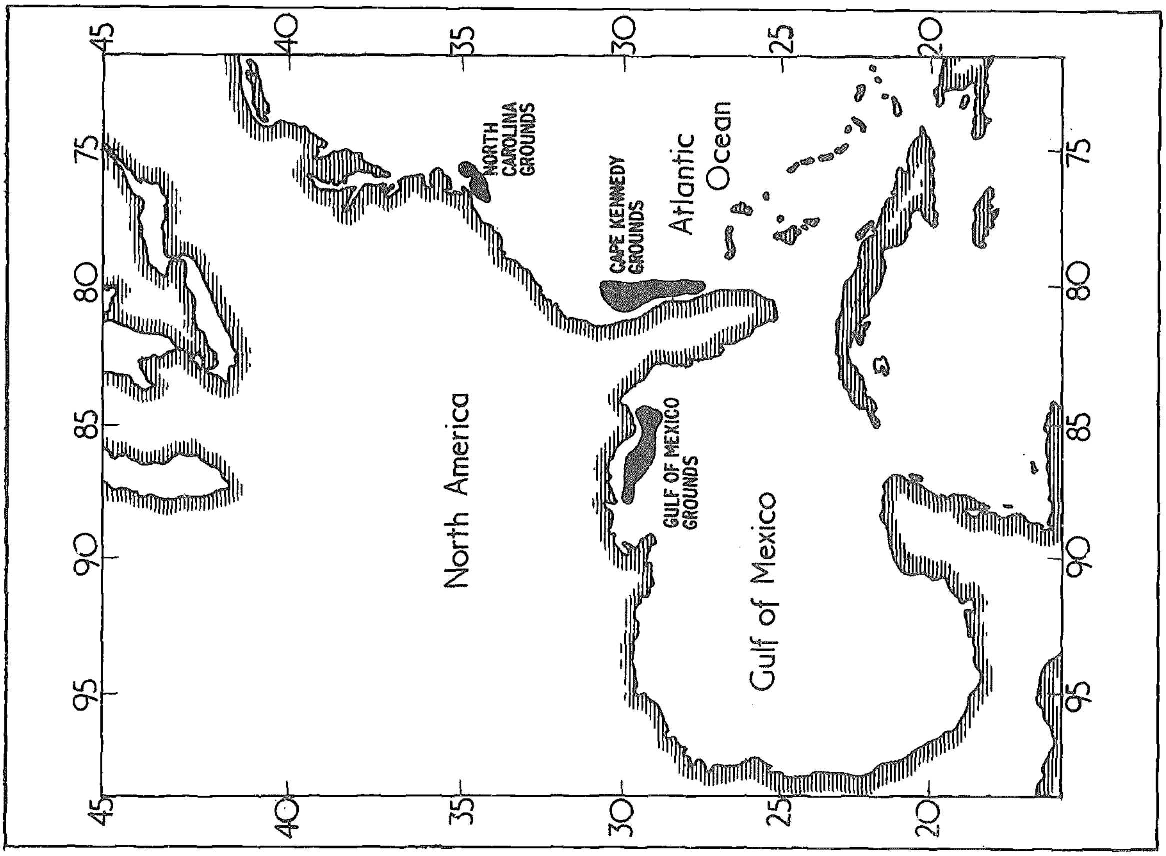

Fig. 10 The distribution of calico scallop fishing grounds. (From Cummins, 1971)

in 15-25 fath (27.4-45.7 m). Fished beds around the British Isles rarely exceed 55 m depth.

The fished beds on the Cape Kennedy calico scallop grounds have a depth range of 5-40 fath (9.1-73.2 m) but the most productive catches in the past have been taken between 15 and 35 fath (27.4 and 64.0 m) (Drummond, 1969). The principal fished beds off North Carolina usually lie in 19-37 m of water (Allen and Costello, 1972). In the Gulf of Mexico, off Cape San Blas, Carpenter (1967) found the heaviest concentrations of calico scallops were in less then 20 fath (36.6 m) and maximum production came from 11 fath (20.1 m).

Bay scallops are harvested from fairly shallow water, rarely deeper than 6 m and often 2 m or less (Gutsell, 1928, 1930; Marshall, 1960).

5.24 Conditions of the grounds

The types of sea bed on the fishing grounds vary from one locality to the next. The ground on the queen bed in the Channel Islands is "medium hard" - shells or stones mixed with mud or sand (Askew, Dunn and Reay, 1974). In Lyme Bay the queen grounds are very sandy whereas in the Firth of Clyde the grounds are gravelly (Pickett, personal communication).

Rivers (1962) indicated that the North Carolina calico scallop grounds are on hard sand and that the relatively smooth bottom is pitted with small depressions in which the scallops aggregate. Drummond (1969) maintained that the Cape Kennedy calico scallop grounds are composed mainly of sand and dead shell. The bed on these grounds is apparently shaped by currents into north-south windrows in which are found the scallops. The windrows may be up to 1/4 mi (0.4 km) long (Roe, Cummins and Bullis, 1971).

According to Gutsell (1930) the bottom types on which bay scallops are found vary from soft mud to hard, but not shifting, sand.

5.3 Fishing seasons

5.31 General pattern of seasons

In the past the development of queen scallop fishing past the stage of a small local fishery was hampered by the poor ability of live animals to survive packing and transport, particularly in summer. The advent of the processing plant has meant that the queens can be fished all year round and the catch still sold. Thus most of the stocks around the British Isles are now fished continually. However, the loss of condition in the shellfish which seems to take place just after spawning time (see Section 3.42), reducing yield, may make other fisheries temporarily more profitable so that effort is switched from queen fishing.

Calico scallops also suffer from a decline in yield as spawning time is approached and the best yields are obtained from September to December (Roe, Cummins and Bullis, 1971). However, at present the fishery is operated all the year round.

5.32 Dates of beginning, peak and end of season

As stated in the previous section, although queen fisheries may be in operation all the year round, changes in condition often make it more profitable to fish for other resources at certain times of the year. Thus, according to Bhatnagar (1972) the season for queens off eastern Eire is from July to December with a peak (in 1970) from 21 September to 10 October.

Marshall (1960) reported that in the Niantic River, Connecticut the 1954-55 season lasted from October to April, with more than half the catch taken in the first two months of this period. In New York State the bay scallop season is from the third Monday in September to 31 March. In Massachusetts this season is from 1 October to 31 March, and in Maine it runs from 1 November to 14 April with the additional provision that in Harrington River and Bay and Pleasant River, Washington County there shall be no dragging for scallops between 15 April and 1 December.

5.4 Fishing operations and results

5.41 Effort and intensity

Unified effort data for shellfisheries are rare in the literature. The ideal measurement of effort would involve some measure of gear size as well as the time the gear was in operation, e.g., catch/ft/h. But usually effort data consists at best of a catch rate/h at sea or catch/boat day.

Askew, Dunn and Reay (1974) reported that in Guernsey the recorded landings of queens fished from the Guernsey bed during the period January-June 1973 varied from 1 to 92 bags/fishing day (1 bag = 100 lb or 45.4 kg). The highest recorded catch per vessel in the space of one month was 638 bags in 14 fishing days - an average of 2 tons/boat day. The average catch/boat day for the vessels fishing during this period was 1½-1¾ tons. The number of vessels working the Guernsey bed varied from 15 in January to 11 in June. It was noted that the above data obscured any differences in gear used, with the concomitant differences in efficiency. Variations in day length and weather conditions were not apparent nor were the number of hauls undertaken to produce the catch given.

For the calico scallop fishery Cummins (1971) reported that on the North Carolina grounds, which are 2-4 hours from port, catches average 400-600 bu (141-211 hl)/boat day, with maximum catches of

900 bu (317 hl)/boat day (1 bu ≏ 70 lb or 31.75 kg). In 1959 only 3 boats were engaged in the fishery and using dredges they landed 6 500 lb (2 950 kg) of meats. In 1966 17 vessels using trawls landed 1 856 760 lb (842 230 kg) of meats. On the Florida grounds by May 1968 at least 16 vessels had landed calico scallops in Florida and Georgia. Landings from 1 boat ranged from 735 to 1 500 bu (260-530 hl), each catch being obtained in about 24 h with a single 8-ft (2.44 m) tumbler dredge (= 3.8-7.8 bu/ft/h or 0.41-0.84 hl/m/h). In 1969 3 factory vessels were working a 24 h day and by September maximum production had reached 4 000 lb (1 814 kg) of processed meats per day.

There are large numbers of small boats working the bay scallop fishery. At Nantucket, Massachusetts the fleet in the 1968-69 season consisted of about 50 boats but in the 1969-70 season it was down to 35 boats (Crise, 1970). Wickford, Rhode Island once possessed a fleet of 400 boats including commercial and amateur scallopers, but by 1967 the numbers of bay scallops in the area had decreased to proportions that were not commercially fishable and the fleet ceased fishing (Ward, 1970).

5.42 Selectivity

Mason (1970) provided the only detailed information on gear selectivity in the queen fishery. Fishing with a Manx queen dredge and a beam trawl in Clunaig Bay, Argyll, he found that the latter gear caught queens of a slightly smaller mean length (57.4 mm) than did the former (63.6 mm). The netting on the dredge was of rather smaller mesh size (45 mm) than the main body of the beam trawl (60 mm) although the mesh size of the cod end of the trawl was the same (45 mm). However, the rings on the belly of the dredge were about 63 mm internal diameter.

Although the fishing gear effects the initial selection the queens may also be passed through a riddle which retains those of commercial size. In Guernsey the size of the riddle used is $1^{3}/4$ in (44.45 mm). This produces a mean selection size of 54.8 mm [i.e., the size at which 50 percent of the queens entering the gear (riddle) are retained]. A reduction in riddle diameter of just $^{1}/16$ in (1.6 mm) would increase meat yield by 50 percent by reducing age at first capture to 3 years. However, it would also produce a very high meat count per lb (<u>ca</u> 140/lb or 308/kg) at the time when the meats are in poor condition (October in this case) and this would be unacceptable to the processing plant. An increase of $^{1}/16$ in would raise the age at first catch to about the age at which growth ceases. This would result in a satisfactory count per lb but a marked decrease in yield (Askew, Dunn and Reay, 1974).

5.43 Catches

Separate catch statistics for queen scallops in England and Wales first became available in 1973. Prior to this they were included with the data for <u>Pecten maximus</u>. In Scotland, however, the catch statistics for queens have been included amongst those for "other shellfish" and in fact this category consists almost entirely of queen scallops (Scottish Sea Fisheries Statistical Tables, 1973). The landins of queens in the United Kingdom, Eire and Spain are given in Table XV. The shellfish are not processed at sea, so landings are equivalent to catches.

TABLE XV

Nominal catches of <u>Chlamys opercularis</u>, 1967-73[a] ('000 metric tons)

Country	Year						
	1967	1968	1969	1970	1971	1972	1973
Spain	0.1	0.2	0.5	0.1	F/0.1	0.0	...
Scotland	0.0	0.0	—	5.03	4.99	4.63	7.49
England and Wales							7.72
Northern Ireland				0.4	0.5	0.6	0.51
Eire				1.37	1.09	0.33	...

a/ Data obtained from FAO Yearbook of Fishery Statistics, Vol. 34, 1972; Scottish Sea Fisheries Statistical Tables, 1973; U.K. Sea Fisheries Statistical Tables, 1973; and Kensler (1974)

F - estimated by FAO
0.0 - negligible amount or less than $\frac{1}{2}$ the smallest figure shown
— - none recorded
... - no data available

TABLE XVI

Nominal catches of A. irradians and A. gibbus landed in the U.S.A., 1965-72 ('000 metric tons)

Area	Year							
	1965	1966	1967	1968	1969	1970	1971	1972
Atlantic, Northwest								
Bay scallops	5.2	5.1	2.6	2.6	5.3	5.8	4.9	1.8
Atlantic, Western Central								
Bay scallops	1.5	2.3	2.2	2.5	3.7	0.5	0.8	-
Calico scallops	3.7	10.9	9.8	0.6	1.3	10.4	10.0	7.6

Bay and calico scallops are landed only in the U.S.A. (FAO Yearbook of Fishery Statistics, Vol. 34). The catches landed in the U.S.A. from 1965 to 1972 are given in Table XVI. Bay scallop catches are divided between those taken north of Cape Hatteras (Northwest Atlantic) and those taken south of it (Western Central Atlantic). There are now a few factory ships working the calico scallop beds and, therefore, landings of this species may differ from nominal catch.

6 PROTECTION AND MANAGEMENT

6.1 Regulatory (legislative) measures

6.11 Limitation or reduction of total catch

No legislative restrictions are placed on total catches of queens or on the efficiency or number of fishing units working queen scallop beds, and a similar situation exists in the calico scallop fishery. However, various restrictions are applied to the bay scallop fishery and these vary from state to state and from county to county. For example, in Massachusetts the daily limit during the season is 10 bu (3.5 hl), inclusive of shell, per person. A similar limit exists in New York State with the additional restriction that two or more people people working from one boat may not take in aggregate more than 20 bu (7.0 hl) in any one day. In the State of Maine licences are issued to those wishing to take bay scallops commercially. In addition anyone may operate a boat engaged in taking scallops for his own or his family's consumption without having a licence provided he does not take more than 2 bu (0.7 hl) of scallops in the shell or more than 4 qt (3.8 l) of shucked meats in any one day. In Maine the public laws relating to marine resources also impose some efficiency restrictions; dragging for scallops in Blue Hill Bay is limited to the use of any one combination of scallop drags not exceeding 8 ft (2.44 m) in width and in Goldsboro Bay, Hancock and Washington Counties dragging is limited to the use of one combination of scallop drags not more than 4 ft (1.22 m) in width.

6.12 Protection of portions of populations

The capture of small scallops tends to be limited by the minimum size of meats accepted by the processing plants. The processing plant in Guernsey accepted 120-130 queen meats/lb (264-286/kg) as a maximum. The maximum acceptable count per lb for calico scallops is 155 meats/lb (231/kg) (Allen and Costello, 1972).

However, because of their proximity to the shore, bay scallops are highly susceptible to harvesting for local consumption and, therefore, the smaller scallops may be more susceptible to capture than in the other fisheries. The bay scallop fishery has a plethora of regulations that alter from state to state. For instance, in Nantucket, Massachusetts there is a minimum air temperature of 25°F (-3.9°C) below which the fleet are not allowed to fish. This was established to keep spat from being frozen on the culling board. The winter fishing seasons, which vary in precise starting and finishing dates, (see Section 5.31) were introduced to ensure protection of the spawning stock.

In addition there are some minimum size limits imposed. In New York State only those scallops with an annual growth line or measuring not more than 2¼ in (57.15 mm) in shell height may be taken. In Maine the minimum size is 3 in (76.2 mm) in the longest diameter and in Massachusetts only adult scallops may be taken, i.e., those with a well defined, raised annual growth line. These regulations do, however, make allowance for the retention of a certain unavoidable percentage of undersized scallops in the catch. In New York this percentage is 2 percent, in Massachusetts it is 5 percent and in Maine, 10 percent.

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