N O T I C I A S   D E   G A L A P A G O S

G A L A P A G O S   N E W S

N O U V E L L E S   D E S   G A L A P A G O S

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N O T I C I A S   D E   G A L A P A G O S , N° 12

SOMMAIRE

NOTICIAS DE GALAPAGOS - 1 rue Ducale, BRUXELLES-1, Belgium

NOUVELLES DES GALAPAGOS

Par la Smithsonian Institution, Center for Short-Lived Phenomena, Cambridge, Massachusetts (U.S.A.), nous avons appris qu'une éruption volcanique a eu lieu aux Iles Galapagos le 11 juin dernier. Nous vous communiquons ci-après extraits des rapports que le Président de la Fondation, le professeur Jean Dorst, a reçu concernant ce séisme.

NAME OF EVENT	Isabela Island Eruption
TYPE OF EVENT	Volcanic Eruption
DATE OF EVENT	11 June 1968
TIME OF EVENT	0350 Hrs. G.M.T.
LOCATION OF EVENT	Galapagos Islands
LATITUDE OF EVENT	00° 20'S
LONGITUDE OF EVENT	91° 07'W
EVENT NUMBER	9-68
DESCRIPTION OF EVENT	Earth Movements, Subterranean rumblings, red and blue streaks visible for ten miles.
DATE OF NOTIFICATION	12 June 1968
TIME OF NOTIFICATION	1400 Local Time
REPORTING SOURCE	U.S.C. & G.S.
SOURCE CONTACT	Mr. James Jordan
RESPONSIBLE SCIENTISTS	Dr. William Melson
DATE OF NOTIFICATION	12 JUne 1968
FOLLOWUP ACTION	Contacted event area, seismic & infrasonic stations
FILE REFERENCES	U.I.I. Report, Boulder Infrasonic Station Report Quito Seismic Station Report
REMARKS	Earth rumblings and quakes accompanied by Explosions. Explosive events reported at 0350 Hrs. G.M.T. 11 June, 0000 Hrs. G.M.T., 12 June 1968.

REPORT : Seismological Station
Quito, Ecuador

ESSA STATION
Boulder, Colorado

Seismic Report from Quito, Ecuador

P wave 05h 56m 28s UT 11 June 1968
S wave missing
600 miles west of Quito

Infrasonic Report from Boulder, Colorado

Acoustic wave reached Boulder at 0329 UT on 12 June. (Origin of wave at Galapagos approximately 2230 UT/1730 local time on 11 June). Stupendous explosion in the multi-megaton range, with gravity waves in atmosphere arriving about the same time as acoustic waves.
Periods as long as 9 minutes amplitudes may be 20-40 dynes/cm^2.

REPORT : Boston, Massachusetts

Isabela Island volcanic eruption. Volcano eruptions have caused earth movements of some magnitude and subterranean rumblings. Blue and red streaks visible in the sky for ten miles. 2 small farms have been evacuated to beaches and people will be evacuated from the island. No casualties but earth rumblings and quakes accompanied by occasional explosions are causing great alarm. Local earthquake at 1600 hrs. local time on 12 June.

REPORT : Commander, 1st Naval Zone of Ecuador

Volcano on blue mountain on Santa Isabela erupted at 122220Z. Eruption terminated early morning hours with dust cloud covering island between 40' - 1° S. Lat. Island inhabitants report sighting small amount of red and blue light. Volcano name sulphur.

REPORT : Forrest Nelson

"Heard eruption for first time, even though the island is 75 miles away. Quite a bit of lightning in the eruption clouds. A lot of lightning. No flames could be seen from Santa Cruz, but smoke seen pouring from area to the west and started again later on. Not sure which crater it came from on Isabela, but it came from the south end of Isabela. The night before last (12 June) there was quite a bit of activity. There may be a lava flow. There was a lava flow on the se slopes of Fernandina a few weeks ago --- about two or three weeks ago. The lava flow was seen on Fernandina from a ship at sea. This one may be Santo Tomas, or it may very well be Blue Mountain".

(observation made from Santa Cruz Island, 75 miles from event area).

REPORT : Mr. Rulf Sievers

"Eruption cloud was first observed at 2[illegible]0 GMT on 11 June. One large shock was felt at approximately 23[illegible]0 GMT same date, intensity 3 to 4. Compass bearing of eruption cloud due west from Academy Bay. Three or four additional shocks and audible explosions followed at ten to fifteen minute intervals. These were less severe than first shock.

Report from Villamil on southeastern Isabela Island states cinder and ash has fallen on town but do not yet know origin. There are still movements on the island. Ship being sent from Guayaquil to pick up people from island.

A lava flow was observed coming down the southeast slopes of Fernandina at Punta Mangle at 2100 GMT on 15 May by the Chilean ship Navarino.

Darwin Station party of four people including Station Director Perry departs tomorrow night (16 June) to island to investigate damage to flora and fauna."

EVENT	Fernandina Volcanic Eruption
DATE OF OCCURRENCE	11 June 1968
SOURCE OF REPORT	Santa Cruz Seismic Station, Galapagos Islands
REPORTER CONTACT	Rulf Sievers
DATE REPORT RECEIPT	23 June 1968

REPORT : Following received from Santa Cruz seismic station at [illegible]115 GMT on 23 June 1968. Darwin Station members visited the rim of the crater of Fernandina on [illegible] June and report the following observations :

" The caldera is collapsing. There is continuing activity and it is causing the rim of the crater to break down. All around the crater the rim is collapsing, especially the south southeast rim. Very strong shocks have been felt. We had great difficulty in standing up because of the continuing shocks. It was not possible to see the crater floor because of heavy dust created by the thousands of tons of rock that was breaking off the rim and falling onto the floor. There are platforms that have also broken down and are continuing to break down. The platform on the SSE side of the crater has broken down. No lava flow was seen (a visit was not made to the SE of the crater where a lava flow was seen by the chilean ship Navarino last month).

There was no sign of fresh lavas and no excessive heat was noted. There was no light or glow at night. Strong tremors continue. We stayed on the slopes of the volcano overnight and could not stand upright because of the strong shocks.

The whole island is covered to a varying extent with volcanic ash. Except for the inside of the crater, there has been no large damage to the island eco system".

DATE OF OCCURENCE	11 June 1968
SOURCE OF REPORT	Nicco Parades
REPORTER CONTACT	Santa Cruz, Galapagos Islands
DATE REPORT RECEIPT	1 July 1968

REPORT : Following report from a sailor, Nicco Parades who was anchored at Urvinia Bay on 11 June 1968 and at Elizabeth Bay on 12 June 1968 and observed the initial stages of the activities :

11 June 1968 (from Urvina Bay)

"First saw a rising, drifting column of smoke coming out of Fernandina crater. Then there was a big blast with a big smoke cloud. The underside of the smoke cloud was pink as if it were reflecting lavas in the crater. There was dust on top of the water after the explosion".

12 June 1968 (from Elizabeth Bay)

"On the north side of Cerro Azul over to the north slopes on Isabella, all the way over to Santa Thomas saw smoke coming from 30 different vents. Smoke was coming from a hill northeast of Santa Thomas near Tortuga Bay on the east side of Isabela".

(Indications are that the original report of activity on Isabela may be valid and that there was activity on both Fernandina and Isabela).

DATE OF OCCURENCE	11 June 1968
SOURCE OF REPORT	Santa Cruz, Galapagos Islands
REPORTER CONTACT	Dr. Thomas Simkin, Smithsonian Institution
DATE REPORT RECEIPT	6 July 1968

REPORT : The following report was received by radio from Dr. Tom Simkin, from Academy Bay, Santa Cruz, Galapagos Islands, at 2315 EDT on 6 July 1968, after a flight over the Fernandina volcano in a U.S. Air Force DC-6 flying out of the Panama Canal Zone. Dr. Simkin was accompanied by a team of six other scientists and observers and two U.S. Air Force photographers :

"Circled the caldera for about 20 minutes. All of the lower slopes were obscured by clouds but we had a good overall view of the caldera. There was no volcanic activity at the time. There is a new cone on the northwest sector of the floor of the caldera and some smoke was observed. Most active slumping took place on the northwest side of the floor which was covered with fresh debris. There is still considerable dust in the caldera. There appears to be substantial subsidence of the total crater floor. The small central one and the lake are still there. Of the two observers in the plane who had previously been in the caldera, one felt that there had been a very substantial change, the other felt that there had not been a significant change. Minor seismic activity continues. There has not been a day without some seismic activity since the start of the major eruption. We are now getting two or three seismic events each day. The cloud cover was quite extensive on Isabela. We obtained good photographs of cerro azul caldera and noted no active volcanism. We do not yet have positive confirmation that volcanism occurred simultaneously on Fernandina and Isabela".

(The expedition will spend the next three to five weeks on Fernandina Island mapping the changes resulting from the eruption activity and recording effects on the island ecosystem).

GALAPAGOS 1964

by

J.B. NELSON

Jordan International Biological
Station, Azraq. c/o Faculty of
Science, University of Jordan.
Amman.

This somewhat tardy account of our sea bird researches in the Galapagos at least enjoys the benefit of reflection on the results ! Here I cannot do more than indicate the scope of our interest and the general nature of our findings.

Apart from brief visits to a few other islands, we spent our time wholly on Tower (December 1963 to July 1964) and Hood (July to November 1964), studying on the former the White and Red-footed Boobies (Sula dactylatra and S. sula), the Great Frigate-bird (Fregata minor) and the Swallow-tailed Gull (Creagrus furcatus) and on Hood the Blue-footed Booby (S. nebouxii), the White Booby, and the Waved Albatross (Diomedea irrorata). In all cases we tried hard to maintain an intimate blend of ecology and behaviour in our species-studies. Accounts of the behaviour of S. dactylatra, S. sula and C. furcatus have already appeared (1967a, 1968a, 1968b) and the ecology of S. sula is due out soon (1968c). Similar accounts are in preparation for the other species and an interpretation along comparative lines is in press. Anybody interested in the full picture is referred to these sources.

Apart from the unexpectedly large population of S. sula (estimated 140,000 pairs) we were most interested to find now precarious was their breeding success in the year of our study. By daily checks on a large number of nests from their first appearance (or before) until they came to some definable end, we established basic facts about their life history and some of the influences determining the nature of their breeding regime.

First and foremost, we found that breeding success was low and that even in successful pairs, the business of chick rearing was lengthy and difficult. Apart from the large number of eggs deserted or lost, and the young that starved to death, there was ample evidence of the difficult food situation in the halting growth of young and their long fledging and post-fledging dependence periods. It was, of course, impossible to know how far this was a special condition of the Galapagos, or even of 1964, but I am now convinced, by comparative work done on Christmas

Island (Indian Ocean) and on the little published evidence available, that conditions in the Galapagos are much more severe than in most of the breeding range of S. sula and that 1964 was probably not really exceptional.

Analysis of our growth records revealed that when young were obviously being hard hit by food shortage, the breeding activities of pairs in the early stages (ie. making nests or incubating new eggs) were suddenly curtailed. The finer details of this situation (Nelson 1968c) suggested quite clearly that when food was relatively good, some birds began breeding activities and when food was scarce, birds either did not come into breeding condition or regressed from it. One obvious result of this connection between the apparently unpredictable (ie. occurring more or less at any time of year) conditions of food shortage and of breeding, is that S. sula in the Galapagos cannot show markedly seasonal breeding, but must be prepared to breed at different times of year. By contrast, in many other parts of its range, S. sula is a seasonal breeder, presumably timing its activities to coincide with the most favourable season.

A small but interesting difference which we later found between S. sula from Galapagos and Christmas Island is that the former lays a significantly larger egg, presumably of some adaptive importance in enhancing the survival chances of the small chick should it hatch during an unfavourable period for food. By reason of the relatively poor Galapagos feeding environment, the fledging period of S. sula there is much longer than on Christmas Island.

S. dactylatra seemed not quite so hard hit as S. sula on Tower, though, as elsewhere in its range, it always reduced its brood from two to one by sibling murder; the older evicting the younger. The two species differed in foraging habits, S. dactylatra typically being absent from the nest for much shorter periods than S. sula, which is the most marked example of a far-forager in the Sulidae. Nevertheless, the fledging and post-fledging feeding periods of S. dactylatra were slightly longer in the Galapagos than on Ascension (Dorward 1962).

The breeding season of S. dactylatra, though variable in the Colon, is more seasonal than that of S. sula, even where the two species coexist on the same island. Whereas S. dactylatra appears to breed annually, successful pairs of S. sula cannot do so because each cycle takes more than 52 weeks; it breeds less than annually, but more than biennially.

With S. nebouxii, on Hood Island, we ran into a most revealing species whose biology was in many ways a key to that of the entire family. Ecologically, S. nebouxii is unusual in that it alone, of the Galapagos sulids, raises more than one young. It also shows a shorter fledging period than S. sula or S. dactylatra and a less than annual breeding cycle. This relatively rapid breeding is assisted by the species' sexual dimorphism and their associated dimorphic behaviour. Despite, as in S. dactylatra, an age difference of about five days between first and second born young, the two live amicably until or unless serious food shortage occurs. In the early stages, the small male parent plys relatively rapidly back and forth and when the young are large the female, who has also fed them from the beginning, takes over almost completely with her bulkier contributions. In this way, one of the difficulties besetting the very small young of S. sula and S. dactylatra (long gaps between feeds) is obviated and hence two young at this stage are not the disadvantage they would be in the other species.

On Hood Island, incidentally, we were fortunate to record a period during which food became extremely short and its effect on the colony of S. nebouxii was dramatic. Of those pairs with two young, none managed to keep both alive and even some single young died. All nest building, pair formation and laying was temporarily suspended and resumed when better conditions ensued.

Behaviourally, we tried to describe the entire repertoire of ritualised displays in the species we studied and also to interpret them in terms of the species' total biology (morphology, habitat, density, etc.). There are many ritualised displays, or their recognisable derivatives, possessed in common by all sulids, but there are also species specific behaviour patterns, as well as species specific emphases and omissions. Many of these can be understood in terms of the species' total biology. The small, agile male S. nebouxii, for example, has emphasised two distinctive territorial displays which show off his brilliant blue feet - one performed in flight and one as a ritualised form of locomotion. Both S. nebouxii and S. dactylatra spend much time defending their territorial boundaries on foot and have evolved a series of ritualised behaviour patterns derived from or connected with locomotion. On the other hand, S. sula, in its arboreal habitat, shows considerably modified behaviour. The evolutionary aspect of comparative behaviour studies is also of great interest, and the Sulidae is an excellent family in which to trace the modification of homologous behaviour patterns due to different selection pressures, some of which can be at least tentatively interpreted.

Fregata minor nests in good numbers on Tower, especially in the Cryptocarpus pyriformes shrub at the head of Darwin Bay. More than 100 marked nests were studied intensively. Perhaps our most important finding was that Fregata minor breeds once every two years, not annually (Nelson 1967b). The incubation period, fledging period and protracted post-fledging dependence of juveniles on their parents, add up to a breeding cycle of more than 12 months. Even more than S. sula, F. minor forages away from the nest for lengthy periods and the average incubation period was 10½ days (maximum 18 days). There was heavy egg loss, largely due to conspecific interference, particularly by unmated males. Because of the nature of the breeding cycle a male F. minor may, upon beginning his next breeding cycle after the recuperative phase, find another pair already engaged in the later stages of their cycle on his nest site. Territory is thus relatively unimportant in this species and indeed males do not defend a territory until they have first obtained a mate. Thus pair bonds, too, are notably impermanent and this may facilitate the interference which was so destructive to eggs and small young in 1964.

It seemed of special behavioural interest to look at Creagrus furcatus with the well known studies of the Tinbergen School in mind and see how this unusual gull fitted into the Larid behaviour system. It has, of course, a number of highly conspicuous ritualised postures and movements as well as a unique vocabulary and it does not apparently fit neatly into either a hooded gull or argentatus-type pigeon hole, though perhaps most affinities are with the latter. Some of its behaviour resembles that of the Kittiwake (Rissa tridactyla) (Nelson 1968b).

Diomedea irrorata on Hood Island was studied for four months at Punta Suarez. The display, or dance, was analysed in detail and proved to be a complex ritual in which two phenomena were important; certain movements were linked, so that in a displaying bird B always followed A, and also certain movements by one partner strongly tended to elicit a certain predictable response from the other. Analysed in these terms, the display seems to consist of an ordered sequence of activities repeated over and over for a variable but often extensive period.

From recapturing birds ringed by Raymond Lévêque, we worked out that most recoveries suggested a biennial breeding cycle. We obtained good data on the growth of the young.

All these displays in all the species mentioned were extensively filmed and the edited colour film, with commentary, is now available, either for a copy or for hire, through the British Film Institute. A semi-popular account of the work is in "Galapagos : Islands of Birds", published by Longmans, Green in 1968.

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SOME OBSERVATIONS ON THE "FOUR-EYED" BLENNY OF THE GALAPAGOS ISLANDS, *Dialommus fuscus* (Pisces : Clinidae)

by

Eberhard CURIO

Bochum, Deutschland [1)]

During my one-year stay in the Galapagos Islands (cf. CURIO 1963, Noticias de Galapagos No.2, p. 11-12) I became interested in the eco-ethology of a strange and endemic clinid fish, *Dialommus fuscus*, inhabiting the rocky shores. The reason for this was two-fold : the uniqueness of the structure of the eye and the amphibious habits of the animal. A few facts will be reported here that suggest a functional explanation for the singular eye. At the same time this new information will confirm or correct earlier observations. While a study of the histology of the eye is still in progress, my comments here are directed only to the gross morphology of the cornea.

The vernacular name "four-eyed blenny" is derived from an anatomical feature of the visible part of the eye, one found in no other fish. By the time *Dialommus* is old enough to leave the water for a couple of hours each day, the cornea of the eye has become divided into an anterior and a posterior half by a narrow strand of pigment cells running across it (fig. 1a). This dark brown band of pigment cuts the frontal plane of the animal nearly vertically; it widens to slightly more than one mm. where it merges into the pigmentation of the skin at the upper and the lower rim of the eye. The shape of the iris is elliptic. The division of the cornea is differently oriented than in the famous four-eyed poeciliоid fish of the Amazon River, *Anableps tetrophthalmus* (Anablepidae), whose eyes are divided by a *horizontal* bar of pigment on the cornea, i.e. into a dorsal and into a ventral zone. Moreover, a corresponding division is shown by the iris, giving rise to two pupils. Thus in *Anableps* the border line of the two eye halves runs parallel to the frontal plane.

Still more peculiar than the bipartition of the cornea in *Dialommus* is its shape. The band of pigment lies in a nearly vertical corneal ridge in which the anterior and the posterior half of the cornea merge

1) The writer is most grateful to Dr. G.W. BARLOW (Berkeley) for the improvement of the English text.

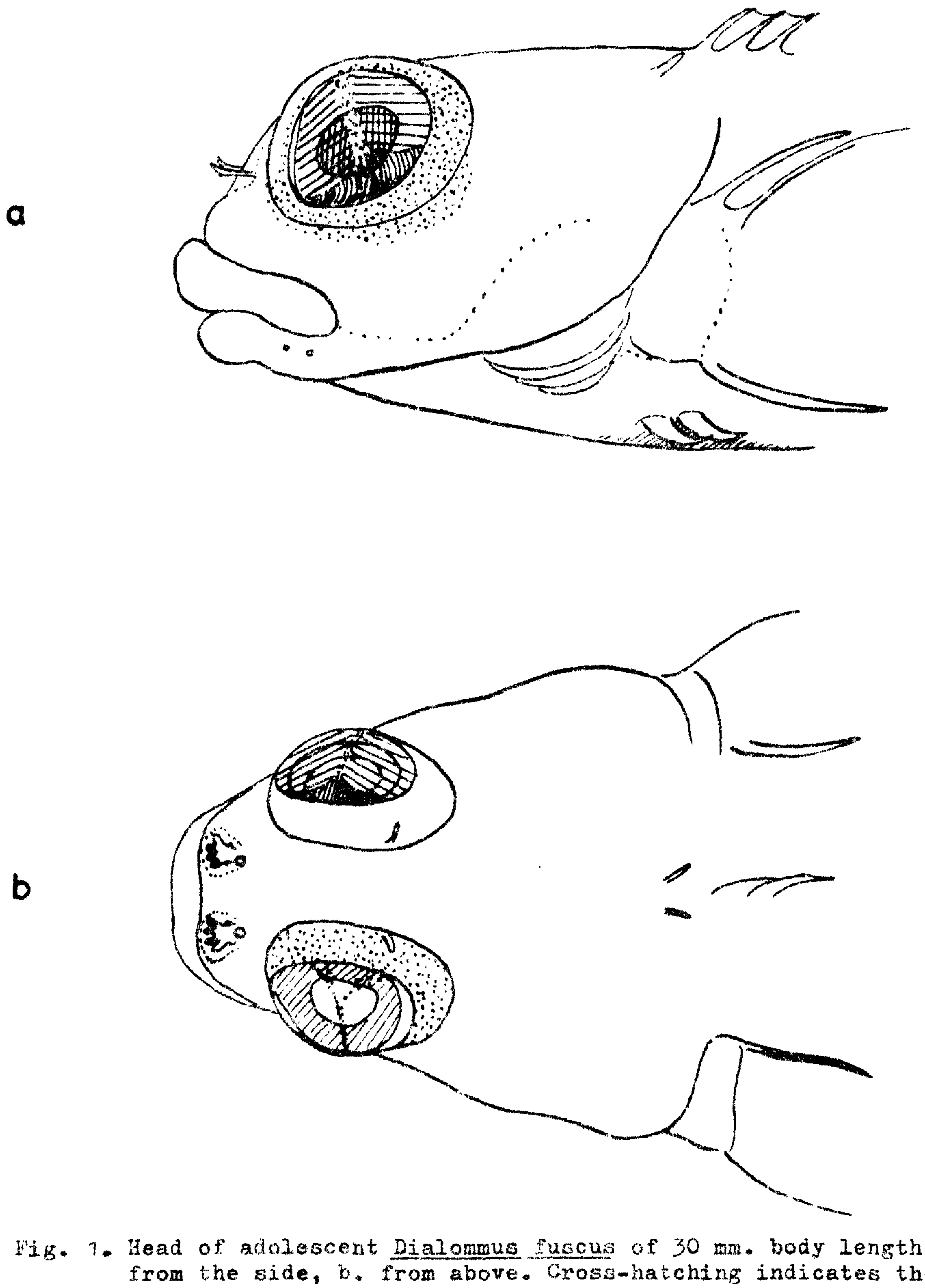

Fig. 1. Head of adolescent Dialommus fuscus of 30 mm. body length a. from the side, b. from above. Cross-hatching indicates the sloping of the corneal plains in a. and in b. right eye; stippled area symbolizes larger pigment cells on the ridged cornea and the surrounding eye socket.

into one another. The two halves of the cornea are each entirely flat as far as they are visible within the skin "socket" of the eye ball in the normal resting position of the eye. In the vertical pigmented ridge these two corneal plains meet at nearly a right angle, which can be seen if one views the fish from above (fig. 1b). The visible part of the cornea, looked at from the side of the body, has the shape of a lying ellipse, which is tilted slightly down toward the front. The two plains forming that visible part of the cornea correspond to two halves of an ellipse, the short axis of which is identical with the already mentioned pigmented corneal ridge.

As is well known, the horizontal division of the eye in Anables of the Amazon, affects not only the cornea but also the iris, the lens, and the retina. This is in good accord with the fact that Anables stays at the water surface. The "upper eye" views objects, for instance enemies, above the surface while the "lower eye", which is submerged, watches those under water. In contrast, the shape of the pupil in Dialommus is roughly elliptic as is the divided cornea. The iris of its eye is beautifully coloured with concentric zones of blue, red, and black. As mentioned, it does not reflect the division of the cornea. Whether this is also true of the retina remains to be determined. A series of fixated eyes, both enucleated and in situ, of all age clases, awaits histological examination.

When Dialommus is killed in formaldehyde the corneal ridge collapses within a few seconds. The eye looks then like any ordinary fish eye, except for its pigment band. This is why earlier writers have overlooked the ridged architecture of the eye, which adds so substantially to its uniqueness.

The peculiar features of the Dialommus eye aroused such intense interest in the life history of the fish that writers, lacking information, substituted speculation for facts. By analogy with the anatomy of the eye of Anables some of them were inspired to describe and even to depict (!) details of the normal position of Dialommus when in the water which no man could ever have observed. There is for instance, an imaginative illustration in a textbook on the ecology of fishes showing Dialommus "hanging" with its head at the water surface of a tide-pool with the snout protruding. The water line coincides with the "line" dividing the eye so that the anterior eye is above water, the posterior below. If the eye of Anables were rotated 90°, one would expect the resulting fish to stand on its tail with one half of the eye in the air. However, nothing could be farther away from the truth !

Another peculiar feature of Dialommus is its locomotion which can be functionally understood in terms of its amphibious way of life. There are three modes of locomotion, one when at the bottom (rarely at the surface in tide pools), one when climbing on the rocks above the water surface, and finally one when fleeing from one rock to another. (These rocks are usually separated by a body of calmer water, e.g. behind the lava boulders that interupt the impetus of the incoming breakers).

Like other clinids and blennies Dialommus lacks a swimbladder and is therefore unable to stay at the water surface without continuous movements. Most of the time Dialommus is in the coastal water where it is shallow and the substrate rocky; or, it rests mainly in tide-pools with its pelvic fins on the bottom. Here it moves around, like so many of the blennies and gobies, by synchronous flicks of the pectoral fins, assisted by lateral undulations of the body and, in general, the tail fin.

Jumping out of the water is inconspicuous because the fish rides up in a swell as it dashes onto the rocks. With astounding skill Dialommus then crawls into one of the innumerable little crevices or crannies on the surface of the lava boulders. There it blends into the dark brown rocks by virtue of its cryptic colouration. If such a lair is found to be unsuitable the fish heads for the next one by quick and effective tail beats, always remaining in the wet zone of the splashing surf. In its temporary resting hole, Dialommus is well protected from the pounding surf that races over it because it coils snugly into its lair. After some time the fish returns to the water in the runoff of the surf, sliding down the rock before the next breaker rushes in, and using the same tail flicks by which it came up.

If an enemy, e.g. a wader or a human, approaches a four-eyed blenny out of the water, it shows a certain tendency to remain there. Either it moves into another crevice and fixates the intruder. If pressed too hard, however, it flees by means of altermate tail movements across the nearest water surface and jumps up onto the next rock, hiding immediately in a new lair. With these tail beats it skims over the water much like a flying fish. However, this functional similarity does not go too far since Dialommus never employs these tail movements to dart out of the water for a ride through the air (see above).

No one knows why the four-eyed blenny leaves the water regularly. It feeds on small crustaceans, e.g. brachyuran larvae, amphipods, and copepods on the bottom of shallow bodies of water such as occur in tide pools. It also feeds when resting on, or crawling over, wet rocks. Moreover, in horizontal crevices typical of the shore on Abingdon Island the four-eyed blenny snaps tiny flies (Nocticanace galapagensis) from the rocky ceiling over-head. Here it may snap its prey out of tiny pools sometimes not larger than one cm^2. Evidently Dialommus is the only fish that locates and lunges at prey (its head is very mobile) from the air into the water.

Thus Dialommus feeds both under and over water. Since the great majority of its prey is living in the water the reason for the amphibious habit of life is far from clear. There are hints, however, that the unique structure of the eye might be related in some way to this specialised way of life. For, first of all, young fish of up to 13 mm. body length stay in the water, and they lack the pigmented and ridged cornea. The young fish leave the water for the first time when they are about 26 mmm. long; it is in this age that the cornea begins to become ridged and pigmented in the way described above. From then on, all stages up to full-grown fish (12 cm. length) show the same peculiarly shaped cornea.

Second, in the coastal waters of Panama there is another clinid, *Mnierpes macrocephalus*, which shows a similarly structured eye as *Dialommus* and again has an amphibious habit of life (ROSENBLATT in litt.). While the evidence presented so far merely correlates eye structure and behaviour, and thus is only suggestive, it might guide further experimental work into the right direction. The fact that there are other amphibious fishes from very diverse families (e.g. *Gobiidae*, *Gobiesocidae*, *Periophthalmidae*) that do not exhibit comparable peculiarities of their eyes does not necessarily preclude the possibility of understanding the eye structure of *Dialommus* in terms of its behaviour. However, this must be resolved by further work.

A STUDY OF SOME NEOTROPICAL OPUNTIAS OF COASTAL ECUADOR AND THE GALAPAGOS ISLANDS

by

Edward F. ANDERSON

Department of Biology, Whitman College, Walla Walla, Washington

and

David L. WALKINGTON

Department of Biology, California State College, Fullerton, California (U.S.A.)

Introduction. During the academic year 1965-66, a project was undertaken to study the naturally occurring populations of Opuntia (Cactaceae) of coastal Ecuador and the Galapagos Islands. We wished to determine if morphological and chemical analysis could indicate if the island plants had migrated from coastal Ecuador and whether any of the ancestral stock still remained on the mainland. Support and cooperation for this investigation were provided by the National Science Foundation (grant GB-4295), the Fulbright Commission of Ecuador, the Charles Darwin Foundation for the Galapagos Islands, and the Instituto Nacional de Pesca del Ecuador. As the coast of Ecuador is the closest portion of the South American mainland to the Galapagos Islands and is along the path of the Humboldt Current as it sweeps northward and thence westward to the islands, we felt that the prickly-pear cacti of the coast might show a relationship to the island species if there had been rafting to the archipelago in the fairly recent geological past. This paper is the result of our investigations to date, and from the data we can draw some tentative conclusions.

Morphology. The opuntias of coastal Ecuador. Field studies indicate that only two species of Opuntia occur along the coast. The first, O. melanosperma Svenson, with yellow flowers and fleshy fruits, occurs on the Santa Elena peninsula in Guayas province and northward into the province of Manabi. It tolerates several soil types and is even found growing on the beaches near Manglaralto. It is highly variable as to spination and habit of growth; some populations, in fact, have arborescent individuals with distinct trunks whereas others consist of sprawling individuals rarely reaching a meter in height. The second species, O. macbridei Br. & R., apparently is a wide-ranging species along the northern Peruvian coast, barely getting into Ecuador near Huaquillas. This species is low growing, has rounded stem joints, green fleshy fruits, and orange flowers. The spination and habit of growth are not highly variable.

The opuntias of the Galapagos Islands. Of the seven putative species described by Dawson (1962, 1965), only five have been dealt with thus far in this study. We found that morphological differences are often subtle despite the fact that several species have become arboreal and have developed a pronounced dimorphism of spines. Apparently the adaptive radiation of the genus has not yet proceeded far enough to produce clear-cut taxa at the species level. Dawson (1965) suggested that there are two main evolutionary lines : (1) the *Opuntia zacana* line which includes *O. zacana* Howell and *O. echios* Howell, and (2) the *Opuntia helleri* line which has the remaining five species of Galapagos opuntias.

The five species included in this investigation are characterized morphologically as follows :

1. *O. zacana*, found only on North Seymour Island, is shrubby, has large fruits, and possesses bristly spines of nearly equal length.

2. *O. echios* is arboreal and with a well developed trunk. It is composed of five varieties, has large fruits, glochids, dimorphic spines, and pendulous or drooping branches. It occurs on Daphne Major, Indefatigable, South Seymour, Plaza, Barrington, and Albemarle Islands.

3. *O. helleri* K. Sch. is possibly the other basic type from which the other island species of *Opuntia* arose. It occurs only on the northern islands of the archipelago and is characterized by having hairy spines of variable length, small fruits, and a clambering or prostrate habit of growth.

4. *O. megasperma* Howell consists of massive plants with very large flowers, fruits, and seeds. It includes two or possibly three varieties and occurs on Charles, Hood, and Chatham Islands.

5. *O. galapageia* Hensl. is similar to *O. megasperma* in growth habit, but has smaller fruits and widely separated areoles. Both species have dimorphic spines, however. The two varieties of *O. galapageia* occur on Abingdon, James, Bartholomew, Jervis, and Duncan Islands.

Two other species of *Opuntia*, *O. insularis* Stewart and *O. saxicola* Howell, occur on the southern islands. Material of these species has only recently been obtained so these taxa have not yet been included in the study.

Morphological indices of relationship were determined between all populations collected. These indices were calculated by making measurements of vegetative parts including spine and glochid characteristics, length and width of stem joints, distance between areoles, and areole diameters. Flower and fruit measurements were available in only a few collections, so they were not used for comparison. The mean and standard deviation were calculated for each measurement, and then the measurements from each collection were compared with those of the other collections. The number of means from one collection that fell within the standard deviation of the other collection were counted. If all measurements matched, the morphological index of relationship (M.I.R.) would be 100.

In analyzing the Ecuadorian coastal populations, the M.I.R.'s between collections of O. melanosperma and O. macbridei were from 40 to 55. Within each taxon the range was from 80 to 94.

In the O. zacana line of the Galapagos populations the M.I.R.'s between collections of O. zacana and O. echios were from 50-59. Within O. echios the range was from 70 to 92. As there was only one population of O. zacana, no comparison could be made within the species.

The M.I.R.'s between the several species of the O. helleri line were in the 60's and below. Within each species in this line the following ranges were determined : (1) O. helleri = 70-84; (2) O. galapageia = 68-94; and (3) O. megasperma = 72-86.

In comparing Ecuadorian collections to Galapagos collections the morphological indices of relationship were all below 50. It is evident that morphology does not indicate a close relationship of the coastal and island opuntias.

Chemistry. Polyphenolic substances were chosen for study as they are good indicators of relationships. These chemicals show a relatively stable and consistent distribution from one plant to another and often demonstrate species specificity. Generally speaking, the more closely related two species are, the more similar their polyphenolic make-up will be.

For extraction of these chemicals, five to seven stem joints from each collection were washed, sliced, dried at 55° C and ground into a powder through a mill. The powder was washed in chloroform, filtered, dried and extracted in 1% hydrochloric acid in methanol v/v. The extract was evaporated to dryness and redissolved in the acidified methanol solvent 1:5 v/v. Two-dimensional Whatman # 1 papers were spotted and developed in n-butanol:acetic acid:water solvent 6:1:2 for the first dimension and 2% acetic acid for the second dimension. Spots were located under ultra-violet light in ammonium hydroxide vapors. They were then sprayed with 1% diphenyl boric acid β-amino ethyl ester in methanol and viewed again under ultra-violet light. All spots were identified by assigning them numbers.

Chemical indices of relationship (C.I.R.) were determined between all populations collected. The calculations were made by dividing the number of matched spots in two chromatograms by the total number of spots in the two chromatograms, and multiplying the quotient by 100. If all the spots match in comparing two chromatograms, the C.I.R. equals 100.

Among the 11 collections from coastal Ecuador a total of 59 different spots were counted, of which 13 occurred in all 11 collections. The C.I.R.'s between collections of O. melanosperma and O. macbridei were between 36-45. Within each taxon the range was from 67 to 78.

In the chemical analyses of the 24 collections from the various islands of the Galapagos Archipelago, a total of 66 different spots were counted, and only 3 were found in all collections. The C.I.R.'s between collections of O. zacana and O. echios were from 45 to 61. Within O. echios the spectrum was particularly wide, ranging from 48 to 79.

Dawson (1965) described the population of O. echios on Daphne Major as consisting of retrogressive variants as they are prostrate to erect in habit. The erect form C.I.R. to O. zacana is 61, whereas the prostrate form C.I.R. to O. zacana is 49. The two forms to each other have a C.I.R. of 79. The O. echios population on nearby Baltra Island has a C.I.R. of 67 to the erect form and a C.I.R. of 64 to the prostrate form. If O. zacana could be considered the ancestral stock to O. echios, then, according to the chemical evidence, the prostrate form of O. echios is more advanced and apparently developed from the erect form.

In the O. helleri line, O. helleri showed consistently high C.I.R.'s, particularly between the Culpepper and Wenman Island collections, and between these collections and those from Bindloe Island. The C.I.R. range was from 67-82. In comparing the Bindloe Island collections with those from Tower Island, however, there was a drop in the C.I.R. to 55. Within the species O. galapageia the range was quite narrow, from 56 to 65, while the range within O. megasperma was wide, from 50 to 70. Most of the C.I.R.'s between the species in the O. helleri line were between 45 and 55. Opuntia galapageia var. macrocarpa from Duncan Island, described by Dawson (1965) as being intermediate in evolution from O. helleri through O. galapageia to O. megasperma, had a C.I.R. to O. helleri of 63 and to O. megasperma of 62. The C.I.R. between O. helleri of Bindloe Island and the O. megasperma of Chatham Island was only 45. In comparing chromatograms from these three species a high degree of chemical summation was seen; ie., many of the spots unique to O. helleri and many of the spots unique to O. megasperma made up the majority of the spots found on the chromatograms of O. galapageia var. macrocarpa. This lends support to Dawson's thesis.

In analyzing chromatograms from both Ecuadorian and Galapagos collections, a total of 102 different spots were counted. Eight spots were present in all collections, leaving 94 significant spots for taxonomic consideration. Of these spots 33 occurred in some collections from both Ecuador and the islands. In comparing chromatograms between coastal and island collections, the range of chemical indices of relationship was from 18 to 37, the lowest being between O. megasperma and O. melanosperma and the highest being between O. helleri and O. macbridei.

In conclusion, morphological and chemical analyses do not seem to support the hypothesis that the Galapagos Island plants had migrated from coastal Ecuador. These analyses, however, do support Dawson's classification and lend evidence to his proposed lines of evolution among the Galapagos opuntias. Either sufficient time has passed since their migration to permit extensive morphological and chemical changes, or the nearest relatives and/or ancestral stock may be within the Andes Mountains or farther to the south along coastal Peru.

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EXPLANATION OF PLATES

Photo 1.- Opuntia helleri on Bindloe Island

Photo 2.- Opuntia galapageia on Jervis Island

Photo 3.- Opuntia melanosperma Svenson

Photo 4.- Opuntia galapageia var. macrocarpa on Duncan Island.

Photo 1

Photo 2

Photo 3

Photo 4

FUNDACION CHARLES DARWIN PARA LAS ISLAS GALAPAGOS

CHARLES DARWIN FOUNDATION FOR THE GALAPAGOS ISLANDS

FONDATION CHARLES DARWIN POUR LES GALAPAGOS

Créée sous les auspices de l'Organisation des Nations-Unies pour l'Education, la Science et la Culture (UNESCO)

1, rue Ducale, BRUXELLES 1, Belgique

Buts et objectifs de la Fondation Charles Darwin pour les Galapagos (Art.2 des Statuts, Bruxelles, 23 juillet 1959).

L'Association est chargée de l'organisation et de la gestion de la Station de recherches "Charles Darwin", dont le gouvernement de la République de l'Ecuador a autorisé l'établissement dans l'archipel des Galapagos à l'occasion du centenaire de l'énoncé de la doctrine de l'évolution (1858-1958).

L'Association propose aux autorités compétentes toutes mesures propres à assurer, dans l'archipel des Galapagos et dans les mers qui l'entourent, la conservation du sol, de la flore et de la faune, et la sauvegarde de la vie sauvage et de son milieu naturel. Elle arrête le programme de recherches de la Station biologique et la charge de toutes études scientifiques en rapport avec les objets ci-dessus.

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