THE UNIVERSITY OF MANITOBA

CONTRAST AND COLORATION
OF ADULT GULLS

by

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ABSTRACT

The hypothesis that a white undersided sea-bird has a smaller undersides contrast against the sky than any other-coloured sea-bird, was supported, for white undersided and black undersided sea-birds by the results of a series of experiments involving a new technique for the measurement of bird contrast. This technique involves noting the distance a photographic negative image of a sea-bird approaches to a human observer, before being seen by the observer. This distance is related to the contrast of the image and, in turn, to the contrast of the sea-bird under its set of environmental conditions. A mounted sea-bird is used which allows, with the use of paints, same-sized individuals of a sea-bird species to have different underside colours thus facilitating experimental control.

A literature search revealed that most adult gulls Larini have partially white i.e. pied, undersides. With a series of similar experiments, involving photographs taken under cloudless skies, a conditional relationship was supported for partially-white undersided Franklin's Gulls *Larus pipixcan*. On some occasions the results supported Craik's hypothesis, however on others the results supported the converse relationship that the Franklin's Gull has a smaller undersides contrast than a white undersided sea-bird.

A probable contingent variable was horizontal bearing of the sun.

The consequences of the experimental findings for the explanation, by natural selection theory, of the partially-white undersides coloration of gulls was briefly discussed. The undersides coloration may either be optimally effective or a compromise property, under natural conditions.

ACKNOWLEDGEMENTS

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CHAPTER 1

INTRODUCTION

K.J.W. Craik (1944a) presented the hypotheses, that a white undersided sea-bird has a smaller contrast against the sky than any other-coloured sea-bird and, that a sea-bird with a small contrast against the sky approaches nearer unseen to fish prey than a sea-bird with a larger contrast. These hypotheses, when joined with various other hypotheses state, in summary, that white undersided sea-birds give rise to more offspring than other-coloured sea-birds i.e. that the undersides colour of white undersided sea-birds is advantageous for survival and could be explained by natural selection theory (Craik 1944a). The objectives of the present study were first, to test Craik's hypothesis concerning sea-bird undersides coloration and contrast, second, to investigate whether adult gulls Larini have white undersides, and third, to evaluate the possible adaptive nature of the undersides coloration of gulls, compared with white under-sided sea-birds.

Craik presented his hypotheses as follows:

"It is often considered that the white plumage of gulls, terns, gannets etc., in temperate climates is in contradiction to the principle of protective and adaptive coloration.... As is now well known, aircraft of Coastal Command on anti-submarine patrol are painted white on their undersides. This treatment was devised by Merton of their Operational Research Section on theoretical grounds to render them less visible to submarines. Merton showed that a white object will have a smaller contrast against the sky than a darker one, even at ranges of several miles and that white paint should therefore decrease the range at which the submarine lookouts spotted the aircraft and gave warning to submerge. Surely the same end may have been achieved by natural selection, in the white coloration of the undersides of many sea-birds which depend for their food on spotting and catching fish very near the surface. If the bird is white its contrast against the sky will be smaller and the fish will be less likely to see it in time to dive beyond the bird's reach. As the visual acuity of fish is much poorer than that of man, the ranges involved are short and the reduction of contrast by scattered light negligible, hence the benefit of white coloration will be greater than in the case of aircraft."

A reconstruction of Craik's apparent argument including both explicit and implicit components follows. The argument (see above) appears to be based on the hypothesis, derived by Merton on theoretical grounds (reported in Craik 1944a) that:

> a white object has a smaller contrast against the sky than an object of any other colour.....hypothesis (1)

and on the relationship:

> an object with a small contrast can approach nearer to a human observer than a same-sized object with a larger contrast, before being seen by the observer....... .... relationship (1)

A less generalized version of hypothesis (1) is:

> a white undersided sea-bird has a smaller contrast, against the sky, than a sea-bird with undersides of any other colour.......................... hypothesis (2)

By analogy with relationship (1):

> a sea-bird with a small contrast against the sky, approaches nearer to a surface living fish than a same-sized sea-bird with undersides of a larger contrast, prior to being seen by the fish........hypothesis (3)

The chain of hypotheses, concerning the advantage of white undersides for survival, with additions by Craik (1944b) and Phillips (1962) may be elaborated as: a white undersided sea-bird has a smaller contrast than any other-coloured sea-bird (hypothesis 2). A sea-bird with a small undersides contrast approaches nearer to a fish unseen, than a same-sized sea-bird with a larger contrast (hypothesis 3). A seabird that approaches nearer to a fish before being seen by the fish and which plunge dives to catch fish, either catches more fish or catches the same number more quickly than a sea-bird which approaches less near, if the fish gives an escape response concommittant with "seeing" the sea-bird. A fish-eating sea-bird which catches more fish or the same number more quickly gives rise to more off-spring than a sea-bird that catches less fish or the same number less quickly.

A) Test of hypothesis (2) - Part i

Hypothesis (2) has not gone unchallenged. Pirenne and Crombie (1944) calculated that under clear cloudless sky, a condition common in many climates e.g. central Canada (Kendrew and Currie 1955, see also world climate surveys by Kendrew 1937 and Rumney 1968), white undersided sea-birds may be more conspicuous i.e. have a larger contrast than black undersided sea-birds against the sky.

Phillips (1962) experimentally confirmed the logical derivative of hypotheses (2) and (3), i.e. white undersided sea-birds approach nearer to fish than etc., for white undersided and black undersided sea-birds, under various conditions including cloudless skies, using flat wooden sea-bird 'models'. Phillips' experiments provide no direct evidence for or against hypothesis (2), in fact, I could find no evidence that hypothesis (2) has been empirically tested.

To test hypothesis (2) concerning white undersided and black undersided sea-birds, I did a large series of simple experiments, using a new photographic technique (Chapter 2). Contrast against the sky, of mounted sea-birds over water, was measured indirectly, with the aid of relationship (1), under many environmental conditions, including cloudless sky.

B) The undersides coloration of adult gulls

Do adult gulls have white undersides? I determined the undersides coloration of adult gulls by means of a literature search, which revealed (see Appendix 1 and Table 3 for full results) that all the gull species except one have partially white, i.e. pied, under-sides.

C) Test of hypothesis (2) - Part II.

With a large series of experiments, using mounted adult Franklin's Gulls Larus pipixcan and the new photographic technique, I tested whether the undersides contrast of the partially white undersided Franklin's Gull is larger or smaller than the undersides contrast of a white undersided sea-bird (Chapter 3).

Apart from white undersides, hypothesis (2) gives little information about differences in contrast between other-coloured undersides. Do adult Franklin's Gulls have a larger or smaller contrast than black undersided sea-birds? I tested the above question (which is not contained in hypothesis (2)) with a similar series of experiments to those mentioned above (Chapter 4).

In Chapter 5, the advantage for survival of the undersides coloration of gulls, and white undersided sea-birds is discussed.

The classification of gulls recommended by Moynihan (1959) is used in this thesis. Although authorities differ as to how many species of gulls exist, I followed Moynihan's species list except for <u>thayeri</u>, treated by Moynihan as a subspecies of <u>argentatus</u>, but now given specific rank on the basis of Smith's publication (1966). A full chronological survey of studies, discussing Craik's (1944a) publication and ideas is given in Appendix lV.

CHAPTER 2

DO WHITE UNDERSIDED SEA-BIRDS HAVE A LARGER OR SMALLER UNDERSIDES CONTRAST THAN BLACK UNDERSIDED SEA-BIRDS?

Physical contrast (C), or relative brightness difference, is the ratio of the difference between the greater object brightness (P) and the surround brightness (U) to the surround brightness i.e.

$$C = \frac{P - U}{U}$$

or in the case of a brighter surround

$$C' = \frac{U - P}{U}$$ (e.g. Tschermak-seysenegg 1952).

Measurement of the brightness of an object is difficult when parts of the object exhibit different values, a condition likely to prevail in sea-birds. In this study I therefore used an indirect measure of contrast, based on relationship (1), where one observes the distance objects approach to a human observer before the objects are seen by the observer. It follows that those objects approaching nearer have smaller contrasts etc..

An assessment of differences in contrast of sea-birds in the field has several other drawbacks, the most important of which is experimental control. I used sea-bird models instead of sea-birds. The models were mounted specimens of the same size and species, their undersides being painted white or black.

Another apparent drawback, at least with indirect measurement is atmospheric scattering which effects contrast, but owing to the short distances involved is believed to have only a negligible effect on contrast for fish vision (Pirenne and Crombie 1944). In the experiments reported here atmospheric scattering was reduced to a low level by photography (see Page 18), negative photographs of the models being used in place of the models. Fortunately a panchromatic film photographic negative also approximately reproduces the contrast of an object, (see Page 19), and has the added advantage of providing a permanent record.

The experiments, conducted in the laboratory, consisted of moving the photographic negatives towards a human observer. Each experiment used a pair of photographs taken under a set of atmospheric and lake conditions, the camera being positioned on the most probable gull/fish axis for first spotting by a fish. The three experimental hypotheses were: the negative photographic image (n.p.i.) of a white undersided sea-bird model approaches nearer (Ha), equally near (Ho_1), or less near (Ho_2) to a human observer than a n.p.i. of a black undersided sea-bird model before the observer

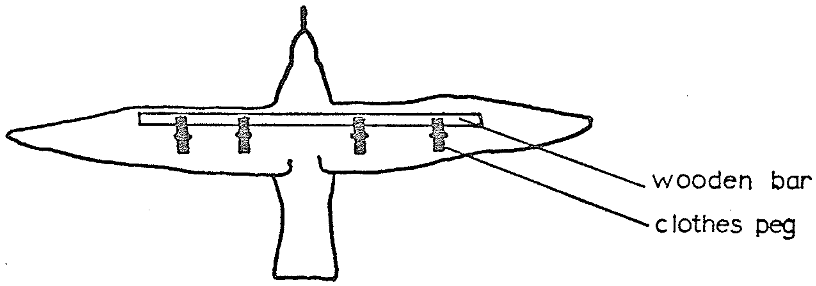


FIG. 1a. DORSAL VIEW OF SEABIRD MODEL

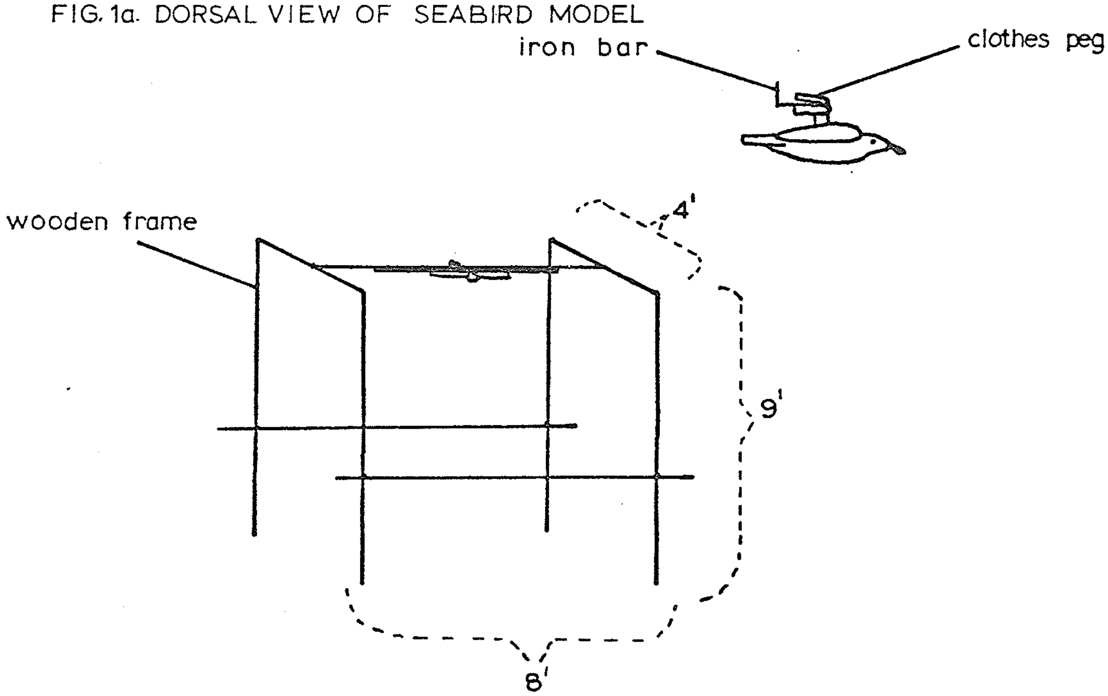


FIG. 1b. MODEL SUPPORT APPARATUS (out of the water)

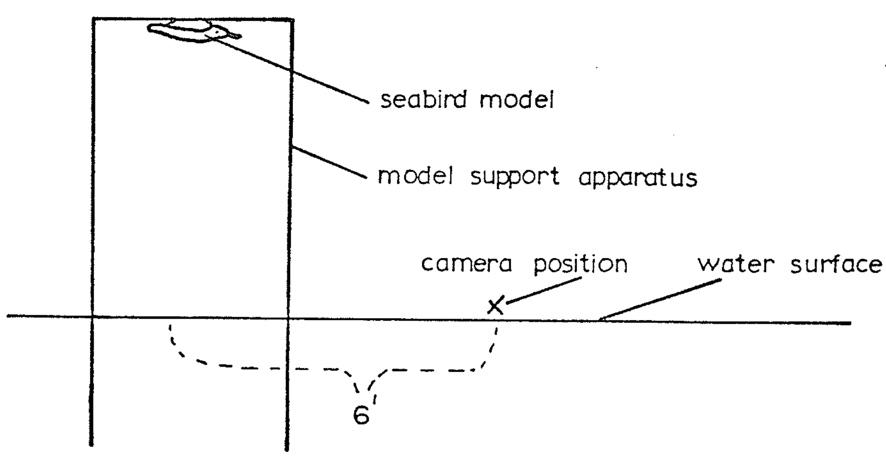


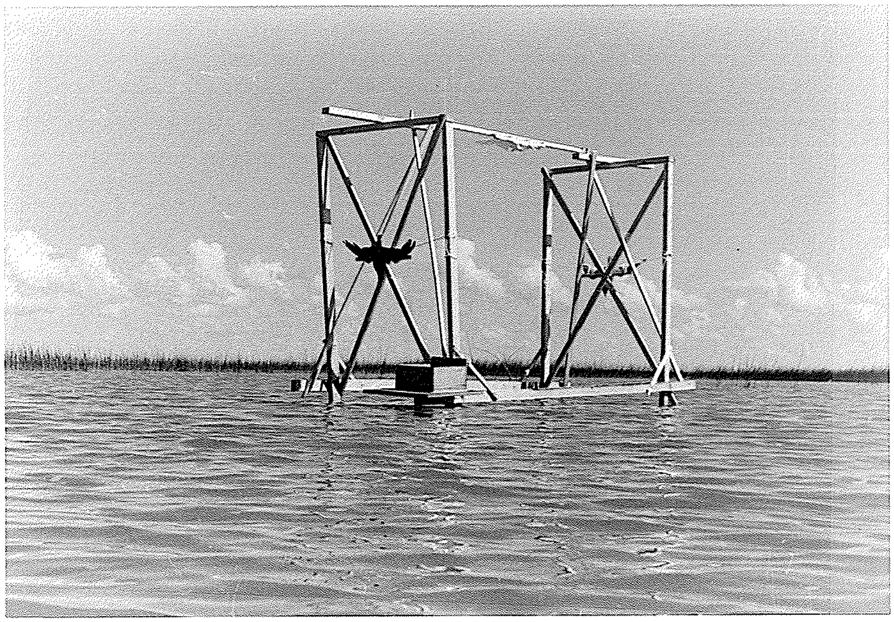
FIG. 1c. LATERAL VIEW OF APPARATUS SHOWING CAMERA POSITION

sees an n.p.i. of a model.

Apparatus and materials

Sea-bird models: three adult Franklin's Gulls were shot near Oak Lake, Manitoba. Plumage was virtually unaffected by the pellets. These gulls were skinned and mounted to resemble a flying sea-bird, wings outstretched. The entire head and undersides of two of the models were painted either white or black with interior flat latex paints (the third was used in the experiments reported in Chapters 3 and 4). To enable a model to be fastened to the 'model support apparatus' described below, a wooden bar, with four attached spring action clothes pegs, was attached to the dorsal surface of the wings by fine cotton thread (fig. 1a).

Model support apparatus: the models were supported by a large wooden frame, having a six foot long L-shaped angled iron bar suspended across the middle (Figs. 1b and 2), in Oak Lake. The clothes pegs of a model were attached to one side of the iron bar, a home-made chair being sunk completely underwater, under the bar, so the photographer could reach to attach a model. The apparatus was positioned such that the long axis of a model was on the east-west compass bearing, facing east, the apparatus having been placed in water about thirty inches deep such that a model, in posi-



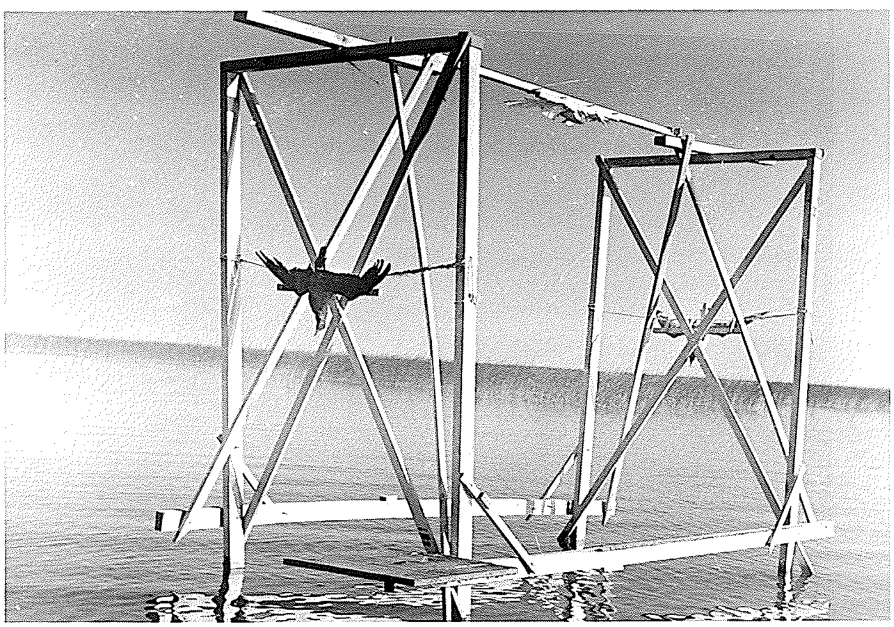


FIG. 2. PHOTOGRAPHS OF APPARATUS IN OAK LAKE
models not being photographed are in the rest position. storage box in the top photograph later discarded.

tion, was suspended about six feet above the water's surface. A map of the site is shown in Fig. 3. A permanent camera holder could not be safely used as a high wave would have flooded the camera. To avoid this problem the position of the camera site, about six feet away from the apparatus (Fig. 1c), was marked by sinking a boulder, the position of which was regularly checked by tape measure. The camera was hand held, above this position, the base of the camera about two inches from the water surface.

Photography: an Asahi Pentax S1-a S.L.R. camera was used with a Super Takumar 55 mm F/2 automatic lens, medium yellow Vivitar filter and lens hood. To assure that the camera remained dry, while focussing and releasing the shutter a twenty inch cable release twisted around the body and a right angle view finder were used. Shutter speed was maintained at 1/250 sec for all photographs, the size of the aperture being estimated with the aid of a Gossen Sixtino light meter. Black and white 35 mm Kodak tri-X panchromatic film was employed throughout, exposed film being developed in a single roll developing tank, with Acufine developer and replenisher, Edwal quick-fix and photo-flo.

Experimental apparatus: the experiments in which contrasts of the photographs were compared, were done under

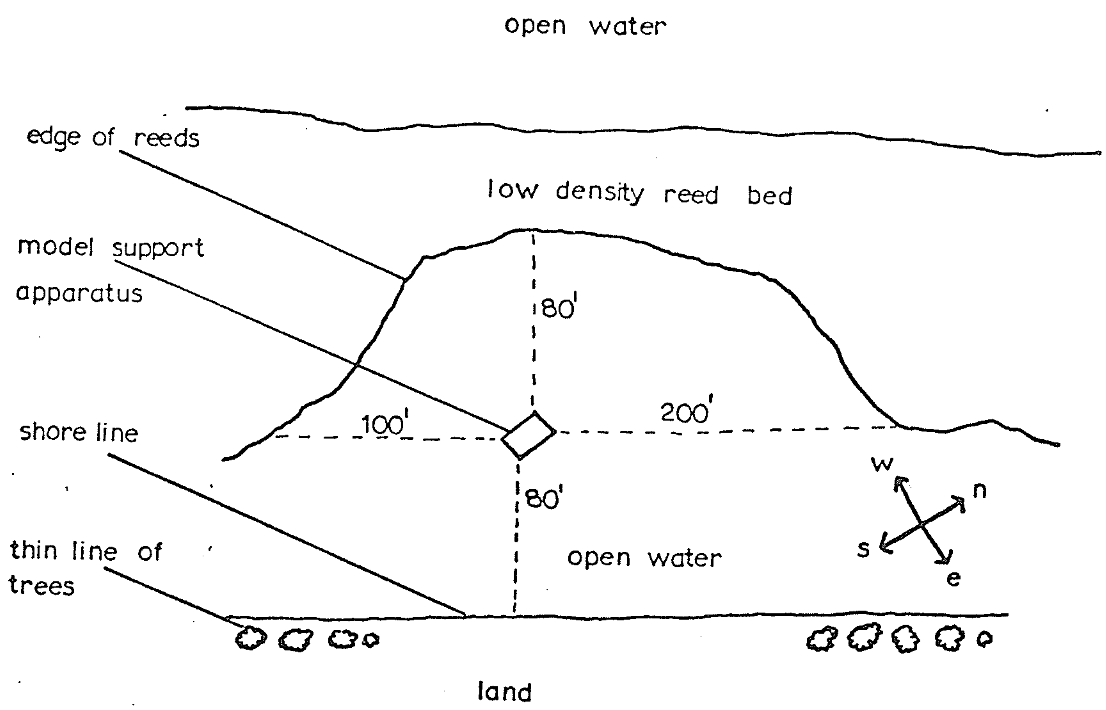


FIG. 3. MAP OF APPARATUS SITE, OAK LAKE

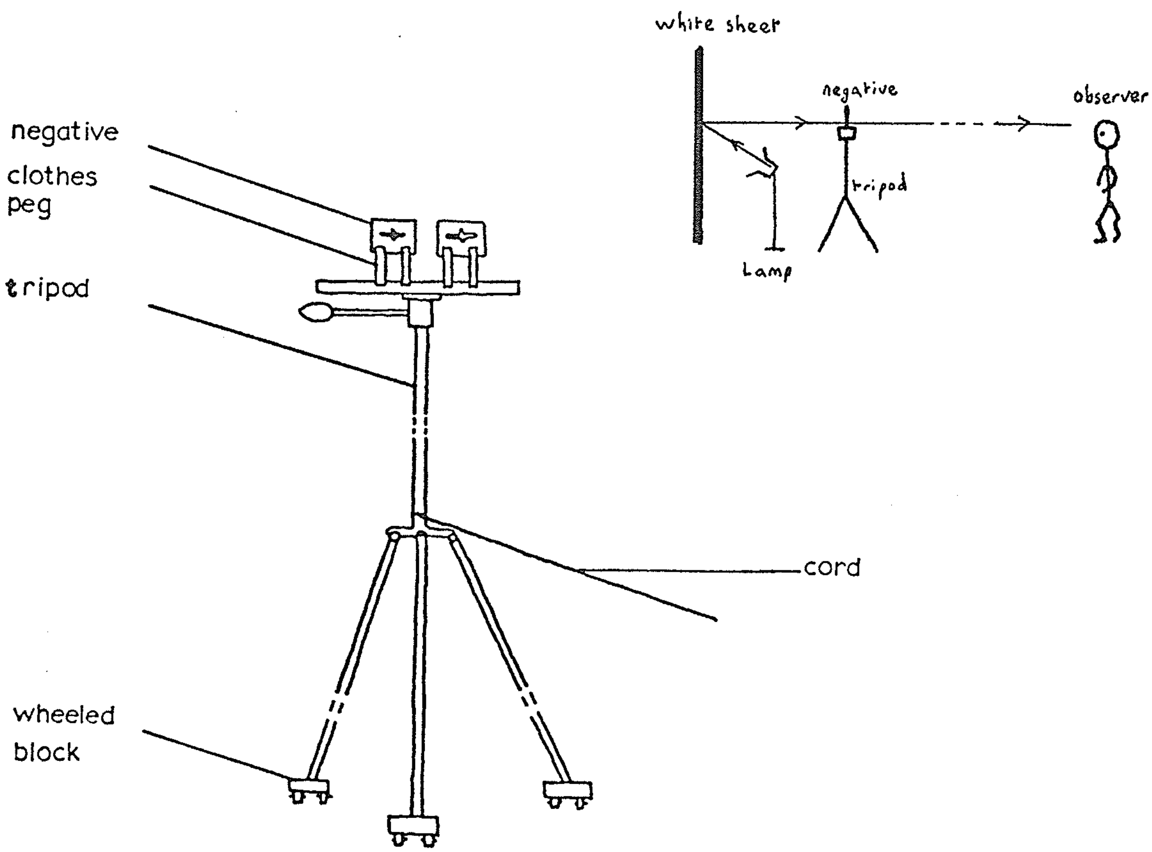


FIG. 4. THE NEGATIVE HOLDING APPARATUS AND A RAY DIAGRAM

laboratory conditions. To standardize the method of comparing the negatives a holding apparatus was used consisting of a wooden bar with four spring-action clothes pegs attached such that each pair of pegs could hold one negative, the bar being attached to the camera plate of a tripod. Small plastic blocks with wheels were placed under each tripod leg, a long cord being attached such that the entire apparatus could be pulled towards the observer (Fig. 4). The apparatus was pulled at a constant rate of approximately 1.5 Ft/sec. Illumination for the negatives was provided by a 120 volt, 60 watt lamp placed behind the negatives and held in a lamp holder set to direct the beam at a white sheet stretched across a wall behind the negatives. Diffuse reflected light from the sheet passed through the negatives, to the observer. All other possible light sources were blacked out.

Methods

Negative preparation: Under a set of environmental conditions, the photograph of one of the models would be taken, then the model would be quickly removed, the second model put up and its photograph taken. The elapsed time between successive photographs was about one and a half minutes. In total, 564 individual photographs were taken on

282 occasions, 2 per occasion, the photographs being taken between the official times of sunrise and sunset, from 13 July to 11 August 1970 (extracted from the Canadian Almanac for 1970, the figures for Winnipeg with a +11 minutes adjustment). To avoid selecting particular conditions photography occasions were randomly selected. Only when torrential and high wind prairie thunderstorms or hailstorms prevented photography were these times ignored.

Environmental variables recorded, at the times photographs were taken, were, cloud cover, position of the sun, wind direction, cloud thickness and colour of cloud obscuring sun, cloud thickness and colour of cloud behind gull (and in the photograph), visibility, wave height, and precipitation. Their values and levels of measurement etc. are fully described in Appendix Vl.

<u>Experimental Design</u>: 282 single experiments, each using a different pair of negatives were done in the laboratory. In each experiment the dependent variable was: the difference between the distance of a n.p.i. of the white model and the distance of an n.p.i. of the black model from the observer before the observer sees an n.p.i. of a model. The nominal level of measurement was used, three values being recorded: +1 (distance of n.p.i. of black model from observer greater), 0 (distance of n.p.i.'s the same), -1

(distance of n.p.i. of white model from observer greater). The negatives, pulled towards the observer, were stopped when the n.p.i. of both models had been detected.

The independent variable was the contrast of the model n.p.i.'s. Each experiment consisted of presenting the two negatives simultaneously, and recording the value of the dependent variable. To eliminate any problems of intersubject variation, one observer, myself, was used. Order effects i.e. instances where the effect of a treatment on a subject depends on the effect of the treatment(s) which precedes it, are usually negligible in psycho-physical experiments (e.g. Ray 1960:104). This design eliminated the effects of time series variation in which the variables change temporally but not spatially. Another equalised variable was the densities of silver, of the model's background, in the negatives. Possible confounding variables were those which varied in value spatially, e.g. the dependent variable might have been affected by a variable, perhaps light intensity, which had different values in the two positions of the negatives. For each experiment the measurements on the dependent variable were therefore replicated, doing 12 presentations in 12 minutes and using the same two negatives on each presentation.

The occasion of measurement (in fact time of the start of each 'pull' i.e. presentation) was randomly assigned by selecting seconds of the 720 second (12 min.) experimental period from a random numbers table. The same selection was used for each experiment. Presumably a set of seconds could have been selected where some of the seconds were too close to allow time to finish a previous presentation. Such sets would be rejected. On any occasion of measurement two arrangements of the negatives were possible - the negative of the white model could be on the left and the other negative on the right or vice versa. The arrangement of negatives was randomly assigned.

When it was necessary to re-enter the experimental room, from the 'outside environment', experiments were not started until at least ten minutes had passed. A preliminary series of experiments in which I was completely unaware of the randomisation routine, was also carried out.

Analysis: The data from each experiment were analysed using the non-parametric, one-tailed, Signs test (Siegel 1956, Goldstein 1964). This test simply involves counting the number of positive and negative signs of the sample of differences. All tied cases are dropped. The sample of differences would represent a population of differences with

$\rho \leq 0$ if Ho_1, or Ho_2 were the case.

Data confirming relationship (1): The differential threshold of visibility of an object has been found, experimentally, to depend on the contrast of the object with its background, and the area of the image of the object on the retina (see summary by Le Grand 1957). This relationship seems to be general e.g. the threshold to a first approximation does not depend on the spectral composition of light from the object. The angular area of the object, which determines the area of its image on the retina (Le Grand) decreases as the reciprocal of the square of the distance away from the observer (e.g. Pirenne and Crombie 1944, Craik 1944b). It follows that the threshold of visibility depends on the contrast of the object and its distance from the observer.

The control of atmospheric scattering: The intensity of atmospheric scattering of light increases approximately with distance (Pirenne and Crombie 1944). To decrease the intensity of atmospheric scattering of light from an object, the object should be brought closer to the observer. A seabird model would be seen first some distance away from an observer, a photographic negative of the model, which is much smaller (see Figure 5) would first be seen close up to the observer. Use of the photograph, as a substitute for the model, must greatly decrease the atmospheric scattering.

A negative photograph approximately reproduces the contrast of an object: In a 'perfect' photographic negative the brightness of parts of a negative are inversely proportional to the brightness of corresponding parts of the photographed scene (Baines 1958). Using the formula given on Page 7 it can be calculated that for a perfect negative the contrast of the negative equals the contrast of the object. Presumably most negatives differ from perfect negatives by the difference between the spectral sensitivity of the photographic emulsion and the spectral sensitivity of the human eye. Orthochromatic film differs considerably from the eye in spectral sensitivity. Panchromatic film used with a medium yellow filter approaches closely the human spectral sensitivity curve. Therefore the contrast of a panchromatic negative must approximately equal the contrast of the corresponding object.

Results and Conclusions

In all 282 experiments, and on every presentation, the n.p.i. of the black model was invariably seen first (+1). Ho_1 and Ho_2 were rejected ($P<0.01$). The environmental conditions recorded during each occasion of photography are listed in Appendix Vl. The number of experiments per cloud cover condition are listed in Table 1. The preliminary series of experiments in which I, as observer, was unaware of the randomisation routine, gave identical results to those above.

Using relationship (1) and the experimental results it follows that in all cases the contrasts of negatives of the white undersided sea-bird model were smaller than those of the black undersided model. Following the proof above (under all the environmental conditions investigated), the white under-sided sea-bird model had a smaller undersides contrast against the sky than the black undersided model. In conclusion these data support the relationship that white undersided sea-birds have smaller undersides contrasts against the sky than black undersided sea-birds, i.e. hypothesis (2) is confirmed for white undersided and black undersided sea-birds.

Table 1

The number of experiments per cloud cover condition

Cloud Cover	Number of experiments
0	73
1	42
2	36 cont'd

Cloud Cover	Number of Experiments
3	33
4	11
5	17
6	21
7	32
8	17

CHAPTER 3

DO ADULT FRANKLIN'S GULLS HAVE A LARGER OR SMALLER UNDERSIDES CONTRAST AGAINST THE SKY THAN WHITE UNDERSIDED SEA-BIRDS

The negative preparation apparatus, experimental apparatus, experimental design and analysis used were identical to those used in the experiments reported in Chapter 2, except that partially white undersided Franklin's Gulls, not black undersided sea-birds were investigated. To prepare suitable negatives, I used an unpainted, mounted, adult nuptial Franklin's Gull, having black wing tips, pale grey primaries, white secondaries, white wing bands, white wing lining, white axillaries, white underparts and a deep black hood (Fig.5). A photograph of this model was taken on every occasion that the photographs used in the previous series of experiments were taken. The white undersided model negatives were used again for this series. 73 experiments were done and only using negatives taken under cloudless skies. The experimental hypotheses were: the n.p.i. of a white undersided sea-bird model approaches nearer (Ha), equally near (Ho_1) or less near (Ho_2) to a human observer than a n.p.i. of a Franklin's Gull model before the observer sees an n.p.i. of a model.

Results

In 31 of the 73 experiments Ho_1 and Ho_2 were rejected ($p < 0.01$), a value of +1 being recorded on every presentation. In a further 10 experiments all measurements were tied, i.e. 0 was recorded on every presentation, and therefore the results were inconclusive. In the other 32 experiments, Ho_1 and Ha were rejected ($P < 0.01$), a value of -1 being recorded on every presentation. Using relationship (1) the experimental data and the proof in Chapter 2, it follows that for 31 of the experiments the undersides contrasts of the white undersided sea-bird model were smaller than the undersides contrasts of the Franklin's Gull model, while, in the other 32 experiments the undersides contrasts of the Franklin's Gull model were smaller than those of the white undersided sea-bird model. In conclusion the data support a conditional relationship, viz, that under some conditions Franklin's Gulls have smaller undersides contrasts against the sky than white undersided sea-birds, and vice versa. The data support hypothesis (2) only under certain conditions.

To evaluate the contingency the environmental conditions recorded during photography and the accepted experimental hypotheses (Ha or Ho_2), were tested for association using Guttman's coefficient of predictability (Freeman 1965). I assumed that the 10 occasions on which the experimental results were not statistically significant fell randomly. There was little association for wind direction ($P > .05$) or wave height ($P > .05$). However, a high association was found for the horizontal bearing of the sun (Lamda = 0.906 in a 2 x 56 contingency table; Lamda = 0.781 in a grouped 2 X 2 contingency table. For the 2 X 2 table chi-square = 40.94 ($P < 0.001$), where observations were grouped on either side of the median compass direction for which data were obtained (Table 2).

TABLE 2

THE ASSOCIATION BETWEEN SUN'S BEARING AND ACCEPTED EXPERIMENTAL HYPOTHESIS

Accepted experimental Hyp.	Horizontal Bearing of the sun (in degrees)		
	35 - 170	175 - 310	Total
Ha	6	25	31
Ho	32	0	32
Total	38	25	63

Lamda = 0.781

$Chi^2 = 40.94$, $P < 0.001$

When the sun was in the sector NE to S, i.e. anterior to the model the undersides contrast was smaller than that of the white undersided model, when the sun was in the sector S to NW, i.e. posterior to the model, the undersides contrast of the Franklin's Gull model was larger than that of the white undersided model. The association suggests that the horizontal bearing of the sun, is an important variable affecting the contrast of a sea-bird.

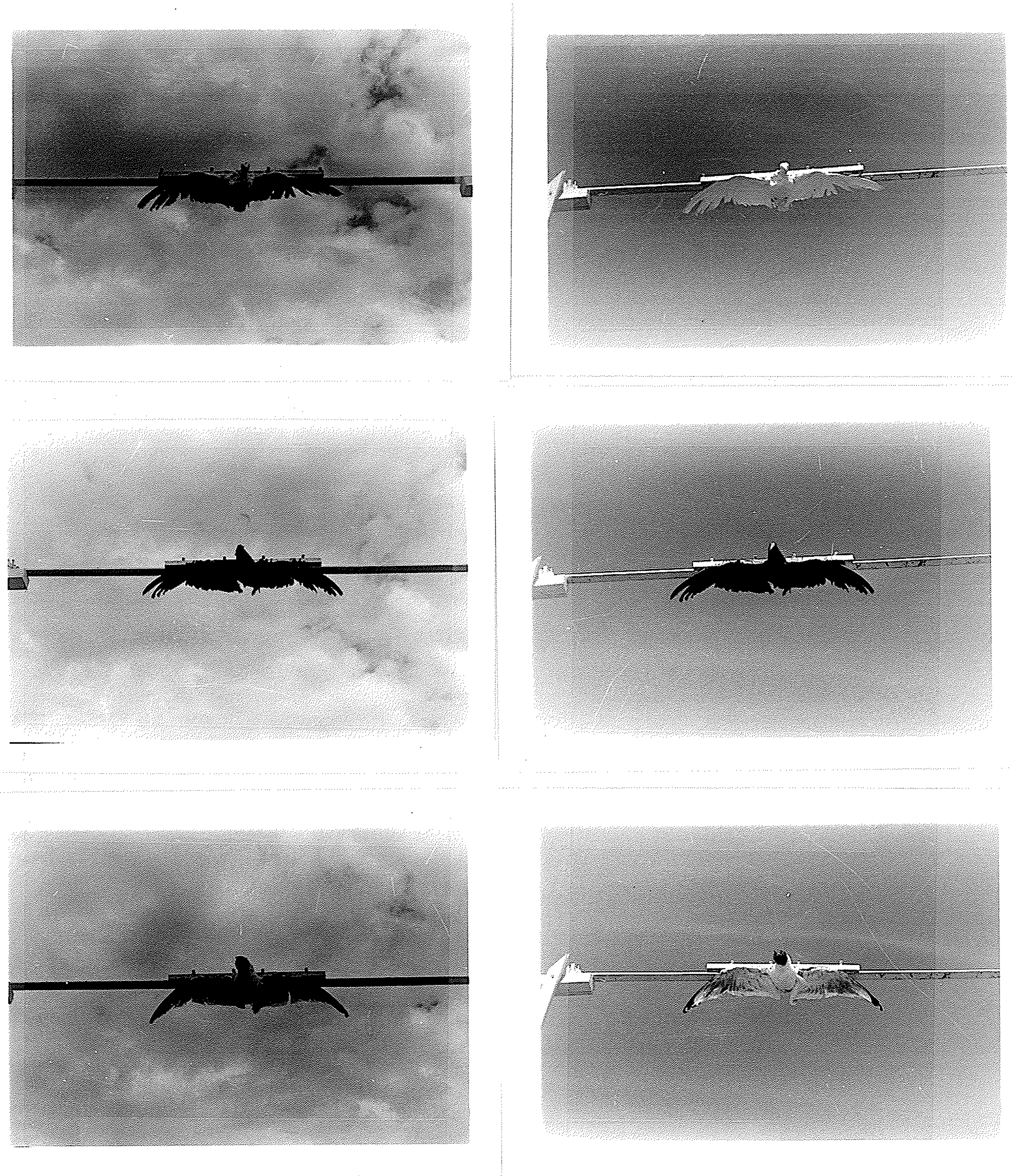
CHAPTER 4

DO ADULT FRANKLIN'S GULLS HAVE A LARGER OR SMALLER UNDERSIDES CONTRAST AGAINST THE SKY THAN BLACK UNDERSIDED SEA-BIRDS?

The only differences between the series of experiments reported here and those in Chapters 2 and 3 are that the negatives of the partially white undersided Franklin's Gull model and the black undersided model were compared.

Results

For all 282 experiments, Ho_1 and Ho_2 were rejected ($P<0.01$). On every presentation +1 was recorded. Using relationship (1) and the experimental results, in all cases the contrasts of negatives of the Franklin's Gull model were smaller than those of the black undersided model. Following the proof in Chapter 2, (under all environmental conditions investigated) the Franklin's Gull model therefore had a smaller undersides contrast against the sky than the black undersided model. In conclusion these data support the relationship that Franklin's Gulls have smaller undersides contrasts against the sky than black undersided sea-birds.



17 july 08.25

9 august 12.26*
(*see appendix vi)

FIG. 5. POSITIVE PRINTS OF SOME OF THE NEGATIVES USED IN THE EXPERIMENTS. actual negatives X·5 (24x36 mm)

CHAPTER 5

DISCUSSION

The experimental results presented in Chapter (2) support hypothesis (2), for white undersided and black undersided sea-birds. The experimental results in Chapter (3) support a conditional relationship. On some occasions the results support hypothesis (2), on others the results support the relationship that an adult Franklin's Gull has a smaller undersides contrast than a white undersided sea-bird. A probable contingent variable is horizontal position of the sun (Chapter 3).

Natural selection theory could simply explain the undersides coloration of the Franklin's Gull if first, it was found that its undersides are optimally effective i.e. no other-coloured sea-bird has a smaller contrast, under certain conditions, second, if the chain of hypotheses, elaborated on Page 4 , received some degree of confirmation and third if it was found that gulls plunge dive for fish when the undersides are optimally effective. In general, it may be hypothesized that partially - white undersided gulls (except probably the nearly all-dark species - Appendix 1) under some conditions have a smaller contrast than white undersided sea-birds. If gulls do not plunge dive mainly when the undersides are optimal, natural selection theory might explain partially-white undersides as a compromise property (see Mayr 1963: 194-197, Tinbergen 1967). This argument also applies to white undersided sea-birds.

Certain other effects of the undersides coloration of adult gulls have been demonstrated. For example, Averill (1923) pointed out that black feathers, often found in the wing tips of adult gulls, resist wear much better than white feathers (see also Van Tyne and Berger 1966: 101). The dark brown hood of the Black-headed Gull assists in the intimidation of territorial rivals, (Mash as reported in Tinbergen 1967). Experimental evidence presented by Smith (1966) showed that the wing-tip pattern of Thayer's Gull, Glaucous Gull, and the Herring Gull act, together with the eye-head contrast, as a species discrimination factor. Other possible effects of white coloration of sea-birds are given in Appendix V .

What is the present status of the 'chain' of hypotheses (Chapter 1)? Phillips demonstrated, with a literature search, that various white undersided sea-birds plunge dive for and eat fish. In Appendices 11 and 111 the results of a literature search show that many gull species plunge dive for and eat fish.

Do fish show escape responses to gulls and other sea-birds? The sticklebacks and pelagic marine fish, used by Phillips gave escape responses to his models (Appendix lV). Descriptions of interactions between fish and gulls are rare in literature. Cowan (1968) observed adult Herring Gulls approaching mullet Mugil sp. from the air (in order to rob offal from the fish) and found that the mullet did not appear to respond to the gulls presence even during offal snatching. Also Cowan (1968 unpubl. note) observed an adult Black-headed Gull, in winter plumage, swimming, while around the gull were several large shoals of small fish, individuals of which often broke the surface, but showed little other activity. When the gull jumped up from the surface and dived, the fish shoals immediately broke up, the fish swimming away in all directions.

Statements concerning the rates of fish capture by white undersided or partially white undersided sea-birds, compared, under similar conditions, with differently coloured sea-birds are rare in the literature.

Antony (1906) observed Heerman's Gulls (nearly all-dark undersides) catching fish at a higher rate than Western Gulls, (partially-white undersides), feeding on herring off

California. However that various other conditions affect the rate of fish capture (rain, high wind), is indicated by Wilson and Greenhalgh's (1965) observations of fishing by Lesser Black-backed Gulls.

Are fish crucial to sea-bird survival? Clearly food affects animals, sufficient quantities promote survival, lack of food or food shortage may cause death. Does such mortality actually occur in nature? For various passerine and neo-passerine species surviving bird numbers in a population and availability of food have been found to be closely correlated (see summary by Lack 1966: 276). That fish are critical in nature, to the survival of sea-birds, however has yet to be demonstrated.

In conclusion Craik's hypothesis (Hypothesis 2) is partially supported but under certain conditions my experimental data support a converse relationship involving the partially white undersided Franklin's Gull and white undersided sea-birds. Pirenne and Crombies' (1944) contrast values, for white sea-birds and black sea-birds are not supported. Craik's chain of hypotheses still remain viable for sea-birds. The measurement of undersides contrast using different positions of model and camera, the elaboration of sea-bird contrast measurement technique and experiments akin to Phillips (1962) using more realistic models are all logical steps for further investigation.

APPENDIX 1

DO ADULT GULLS HAVE WHITE UNDERSIDES?

Dwight's work (1925), "The gulls (laridae) of the world; their plumages, moults, variations, relationships and distributions" contains extensive descriptions of gulls. For some species, Dwight ommitted reference to coloration of various parts of the undersides. To supplement Dwight's work, I searched through the modern literature. Law statements of the coloration of adult gulls are listed below. In some cases the author originally gave his descriptions in this form, others I have inductively converted. Their degree of confirmation is varied. Only a few species of gulls have been shown to exhibit geographical variation in undersides coloration.

Descriptions of plumages are usually either taken from extant birds or from dead specimens, often in a museum. After long periods of time, the plumage of most museum specimens fades (Vevers, 1964), so that a described colour may be lighter than the counterpart colour in a live bird. Soft parts coloration and adherent colours such as the pink cosmetic colours derived from the coloured oil of the preen gland (Berthold, 1967) may disappear or change after only a short period of time. For the purposes of the present

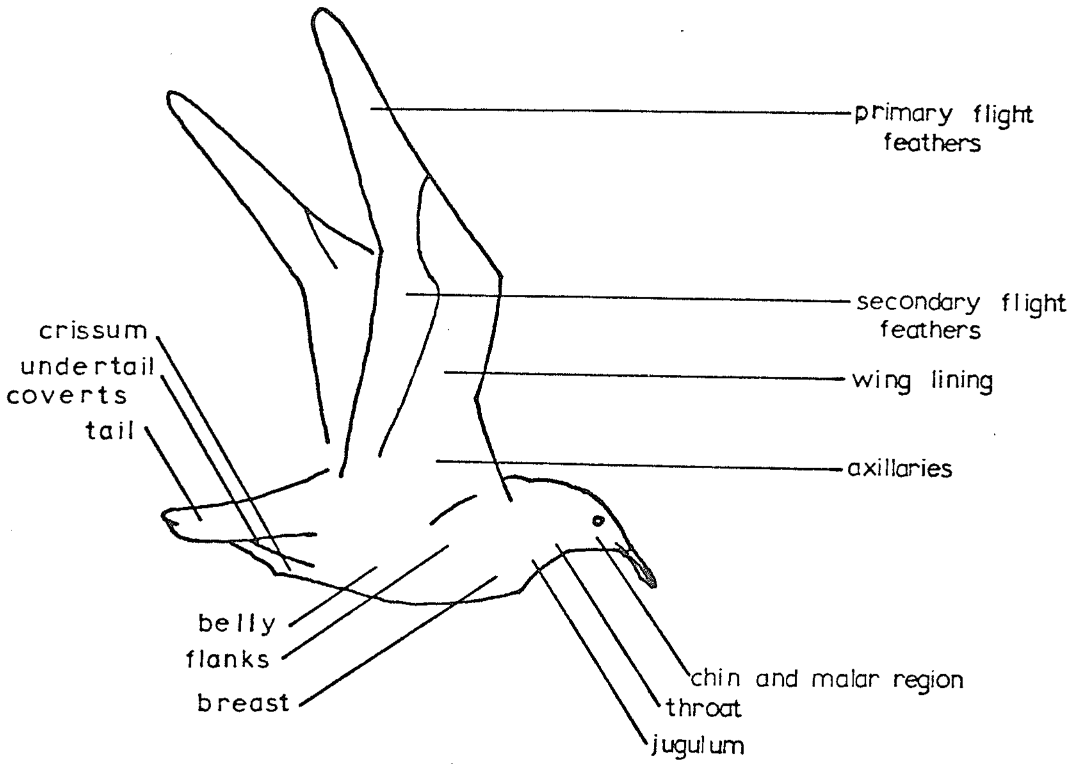


FIG. 6a. TOPOGRAPHY OF A GULL'S UNDERSIDES BY PLUMAGE AREAS

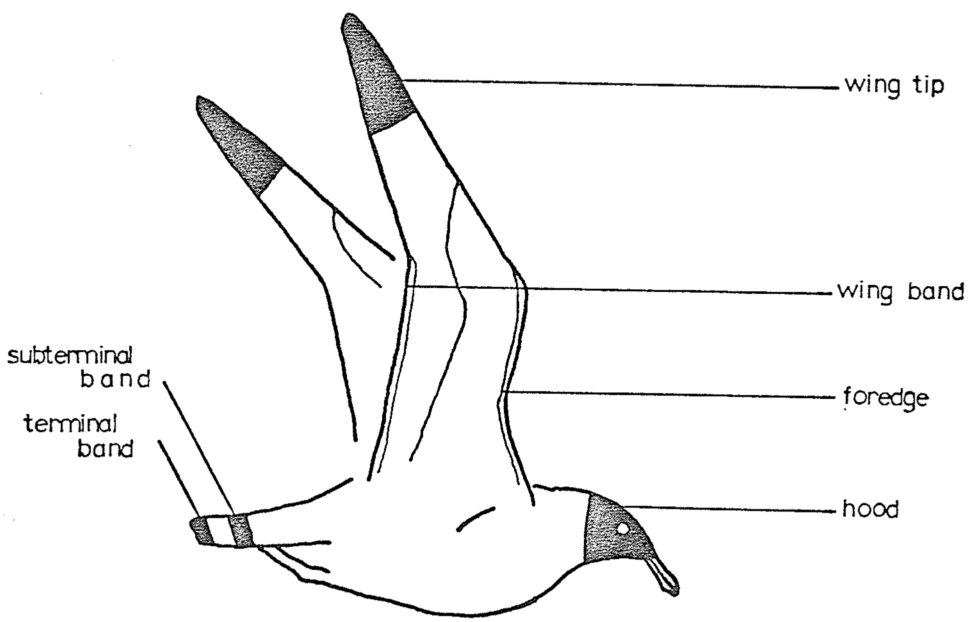


FIG. 6b. TOPOGRAPHY OF A GULL'S UNDERSIDES BY COLOUR PATTERN

study it is important to note that loss of adherent colours and the fading of feathers in museum skins apparently tends to bias descriptions in favour of light or white rather than dark coloration.

The undersides of a gull (Fig. 6a) consist of the ventral portion of the head or "under-head", including chin, malar region and lower cheek, the throat, jugulum, breast, flanks, belly, crissum, undertail coverts, undertail, and underwings including the wing-lining (underwing coverts), and axillaries (Thomson 1964 and Petersen et al 1966). Terms which derive from colour patterns e.g. hood, wing-tip, are illustrated in Fig. 6b. "Underparts" has been used in the literature in two ways -- as synonymous with "undersides" or as the underparts of the body as distinct from the wings. As authors often fail to make the distinction, I use the latter definition throughout in this thesis. Many authors also do not mention whether their descriptions of primaries, secondaries, wing-bands or tail refer to the upper surface or under surface. This uncertainty exists in all the statements given below unless otherwise stated. Dwight (1925) seemed to use "edge" as referring to the foredge of the wing.

Group 1

Laughing Gull <u>Larus atricilla</u>: underhead white, underparts white, dusky clouding on sides of throat and breast, primaries black, grey and white, wing-lining grey, axillaries white, white wing-bands, tail white (Dwight). Peculiarities of adult nuptial: black hood, loss of clouding on throat and breast (Dwight). Breast suffused with pink (Murphy 1936).

Lava Gull <u>L. fuliginosus</u>: dark sooty brown, sometimes greyer, hood extending to chin, chin brown, grey throat and sides paling on breast and abdomen, crissum nearly white, primaries black and grey, tail clear pale grey, middle pairs of rectrices darker, outer pairs nearly white, undertail coverts paler grey (Dwight).

Hemprich's Gull <u>L. hemprichi</u>: dark brown hood, grizzled with grey at posterior margin, pale brown chin, grey brown throat, grey brown breast and sides merging gradually into white posteriorly, primaries black and grey, secondaries deep clove brown, wing-lining wholly brown, white wing-bands, tail white (Dwight). Greyish brown underwings (Fogden 1964). Underwing and axillaries brown (Meinertzhagen 1954). Peculiarities of adult nuptial: hood clear blackish brown (Dwight).

Great Black-headed Gull L. ichthyaetus: head white, underparts pure white, primaries white, black grey, secondaries grey, and white wing-bands (Dwight). Underwing and tail white (Meinertzhagen 1954, Bannerman and Bannerman 1958). Peculiarities of adult nuptial: deep black hood (Dwight).

White-eyed Gull L. leucopthalmus: grizzled black hood, grey breast and sides paling into white of abdomen, primaries black and white, secondaries mouse-grey to black, white wing-bands, wing-lining grey, tail white, greyish at base of central pairs, edge of wing white (Dwight). Underwings dark brownish grey (Cave and Macdonald 1955). Peculiarities of adult nuptial: hood and "apron" black (Dwight).

Mediterranean Gull L. melanocephalus: underhead white, underparts snowy white, primaries pale from faint grey to white tips, secondaries grey and white, white wing-bands, tail white (Dwight). Peculiarities of adult nuptial: Jet black hood (Dwight). Jet-black hood in all lights (Taverner 1970).

Franklin's Gull L. pipixcan: underhead white, underparts white, primaries white, grey and black, grey secondaries, white wing-bands, tail white, central pair of rectrices grey (Dwight). Black wing tips (undersurface), pale grey primaries (except for black wing tips), white secondaries (undersurface), white wing bands (undersurface), white wing-lining, white axillaries (Cowan 1970 pers. obs., Oak Lake, Manitoba). Peculiarities of adult nuptial: deep black hood, rosy tinted underparts (Dwight). Rosy pink breast and underparts remarkably bright at beginning of breeding season (Moynihan 1958, Cowan 1970 pers. obs., Delta Marsh and Oak Lake, Manitoba).

Group 2

Heermann's Gull L. heermanni: head with dusky hood indistinctly streaked with brown and white, underparts grey, chin and upper throat white, latter with dusky flecks on sides, primaries black, white wing-bands, tail black with white tip (Dwight). Peculiarities of adult nuptial: creamy-white hood blending into grey of breast (Dwight)

Gray Gull L. modestus: wood brown hood, underparts uniformly grey, white wing bands, tail grey (Dwight). Axillaries and wing-lining greyish clove-brown (Murphy 1936). Peculiarities of adult nuptial: hood completely white (Murphy).

Group 3

Red-legged Kittiwake L. brevirostris: head and neck white, underparts white, primaries grey tipped with black, secondaries grey, white wing bands, wing-lining grey, tail white (Dwight). Wing-lining grey (Pough 1957).

Kittiwake L. tridactylus: underhead white, underparts white, primaries pale grey, black, secondaries grey, white wing bands, tail white (Dwight).

Group 4

Saunder's Gull L. saundersi: underhead white, underparts white, primaries grey, black and white, secondaries largely white, white wing bands, wing-lining pale grey, tail white, edge of wing white (Dwight). Peculiarities of adult nuptial: black hood (Dwight).

Group 5

Black-billed Gull L. bulleri: head, underparts and tail pure white, primaries largely black, secondaries grey, wing lining greyish (Dwight). Underparts entirely white (Falla 1960). Peculiarities of adult nuptial: white breast has a more rosy tint in the breeding season (Dwight).

Grey-headed Gull L. cirrocephalus: underhead white, underparts white, primaries black, white and grey, secondaries grey, wing-lining grey (Dwight). Peculiarities of adult nuptial: pale grey hood, almost white on chin (Dwight). Ventral surface has rosy bloom (Murphy 1936).

Slender-billed Gull L. genei: underhead white, underparts white, primaries white, black and grey, secondaries neutral grey, axillaries white, wing-lining grey (Dwight). Pink or rosy pink tinge on white coloured underparts less bright than in nuptial plumage (Bannerman 1953, Geroudet 1965). Peculiarities of adult nuptial: White everywhere, including wings, becomes more rosy (Dwight, Wallace 1964, Bannerman 1953, Geroudet 1965, Cave and Macdonald 1955).

Silver, Hartlaub's and Red-billed Gull L. novaehollandiae: head pure white, underparts white, primaries black, white, secondaries grey, tail white (Dwight).

Bonaparte's Gull L. philadelphia: white underhead, underparts white, primaries black, white and grey, secondaries grey, white wing-lining, tail white (Dwight). Peculiarities of adult nuptial: bluish-black hood (Dwight). Rosy breast in spring (Gabrielson and Jewett 1970).

Black-headed Gull L. ridibundus: under-head white, underparts white, primaries white, black and grey, secondaries grey, wing-lining grey, axillaries grey, tail white (Dwight). Underwing pale blue-grey (Gibson-hill 1949). Underside of wing dark (Brunn and Singer 1970). Broad dusky streak on underwing (Bond 1960). Peculiarities of adult nuptial: brown hood (Dwight). Pink cosmetic coloration (Berthold 1967).

Andean Gull _L. serranus_: head pure white, underparts white with rosy tinge, primaries black, white and grey, secondaries grey, tail white (Dwight). Wing-lining grey, axillaries white (Murphy 1936). Peculiarities of adult nuptial: black hood (Dwight). Brownish-black hood, rosy ventral surface (Murphy 1936).

Group 6

Little Gull _L. minutus_: underhead white, underparts white, primaries and secondaries pale neutral grey, white tipped, white wing band, wing-lining plumbeous grey, tail white (Dwight). Underwing dark slaty grey, bordered by white (Furse 1967). Dark slaty underwing (Fisher 1947). Peculiarities of adult nuptial: black hood and rosier tinge of underparts (Dwight). Rosy tinge on breast and abdomen (Harrison 1950, Coward 1952).

Ross's Gull _L. roseus_: under-head white, underparts white with decidedly rosy tinge most marked on breast. Primaries wholly grey, black outer web of tenth, white wing band, secondaries grey, axillaries white, pale neutral grey-wing-lining (Dwight). Underwings greyish (Curtis 1967). "One distinctive character which was visible in skins although not emphasized in any books I have consulted is the very grey underwing". (Bourne 1967). Underwings pale pearly grey (Snyder 1957). Underwings creamy-grey (Aldcroft, Cowan and Kennedy 1969). Peculiarities of adult nuptial: narrow black collar and rosier white underparts (Dwight). Delicate black necklace (Snyder 1957).

Group 7

Swallow-tailed Gull L. furcatus: underhead pure white, ill-defined grey collar, underparts white clouded with pale grey on throat, the sides of the throat markedly grey, primaries grey, black and white, secondaries pale grey, white wing-bands, tail white (Dwight). Ventral surface white (Murphy 1936). Peculiarities of adult nuptial: dusky hood and rosy throat and breast (Dwight). Velvet-grey hood (Hailman 1966). Dark grey head and neck (Harris 1970).

Sabine's Gull L. sabini: underhead white, underparts white, sides of breast faintly grey, primaries black, grey and white, secondaries white, white wing-bands, white wing-lining with dusky margins at edge of wing, tail white (Dwight). Peculiarities of adult nuptial: plumbeous or dark neutral grey hood with narrow black collar (Dwight). Grey hood, narrow black ring dividing hood from white neck (Brown et al 1967). Sometimes pinkish underparts (Snyder 1957).

Group 8

Ivory Gull L. *eburneus*: entire plumage ivory white (Dwight).

Group 9

Dolphin Gull L. *scoresbii*: head with dusky grey hood reaching only to sides of throat, underparts pale grey, nearly white on chin, nearly white on upper throat and crissum, primaries black and white, secondaries grey, white wing-bands, wing-lining deep grey, tail white (Dwight). Peculiarities of adult nuptial: pale grey head, uniform with neck (Dwight).

Group 10

Herring Gull L. *argentatus*: under-head snowy white, underparts white, primaries black, white and grey, secondaries grey, white wing bands, axillaries and wing-lining pure white, tail snowy white, edge of wing white (Dwight).

Audouin's Gull L. *audouini*: head white, underparts pure white, primaries black, white and grey, secondaries grey, white wing-bands, greyish wing-lining and axillaries, white tail (Dwight). Pale grey wing-lining (Meinetzhagen 1954). Underwing suffused greyish, lower breast and flanks lightly suffused grey (Wallace 1969).

Belcher's Gull L. *belcheri*: head with dull brownish-black hood to well below eye, underparts white, pale grey wash on breast, dusky spotting and slight, streaked collar across upper throat, primaries black, grey and white, secondaries slate, white wing-bands, white tail with broad black sub-terminal band (Dwight). Atlantic race does not have the black hood of the Pacific race (Olrog 1967). Wing-lining white in Atlantic race, grey in Pacific race (Escalante 1966). Pearl-grey tinge on breast of Pacific race -- not found in Atlantic race. Black tail band narrower in Atlantic race (Olrog 1967). Peculiarities of adult nuptial: probably has white head (Dwight).

California Gull _L._ _californicus_: under-head white, underparts pure white, primaries black, white and grey, secondaries grey, white wing band and tail (Dwight).

Common Gull _L._ _canus_: underhead white, underparts pure white, primaries black, grey and white, tail white (Dwight). Axillaries white (Meinertzhagen 1954).

Black-tailed Gull _L._ _crassirostris_: underhead white, underparts pure white, primaries black, grey and white, secondaries deep neutral grey, white wing bands, wing-lining and axillaries white, tail white with black sub-terminal band, edge of wing white (Dwight).

Ring-billed Gull _L._ _delawarensis_: underhead white, underparts white, primaries black, white and grey, secondaries grey, white wing bands, wing-lining white, tail pure white, edge of wing white (Dwight). Shows larger black area on undersides of primaries than Herring Gull (Bond 1960, Robbins et al 1966).

Southern Black-backed Gull L. dominicanus: underhead white, primaries black and white, secondaries greyer than primaries, white wing bands, white wing-lining and tail (Dwight). Body plumage entirely white except for wings and mantle (Falla 1960). White underwings (Murphy 1936).

Lesser Black-backed Gull L. fuscus: underhead white, underparts white, primaries black, white, grey, secondaries slaty, white wing bands, wing-lining and tail white (Dwight). More extensive black on under primaries than Great Black-backed Gull (Bruun and Singer 1970).

Glaucous-winged Gull L. glaucescens: underhead white, underparts white, obscure dusky barring or spotting across throat, primaries drab grey, white, secondaries grey, white wing bands, tail white (Dwight). Peculiarities of adult nuptial: Throat all white (Dwight).

Iceland Gull L. glaucoides: head white, faintly clouded underparts white, primaries grey and white, secondaries grey, white wing bands, also white wing-lining, axillaries, tail and edge of wing (Dwight). Peculiarities of adult nuptial: head completely white (Dwight).

Glaucous Gull L. hyperboreus: head, underparts, and tail pure white, primaries white, grey, secondaries grey, white wing bands, wing-lining white, axillaries white (Dwight).

Great Black-backed Gull L. marinus: head white or lightly streaked with dusky brown, underparts snowy white, primaries black and white, secondaries slaty to sooty black, white wing bands. Peculiarities of adult nuptial: Head completely white (Dwight).

Western Gull L. occidentalis: head white, underparts white, primaries black, white and grey, secondaries grey, white wing bands, tail white (Dwight).

Pacific Gull L. pacificus: underhead white, underparts pure white, often with rosy tinge, primaries black and white, secondaries black, white wing bands, white wing lining, tail white with subterminal black band (Dwight). Snowy white head and undersurface (Tarr 1961).

Slaty-backed Gull L. schistisagus: underhead white, underparts white, primaries black, white and grey, secondaries dark neutral grey to slate black, white wing lining, white axillaries, tail pure white (Dwight). White underparts, white head and tail (Yamashina 1961).

Thayer's Gull L. thayeri: very similar to Herring

Gull except differs in area of black in wing tips, the black paler (Godfrey 1966).

Therefore, one species has entirely white undersides, 35 species have partially white undersides while six species have undersides with little white coloration. A summary is given in Table 3.

TABLE 3

The undersides colouration of adult gulls - a summary.

Colour category (in order of increasing area of dark coloration)	No of species (non-nuptial plumage) which fit each category	No. of species per category which acquire a dark nuptial hood
Entirely white	1	0
White and grey e.g. grey remiges.	4	1
White and some grey/black e.g. Grey remiges, black wing tips.	17	4
White and grey/black e.g. grey remiges, Grey wing-lining, black wing tips.	13	5
White and dark grey/black e.g. black. Wing-tips, slate wing-lining, grey remiges.	2	1
Mainly dark.	5	2
Total	42	13

APPENDIX 11

DO ADULT GULLS FEED ON FISH?

Phillips (1962) carried out a literature search to investigate whether gulls feed on fish. He found records of fish as food for the majority of gull species, but was unable to trace food records for Audouin's Gull, the White-eyed Gull, and the Andean Gull. The emphasis of my literature search was the coverage of records published since Phillip's work and records published in the North American literature, which perhaps were less available to Phillips.

Most gull species are highly omnivorous. The usual methods of studying their foods include examination of gut contents, examinations of droppings and pellets, examination of regurgitated gut contents and direct observation of easily identified foods during food capture or the feeding of young (see Hartley 1964). The literature contains either simple generalizations of the food of gulls or singular statements. These are given here as law statements or as singular statements of fact for adult gulls, whether the fish were directly eaten or fed to young. Some records failed to distinguish between fish offal and fish. Scientific names for fish are given if given by the author cited.

'No records located' refers to the literature surveyed.

Group 1.

Laughing Gull: eats fish (obtained by parasitism) (Leck 1967, Hatch 1970). Fish offal taken (Hatch). Catch live individuals of small-size fish (Murphy 1936, Pough 1951, Bent 1963). Eats fish (Oberholser 1938).

Lava Gull: catch live small fish (Nelson 1968). Eats fish offal (Hailman 1963).

Hemprich's Gull: eats offal (Fish offal?) (Fogden 1964). Catch live small fry (Fogden).

Great Black-headed Gull: no records located.

White-eyed Gull: no records located. "In non-breeding season off Eritrea follows fish shoals and whales off-shore" (Smith 1957).

Mediterranean Gull: eats small fish (Geroudet 1965).

Franklin's Gull: fish taken off Peru, follow anchovy shoals off Peru, Silversides (Atherinidae) found in stomachs (Murphy 1936). Possibly catch live small fish (Bent 1963). Fishes in ponds (Robbins et al 1966).

Group 2

Heermann's Gull: eats fish offal, catch live herring off California (Antony 1906). Eats small fish (Pough 1957).

Gray Gull: bones of fish found in stomachs (Murphy

1936).

Group 3

Red-legged Kittiwake: catch live fish (Pough 1957).

Kittiwake: eats fish offal (Boswall 1960). Catch live fish (Geroudet 1965, Fisher 1947, Coward 1952, Bent 1963). Fish found in stomachs on Newfoundland include Caplin and Sand Launce, catch live Caplin and Sand Launce (Ammodytes americanus) off Newfoundland (Threlfall 1968). Catch live Caplin off Labrador (Todd 1963, Bent 1963). Catch live sticklebacks on Pacific Coast (Bent 1963). Ammodytes Lancolatus, A. tobianus, A. marinus, Clupea harengus, C. sprattus, Gadus merlangus, G. morrhua found in stomachs and directly observed fed to young on Farne Islands, England (Pearson 1968). Ammodytes tobianus, Mallotus villosus, Clupea harengus, Gadus morrhua, Boreogadus saida, Gasterosteus oculatus, Zoarces viviparus eaten, catches live pelagic fish - Barents Sea (Belopolskii 1957).

Group 4.

Saunder's Gull: no records located.

Group 5.

Black-billed Gull: freshwater Galaxiad fish (Galaxias attenuatus) fed to young (Beer 1966).

Grey-headed Gull: eats fish offal (Murphy 1936).

Slender-billed Gull: eats fish (Wallace 1964). Catches live fish (Meinertzhagen 1954).

Silver, Hartlaub's and Red-billed Gull: Omnivorous diet (Carrick and Murray 1964). Small fish regurgitated by nestlings (Gurr 1954), live sprats and flounders caught (Blackburn 1962). Catches live small post-larval fish (Falla et al 1966).

Bonaparte's Gull: catch live fish (Gabrielson and Lincoln 1959, Wolf and Gill 1961, Tufts 1961, Bent 1963). Fish in stomachs (Sprunt and Chamberlain 1970).

Black-headed Gull: Catch live fish (Crook 1953, Fisher 1947). Eats fish offal (Geroudet 1965). Eats fish (Spärck 1950).

Andean Gull: no records located.

Group 6.

Little Gull: catch live small fish (Geroudet 1965, Bent 1963, Fisher 1947, Coward 1952).

Ross's Gull: no records located. Probably eats fish (Pough 1951).

Group 7.

Swallow-tailed Gull: regurgitate clupeoid fish (including *Sardinops* sp.) and flying fish (Snow and Snow 1967, Harris 1970). Whole fish fed to young (Hailman 1964).

Sabine's Gull: eat small fishes at breeding grounds (Gabrielson and Lincoln 1959, Bent 1963).

Group 8.

Ivory Gull: remains of fish found in stomachs -- including Boreogadus saida (Bateson and Plowright 1959).

Group 9.

Dolphin Gull: no records located. Omnivorous (Murphy 1936).

Group 10

Herring Gull: eats fish (Geroudet 1965, Sparck 1950, Tinbergen 1953). Catch live fish (Fisher 1947, Roberts 1932, Bent 1963). Eats fish offal (Threfall 1968, Geroudet 1965, Cowan 1968, Sprunt and Chamberlain 1970). Eats dead fish thrown from trawler (mainly gurnets Trigla spp. and flatfish, probably Solea variegata) (Boswall 1960). Caplin (Mallotus villosus) found in stomachs - Newfoundland, also catch live Caplin (Threlfall 1968). Cod, herring eaten by young, cod, herring and Caplin eaten by adults - Barents Sea (Belopo-skii 1957). Fish found in stomachs (see Harris 1965 for review). Eats Sea Lamprey (Southern and Schnell 1964).

Audouin's Gull: catches live small fish (Wallace 1969)

Belcher's Gull: feeds on fish at breeding place (Olrog 1967). Remains of fish including Trachinotus paloma, *Engraulis ringeus* and sciaenids in stomachs - South Chincha Islands, Peru (Murphy 1936).

California Gull: eats dead fish (Bent 1963). Remains of small minnows, carp around breeding colony, catfish eaten (Gabrielson and Jewett 1970). Eats fish (Pough 1951).

Common Gull: eats dead fish, sticklebacks and small fry (Bent 1963). Catch live fish (Fisher 1947). Catch live herring and Caplin-Barents Sea (Belopolskii 1957). Catch live smelt (Rand 1956). Eats fish (Sparck 1950), Gabrielson and Lincoln 1959).

Black-tailed Gull: feeds on sardines, launce and other small fish (Pough 1957). Collect in Ajiro and Usami Bay where sardines and other fish supposedly plentiful (Kuroda 1963).

Ring-billed Gull: eats fish and dead fish (Gabrielson and Jewett 1970, Sprunt and Chamberlain 1970). Catch live fish (Rand 1956).

Southern Black-backed Gull: catch live fish (Murphy 1936). Eats offal (Fish?) (Fordham 1967). Numerous in Copacabana Bay when great run of sardines present (Mitchell 1957).

Lesser Black-backed Gull: dead fish thrown from trawler eaten (Boswall 1960). Catches live eels (*Anguilla anguilla*) in freshwater (Wilson and Greenhalgh 1965). Catch live fish (Geroudet 1965, Fisher 1947). Fish found in stomachs (see Harris 1965). Ammodytes lanceolatus, A. tobianus, A. marinus, Gadus merlengus, G. morrhua, Anguilla vulgaris found in stomachs, Farne Islands, England (Pearson 1968).

Glaucous-winged Gull: dead salmon, live fish caught (Gabrielson and Jewett 1970, Pough 1957, Bent 1963).

Iceland Gull: eats fish (Fisher 1947). Catches fish (Pough 1951).

Glaucous Gull: eats fish (Fisher 1947, Bent 1963, Macpherson 1961). Eats fish offal (Belopolskii 1957, Macpherson 1961).

Great Black-backed Gull: dead fish thrown from trawlers eaten (Boswall 1960). Eats fish (Geroudet 1965, Bent 1963). Fish in stomachs (inc. Salmon taken from gill nets), Tomcod (Microgadus tomcod) Newfoundland (Threlfall 1968). Fish in stomachs (see Harris 1965). Catches live fish (Fisher 1947), Cod, herring eaten by young, cod, herring, caplin eaten by adults, Barents Sea (Belopolskii 1957).

Western Gull: catch live fish (Pough 1957, Antony 1906). Eats dead fish, dead salmon (Gabrielson and Jewett 1970). Catches fish, by parasitism (Pough 1957).

Pacific Gull: eats fish (Tarr 1961).

Slaty-backed Gull: eats dead salmon (Pough 1957, Bent 1963). Follows trawlers off Kushiro (Kuroda 1963). Catches live fish (Yamashina 1961).

Thayer's Gull: no records located. Feeds at garbage dumps (Macpherson 1961).

In summary, in the literature I searched, I located records often involving live caught fish, of fish in the diet, for thirty-five species. For seven species no fish records were located.

APPENDIX 111

DO ADULT GULLS PLUNGE DIVE FOR FISH?

The large food spectrum of gulls is reflected in the large number of ways gulls obtain food, which vary from capturing bats in flight (Cleeves 1969), to foot paddling for shore invertebrates (e.g. Buckley 1966), to parasitizing fish (Cowan 1968). This Appendix is concerned with whether gulls catch fish by a particular method: plunge diving. The definition of plunge diving used in this thesis is simply, "diving suddenly into water direct from the air" and includes cases which involve just partial submersion. Various kinds of plunge diving have been described in the literature, as well as other feeding methods which perhaps fit the above definition (e.g. skimming for or snatching fish, whilst in flight). The various types are described below and listed in Figure 7.

Phillips (1962) made a literature search and found records of plunge diving for fish for various gull species. Both Phillips and Tinbergen (1967) commented on gaps in the literature which prevented a thorough survey. Again my search concentrated on records published since 1960, and the North American literature. These records are given below as law statements whether originally stated as such or not. All the statements below either refer to adult gulls or include adults. 'No records located' refers to the literature I surveyed.

Group 1

Laughing Gull: snatch small fish from surface (Rand 1956, Murphy 1936).

Lava Gull: no records located.

Hemprich's Gull: plunge dives for fish (Fogden 1964).

Great Black-headed Gull: no records located.

White-eyed Gull: no records located.

Mediterranean Gull: no records located.

Franklin's Gull: on 18 July 1970 near Oak Lake, Manitoba I watched an adult nuptial Franklin's Gull "plunge dive". The gull was flying south across a pond at a height of about eight feet and 100 yeards from the nearest bank when it twisted its head back and suddenly fell to the surface, and partially submerged, hitting the surface hard with its breast, its head and foreparts already under water. An instant later the gull seemed to jab quickly with its bill. It then immediately surfaced and flew off to a field with a large object in its bill, probably a fish or an amphibian.

Just prior to the observation several Forster's Terns Sterna forsteri had been plunge diving and catching fish at the pond. On 22 July an adult nuptial Franklin's Gull was seen performing an identical dive and it flew off with a similar prey (Cowan pers. obs.). No records were located in the literature.

Group 2

Heermann's Gull: snatches fish from the surface (Antony 1906).

Gray Gull: no records located.

Group 3

Red-legged Kittiwake: plunge dives for fish (Pough 1957).

Kittiwake: plunge dives for fish (Fisher 1947, Gabrielson and Lincoln 1959). Dives "with more skill than any other gull" for fish (Coward 1952). Often submerges completely when plunge diving (Geroudet 1965, Bent 1963). Plunge dives in a tern-like manner (Harrison 1950, Bent 1963). Plunges partly below the water surface to catch live Caplin and Sand Launce with a sharp downward movement of the head (Threlfall 1968). Snatches fish from surface (Bent 1963). Dives to a depth of 0.5 to 1.0 metres (Belopolskii 1957).

Group 4

Saunder's Gull: no records located.

Group 5

Black-billed Gull: may dive for fish (Beer 1966).

Grey-headed Gull: no records located.

Slender-billed Gull: no records located.

Silver, Hartlaub's and Red-billed Gull: no records located. Blackburn (1962) recorded an interesting feeding sequence which involved 'beating' for fish prey.

Bonaparte's Gull: plunge dives for fish in tern-like fashion (Tufts 1961, Bent 1963, Rand 1956). Dives for fish from two to five feet above the surface, enters the water at a sixty degree angle and completely submerges or manouvers from a height of five to fifteen feet to the surface and doesn't submerge completely (Wolf and Gill 1961).

Black-headed Gull: plunge dives for fish (Fisher 1947, Bent 1963, Crook 1953). Fish obtained by a jump into the air and a plunge dive (e.g. Crook 1953). Plunge dives but rarely completely submerges (Geroudet 1965). An adult has been recorded skimming, just the lower mandible entering the water (Buckley and Hailman 1970).

Andean Gull: no records located.

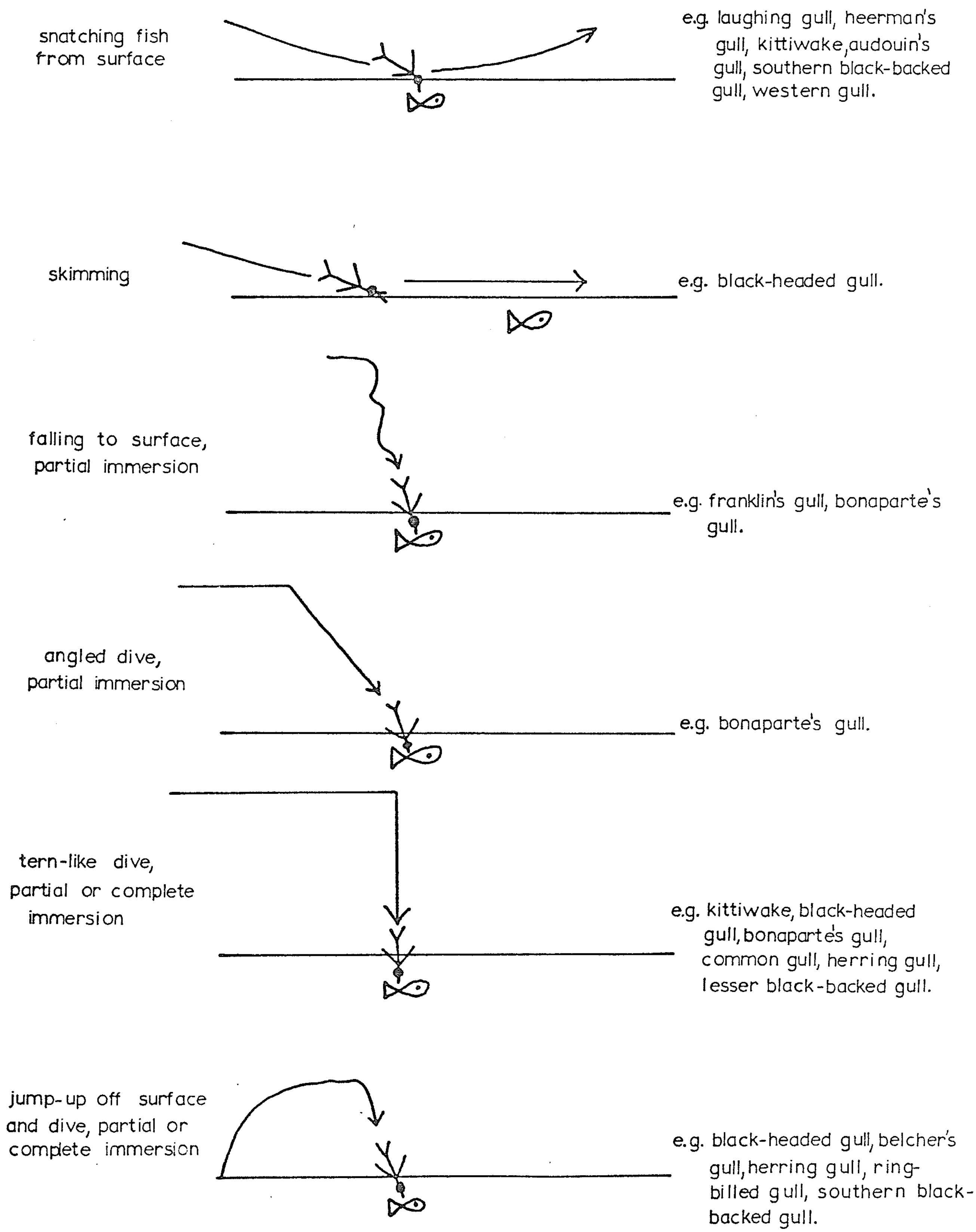


FIG. 7. A CLASSIFICATION OF GULL PLUNGE DIVING TYPES

Group 6

Little Gull: plunge dives for fish (Fisher 1947).

Ross's Gull: no records located.

Group 7

Swallow-tailed Gull: no records located.

Sabine's Gull: plunge dives for fish in tern-like fashion (Brown et al 1967)

Group 8

Ivory Gull: extremely unwilling to settle on water and picks up food as it hovers (Bateson and Plowright 1959).

Group 9

Dolphin Gull: no records located.

Group 10

Herring Gull: plunge dives for fish from various heights, sometimes completely submerging (Fisher 1947, Tinbergen 1953, Bent 1963, Geroudet 1965). Fish caught by plunge diving in tern-like manner (Roberts 1932, Gabrielson and Lincoln 1959, Bent 1963, Bruun and Singer 1970). May fly up a foot or so from swimming and plunge dive, submerging or partially submerging (Tinbergen 1953, Thomas and Thomas 1965).

Audouins Gull: snatch fish from surface (Wallace 1969).

Belcher's Gull: swimming birds take flight with a few flaps and then plunge downwards like terns from a height of one to three metres (Escalante 1966).

California Gull: no records located (I observed two immature California Gulls plunge diving at Chesterman's Beach, Vancouver Island, August 1970 but no prey were seen caught, (Cowan pers. obs.).

Common Gull: plunge dives for fish (Fisher 1947). Catches smelt by diving from the air (Rand 1956). For ten minutes I observed one adult and two near-adults (black tipped tails) plunge diving from two to seven feet into shallow water, and catching fish, at Chesterman's Beach, Vancouver Island, August 1970 (Cowan pers. obs.).

Black-tailed Gull: no records located.

Ring-billed Gull: rises a few feet above water from swimming position and plunge dives for fish, almost completely submerging (Rand 1956).

Southern Black-backed Gull: fish snatched from surface, also plunge dives after a short forward leap from swimming position, nearly completely submerging (Murphy 1936).

Lesser Black-backed Gull: plunge dives for fish (Coward 1952). Plunges into water from height of up to eight feet, without completely submerging, to catch eels

(Wilson and Greenhalgh 1965).

Glaucous-winged Gull: no records located.

Iceland Gull: plunge dives (Tingergen 1953).

Glaucous Gull: plunge dives (Tinbergen 1953).

Great Black-backed Gull: plunge dives for fish (Fisher 1947).

Western Gull: snatches fish from surface (Pough 1957, Antony 1906).

Pacific Gull: no records located.

Slaty-backed Gull: no records located. "Feeds on fish by picking up with bill" (Yamashina 1961).

Thayer's Gull: no records located.

In summary, in the particular literature I searched, I located records of plunge diving for fish for seventeen gull species. For four additional species the records concerned plunge diving but either the prey was not given or the prey was not a fish. No records at all were located for twenty-one species.

APPENDIX lV

CHRONOLOGICAL SURVEY OF STUDIES INVOLVING CRAIK'S HYPOTHESES

Thayer (1909) produced a forerunner to hypotheses (2) and (3): "the more vital service rendered by their sea-bird coloration is doubtless concealment against the sky above, from the eyes of aquatic animals below them". "Aquatic animals" -- as Phillips (1962) pointed out -- may be either predators or prey. Craik's publication (1944a) is fully reviewed in Chapter 1. Pirenne and Crombie (1944) calculated, using relationship (1), that under an overcast sky the difference between the critical ranges of visibility of black objects and white objects, neglecting atmospheric scattering, will be of the order of ten per cent and also that a black bird ten per cent smaller in linear dimensions than a white bird would become invisible at the same range as the latter. Their calculations for cloudless skies are referred to in Chapter 1. Craik (1944b), in reply to Pirenne and Crombie (1944) stated, "Further the conditions of cloudless blue sky, under which the bird will be brighter than the sky are rather rare in temperate climates and there will be other conditions, such as sun shining through breaks in cloud, in which the brightness of the bird may exactly equal that of the background". No climatical references were given. Armstrong (1944) attempted to show that the white colouration of various white-coloured sea-birds could not be advantageous for survival in the manner suggested by Craik (1944a). Armstrong (1944) pointed out that those albatrosses (Diomedidae) and shearwaters (Procellaridae) which are predominantly white,"... do not feed mainly on living fish but on organisms not endowed with sufficiently long sight for the colouration of the bird predator to be of importance". He also mentioned that some white sea-birds feed chiefly at night and, that gulls are primarily scavengers. These objections fall short in that the birds he used as examples, as he himself admitted, do either sometimes feed on fish, sometimes feed by day and sometimes don't scavenge. Tinbergen (1953) summed up the situation well, "in my opinion the criticism is not very convincing and like Craik's contribution should be regarded as speculative".

The only empirical data pertaining to Craik's hypotheses has come from G.C. Phillips (1962) whose doctoral thesis was directed at evaluating and testing the logical derivative of hypotheses 2 and 3. Phillips confirmed this derivative regarding white sea-birds and black sea-birds by experiments in which the responses of fish, stickle backs Gasterosteus aculeatus, in a tank, were observed to flat wooden sea-bird models that were completely white or completely black. In addition, various pelagic fish showed excape responses to the models but some cryptically coloured fish remained motionless in the presence of the models. Craik (1944a) mentioned fish as "seeing", this term being used in his hypotheses. "Seeing" is obviously not an observable. Phillips (1962) substituted "escape-response" for"seeing", an escape response probably being the first gross effect of the gull stimulus. Phillips pointed out that Craik's ideas could apply only to those white undersided sea-birds which plunge-dive for their epipelagic fish prey, as apart from those that swim on the surface and then grasp prey, or submerge for prey. If a bird swam around on the surface prior to chasing prey it would presumably lose the advantage of white underside colouration. Phillips also demonstrated that black objects held in the air and viewed against the sky from an underwater position by a frogman Homo sapiens are more conspicuous than white objects. By a literature search Phillips found records of fish as food and of plunge diving for fish, for many sea-bird species. Phillips speculated that dark nuptial hoods, "... may be expected to render a hooded gull more conspicuous to aquatic prey ... it could provide a handicap to fish-eating gulls during the winter months when food may be less easily obtained".

Tinbergen (1967) discussed Phillips (1962) experiments in relation to the colouration of Black-headed Gulls. After noting that Black-headed Gulls feed mainly on insects and earthworms during the summer, he stated, "...we understand why the Black-headed Gull can afford a dark face...". And later, "we will also have to find positive advantages of the colour patterns ...". Tinbergen (1969 pers. corres.) wrote, "Another puzzling thing in an otherwise pretty clear situation is the fact that the white headed Common Gull undoubtedly eats many insects. Yet if Phillips' findings can be extrapoated we should expect the Common Gull to spend quite a proportion of its feeding activity plunge-diving for fish". Perhaps it should be noted that in fact, both the Black-headed Gull and the Common Gull do eat fish during the breeding season (e.g. Sparck 1950) though a smaller proportion of the total diet than insects. Salomonsen (1968), after a review of Tinbergen's paper (1967), added, "the theory may explain why the young Kittiwake, unlike all other immature marine gulls, quickly adopts a white head and underparts similar to those of the adult: just after feeding it leaves the inshore zone again unlike other immature gulls and starts feeding in the pelagic zone".

APPENDIX V

OTHER POSSIBLE EFFECTS OF THE WHITE COLORATION OF SEA-BIRDS

Conspicuousness: Darwin (1890) stated that the all-white or all-black plumage of some sea-birds renders these birds conspicuous and is adapted for facilitating the "meeting of the sexes". Darwin also considered that these colorations will allow feeding birds to be seen from greater distances and so facilitate the collection of sea-birds around a food source but that this effect is fortuitous. Armstrong (1946) hypothesized that white coloration enhances the collection of sea-birds around food items such as fish shoals but unlike Darwin considered white coloration to be adapted for this possibly altruistic effect and was criticized for this reason by Phillips (1962). Huxley (1934) and Cott (1940) both stated that various sea-birds are consipicuous, including gulls and gannets Sula spp, although empirical contrast values, e.g. of gulls seen against sea, are lacking.

Moynihan (1960) revealed a possible functional advantage of the conspicuousness of sea-birds (as viewed by other sea-birds). He stated, "It will be generally advantageous for any species to be as conspicuous as possible, insofar as conspicuousness will make it easier for individuals to locate and recognize one another. It is also possible that conspicuousness may actually make a bird more "attractive" to its fellows; or even enable it to convey stronger and more effective sign stimuli for all sorts of social reactions". It should be pointed out that conspicuousness may be a function of hue, or movement as well as contrast.

Flashing: the rapid change in contrast of light reflected from the grey or black (hood, mantle) and white surfaces during the movements of a gull or tern prior to plunge-diving produce a "flash" (Feare 1967). Feare considered that flashing facilitates the collection of Larids around a food source but that white coloration is not adapted for feeding enhancement as such but for assisting adult/young attraction after the young leave the nest.

Inconspicuousness; Phillips (1962) commented that the white underparts of a swimming bird (the distinction between underparts and undersides is important here) may render such birds less conspicuous to underwater predators and prey and gave a record of an adult Black-headed Gull being taken from underwater, probably by a pike. Glegg (1945, 1947) gave records of fish taking various sea-birds including the Herring Gull and other gulls and what was probably a fish, taking a Grey-headed Gull. Pitman (1962 a,b) presented records of fish and Snapping Turtles *Chelydra serpentina* taking water-birds, but no gulls were taken.

Reduction in aggression: perhaps the white coloration or the pied plumage pattern is non-aggressive and functions to reduce intra- and inter- specific hostility (in the non-breeding season for hooded gulls) as in the more general hypothesis put forward by Hamilton and Barth (1962). That gulls may be aggressive (as apart from an increased or lowered rate of aggression) in the non-breeding season is reflected in the observations of, for example, defense of winter food supplies (Ingolfsson 1969, Drury and Smith 1968).

APPENDIX V1

The environmental variables recorded on each occasion of photography (Chapter 2) were, after date (A) and time of day (B):

(C) Cloud thickness of cloud obscuring sun: visually reported as either no cloud (0), silky (1), "thicker" (2) (not silky, no vertical development), some vertical development (3) and much vertical development (4). These are observable properties of various cloud types (e.g. Pettersen 1958) and are associated with increasing thickness of cloud.

(D) cloud colour of cloud obscuring sun: recorded as no cloud (0), white (1), light grey (2), dark grey (3), black (4).

(E) position of the sun: the horizontal bearing was estimated in degrees with a compass. The position was sometimes unobtainable owing to obscuring cloud (0).

(F) wind direction: a thumb estimate given as one of the eight major compass bearings or as no wind (0).

(G) precipitation: no precipitation (1), precipitation (2).

(H) cloud thickness of cloud behind gull and in the photograph: as (C).

(I) cloud colour of cloud behind gull and in the photograph: as (D).

(J) visibility: not poor (1) (could see to pre-selected point), poor (2) (could not see to pre-selected point).

(K) wave height: recorded as millpond (1), ripples (2), waves but no white caps (3), waves with white caps (4).

(L) cloud cover: visually estimated and expressed on the standard scale ranging from 0 to 8. (Petterssen 1958, World Meteorological Association 1956).

The actual conditions recorded are listed below. For cloudless skies, where the corresponding experiment demonstrated that the Franklin's Gull model had a smaller contrast than the white undersided model (Chapter 3), an asterisk is given. Those occasions (10), where the experiments gave statistically inconclusive results are given two asterisks.

<u>Cloud cover - 0</u>

A	B	C	D	E	F	G	H	I	J	K
15.7.70	6.21	0	0	45	N.W.	1	0	0	1	2
" " "	6.45	0	0	50	N.W.	1	0	0	1	2
" " "	10.52*	0	0	95	N.W.	1	0	0	1	2
" " "	11.08*	0	0	100	N.W.	1	0	0	1	2
" " "	12.35*	0	0	120	W.	1	0	0	1	2

cont'd

<u>Cloud cover - 0</u> cont'd

A	B	C	D	E	F	G	H	I	J	K
15.7.70	20.30	0	0	300	N.W.	1	0	0	1	2
" " "	20.50	0	0	305	N.W.	1	0	0	1	2
" " "	21.24	0	0	310	N.W.	1	0	0	1	2
16.7.70	7.52**	0	0	70	N.W.	1	0	0	1	2
" " "	8.32*	0	0	80	N.W.	1	0	0	1	2
" " "	8.34*	0	0	80	N.W.	1	0	0	1	2
" " "	8.54*	0	0	90	N.W.	1	0	0	1	2
" " "	10.26*	0	0	95	N.W.	1	0	0	1	2
" " "	10.33*	0	0	100	N.W.	1	0	0	1	2
" " "	10.35*	0	0	100	N.W.	1	0	0	1	2
" " "	10.38*	0	0	100	N.W.	1	0	0	1	2
" " "	10.54*	0	0	105	N.W.	1	0	0	1	2
" " "	11.07*	0	0	110	N.W.	1	0	0	1	2
" " "	19.08	0	0	285	N.W.	1	0	0	1	2
" " "	19.45	0	0	290	N.W.	1	0	0	1	2

16.7.70	20.39	0	0	295	N.W.	1	0	0	1	2
" " "	21.31	0	0	300	N.W.	1	0	0	1	2
" " "	21.36	0	0	300	N.W.	1	0	0	1	2
19.7.70	20.57	0	0	290	N.W.	1	0	0	1	2
27.7.70	6.43**	0	0	40	N.	1	0	0	1	2
" " "	10.08*	0	0	85	N.E.	1	0	0	1	2
" " "	10.48*	0	0	95	N.E.	1	0	0	1	2
" " "	10.49*	0	0	95	N.E.	1	0	0	1	2
" " "	12.16*	0	0	150	N.E.	1	0	0	1	2
" " "	12.58*	0	0	155	N.E.	1	0	0	1	2
31.7.70	7.50**	0	0	80	N.W.	1	0	0	1	4
" " "	8.22**	0	0	80	N.W.	1	0	0	1	4
1.8.70	10.27*	0	0	95	W.	1	0	0	1	3
" " "	11.09*	0	0	105	W.	1	0	0	1	3
2.8.70	10.24**	0	0	95	N.W.	1	0	0	1	4
" " "	19.42	0	0	270	N.W.	1	0	0	1	4
" " "	20.17	0	0	280	N.W.	1	0	0	1	3
" " "	20.58	0	0	285	N.W.	1	0	0	1	3
3.8.70	6.54**	0	0	55	S.W.	1	0	0	1	2
" " "	6.56	0	0	55	S.W.	1	0	0	1	2
4.8.70	8.09**	0	0	80	S.W.	1	0	0	1	2
" " "	8.18**	0	0	80	S.W.	1	0	0	1	2
" " "	11.12*	0	0	110	W.	1	0	0	1	2
" " "	11.56*	0	0	115	W.	1	0	0	1	2
" " "	12.19*	0	0	130	W.	1	0	0	1	2
" " "	13.07	0	0	155	W.	1	0	0	1	2
" " "	19.37	0	0	275	S.W.	1	0	0	1	2

4.8.70	20.04	0	0	280	S.W.	1	0	0	1	2
" " "	20.24	0	0	285	S.W.	1	0	0	1	2
5.8.70	8.46*	0	0	80	S.W.	1	0	0	1	2
" " "	9.40*	0	0	90	O.	1	0	0	1	2
" " "	20.29	0	0	285	N.	1	0	0	1	2
" " "	21.07	0	0	290	N.	1	0	0	1	2
7.8.70	17.59	0	0	255	S.E.	1	0	0	1	2
8.8.70	8.10**	0	0	80	S.	1	0	0	1	2
" " "	8.19*	0	0	80	S.	1	0	0	1	2
" " "	8.31*	0	0	85	S.	1	0	0	1	2
" " "	9.52*	0	0	95	S.	1	0	0	1	2
" " "	19.53	0	0	280	E.	1	0	0	1	2
9.8.70	12.05*	0	0	130	W.	1	0	0	1	4
" " "	12.10*	0	0	130	W.	1	0	0	1	4
" " "	12.26*	0	0	135	W.	1	0	0	1	4
" " "	13.47**	0	0	170	W.	1	0	0	1	3
" " "	15.05	0	0	210	W.	1	0	0	1	3
" " "	15.23	0	0	210	W.	1	0	0	1	3
" " "	15.45	0	0	220	W.	1	0	0	1	3
" " "	16.26	0	0	230	W.	1	0	0	1	3
" " "	17.02	0	0	245	W.	1	0	0	1	3
10.8.70	6.47	0	0	60	S.	1	0	0	1	2
" " "	7.15	0	0	80	S.	1	0	0	1	2
" " "	7.16	0	0	80	S.	1	0	0	1	2
" " "	9.10*	0	0	100	S.W.	1	0	0	1	2
" " "	10.09*	0	0	110	S.W.	1	0	0	1	2

Cloud cover - 1

15.7.70	7.42	0	0	70	N.W.	1	0	0	1	2
" " "	12.55	0	0	130	W.	1	0	0	1	2
" " "	13.31	0	0	170	W.	1	0	0	1	2
" " "	13.53	0	0	180	W.	1	0	0	1	2
" " "	17.56	0	0	280	W.	1	0	0	1	2
" " "	18.40	0	0	285	W.	1	0	0	1	2
" " "	18.51	0	0	285	W.	1	0	0	1	2
16.7.70	13.05	0	0	150	N.W.	1	0	0	1	2
" " "	15.03	0	0	210	N.W.	1	0	0	1	2
" " "	15.33	0	0	220	N.W.	1	0	0	1	2
" " "	16.04	0	0	230	N.W.	1	0	0	1	2
" " "	16.27	0	0	250	N.W.	1	0	0	1	2
19.7.70	7.43	0	0	60	N.W.	1	0	0	1	3
" " "	9.46	0	0	70	N.W.	1	0	0	1	2
" " "	10.32	0	0	75	N.W.	1	0	0	1	2
" " "	10.45	0	0	80	N.W.	1	0	0	1	2
" " "	10.49	0	0	80	N.W.	1	0	0	1	2
20.7.70	17.30	0	0	250	S.W.	1	0	0	1	2
" " "	18.09	0	0	255	S.W.	1	0	0	1	2
1.8.70	13.40	0	0	170	N.W.	1	0	0	1	4
" " "	13.41	0	0	170	N.W.	1	0	0	1	4
3.8.70	10.16	0	0	95	S.W.	1	0	0	1	2
" " "	10.46	0	0	100	S.	1	0	0	1	2
4.8.70	13.37	0	0	165	W.	1	0	0	1	2
5.8.70	11.14	0	0	105	O.	1	0	0	1	1
" " "	11.26	0	0	105	O.	1	0	0	1	1

5.8.70	11.53	0	0	125	O.	1	0	0	1	1
" " "	18.59	0	0	275	N.	1	0	0	1	2
7.8.70	16.37	0	0	230	S.E.	1	3	1	1	2
8.8.70	11.53	0	0	135	S.E.	1	0	0	1	2
" " "	11.56	0	0	135	S.E.	1	0	0	1	2
" " "	16.59	0	0	240	E.	1	0	0	1	2
" " "	17.16	0	0	245	E.	1	0	0	1	2
" " "	20.56	2	3	0	E.	1	0	0	1	2
9.8.70	7.13	0	0	70	W.	1	0	0	1	3
" " "	9.05	0	0	90	W.	1	0	0	1	3
" " "	9.45	0	0	95	W.	1	0	0	1	3
" " "	9.46	0	0	95	W.	1	0	0	1	3
" " "	18.14	0	0	265	W.	1	0	0	1	2
10.8.70	15.57	0	0	230	S.W.	1	0	0	1	2
" " "	16.37	0	0	240	S.W.	1	0	0	1	2
" " "	16.46	0	0	240	S.W.	1	0	0	1	2
<u>Cloud cover - 2</u>										
13.7.70	6.01	0	0	45	O.	1	0	0	1	2
" " "	6.53	0	0	45	N.E.	1	0	0	1	2
14.7.70	20.41	0	0	290	N.W.	1	0	0	1	2
15.7.70	8.22	0	0	85	N.W.	1	2	1	1	2
19.7.70	10.59	0	0	80	N.W.	1	0	0	1	2
" " "	18.55	0	0	270	N.W.	1	2	1	1	2
20.7.70	7.38	0	0	60	S.W.	1	2	1	1	2
" " "	8.40	0	0	70	S.W.	1	2	1	1	2
" " "	11.34	0	0	100	S.W.	1	0	0	1	2
" " "	11.58	0	0	100	S.W.	1	0	0	1	2

21.7.70	7.52	0	0	65	S.W.	1	0	0	1	2
" " "	8.01	0	0	70	S.W.	1	0	0	1	2
22.7.70	20.16	0	0	290	S.E.	1	0	0	1	2
29.7.70	10.07	0	0	95	0.	1	0	0	1	1
30.7.70	13.33	0	0	175	S.W.	1	0	0	1	2
31.7.70	17.33	0	0	255	N.W.	1	0	0	1	3
" " "	17.42	0	0	255	N.W.	1	0	0	1	3
" " "	18.52	0	0	275	N.W.	1	0	0	1	3
3.8.70	11.33	0	0	110	S.	1	0	0	1	2
6.8.70	11.14	0	0	115	N.E.	1	0	0	1	2
" " "	11.32	0	0	120	N.E.	1	0	0	1	2
" " "	12.24	1	1	135	0.	1	0	0	1	1
" " "	12.34	1	1	135	0.	1	0	0	1	1
" " "	12.42	1	1	140	N.E.	1	0	0	1	2
" " "	13.00	0	0	145	N.E.	1	0	0	1	2
8.8.70	14.36	0	0	180	E.	1	0	0	1	2
" " "	14.37	0	0	180	E.	1	0	0	1	2
9.8.70	6.55	2	1	65	W.	1	0	0	1	2
" " "	19.59	0	0	285	W.	1	0	0	1	2
10.8.70	17.18	0	0	245	S.W.	1	0	0	1	2
11.8.70	8.08	0	0	80	N.W.	1	0	0	1	2
" " "	8.11	0	0	80	N.W.	1	0	0	1	2
" " "	9.09	0	0	95	S.W.	1	2	1	1	2
" " "	9.15	0	0	95	S.W.	1	2	1	1	2
" " "	10.53	0	0	110	S.W.	1	2	1	1	2
" " "	11.05	0	0	110	S.W.	1	2	1	1	2

Cloud cover - 3

13.7.70	14.09	2	1	0	N.E.	1	1	1	1	2

17.7.70	14.25	0	0	210	N.W.	1	0	0	1	2
" " "	14.38	0	0	210	N.W.	1	0	0	1	2
19.7.70	11.38	0	0	100	N.W.	1	0	0	1	2
20.7.70	16.20	0	0	240	S.W.	1	0	0	1	2
" " "	16.21	0	0	240	S.W.	1	0	0	1	2
" " "	16.28	0	0	240	S.W.	1	0	0	1	2
" " "	16.32	0	0	240	S.W.	1	0	0	1	2
" " "	17.02	0	0	245	S.W.	1	2	1	1	2
21.7.70	8.38	0	0	75	S.	1	0	0	1	2
" " "	14.22	0	0	170	S.	1	1	1	1	2
" " "	16.18	0	0	230	S.	1	0	0	1	2
22.7.70	14.41	0	0	200	N.W.	1	0	0	1	2
" " "	15.48	0	0	220	S.E.	1	0	0	1	2
" " "	15.54	0	0	220	S.E.	1	0	0	1	2
25.7.70	6.52	2	2	45	S.E.	1	0	0	1	2
26.7.70	15.24	0	0	205	N.W.	1	3	2	1	4
" " "	15.50	0	0	210	N.W.	1	3	2	1	4
27.7.70	20.32	2	3	0	S.E.	1	1	1	1	2
" " "	20.53	2	3	0	O.	1	1	2	1	1
29.7.70	14.00	0	0	185	S.	1	0	0	1	2
30.7.70	14.02	0	0	180	S.W.	1	0	0	1	2
3.8.70	11.54	3	1	120	S.	1	0	0	1	2
5.8.70	16.00	0	0	215	N.W.	1	0	0	1	2
" " "	16.12	0	0	215	N.W.	1	0	0	1	2
" " "	16.26	1	1	220	N.W.	1	1	1	1	2
" " "	16.52	0	0	230	N.W.	1	0	0	1	2
" " "	16.55	0	0	230	N.W.	1	0	0	1	2

6.8.70	8.49	1	1	85	N.	1	1	1	1	2
8.8.70	15.37	3	2	210	E.	1	3	1	1	2
9.8.70	6.18	2	2	0	W.	1	0	0	1	2
" " "	6.21	2	2	0	W.	1	0	0	1	2
11.8.70	8.28	0	0	90	N.W.	1	0	0	1	2
Cloud cover - 4										
19.7.70	17.50	0	0	245	N.W.	1	0	0	1	2
20.7.70	12.34	0	0	110	S.W.	1	3	1	1	2
" " "	12.38	0	0	110	S.W.	1	3	1	1	2
21.7.70	12.37	0	0	120	S.	1	1	1	1	2
" " "	12.45	0	0	120	S.	1	1	1	1	2
25.7.70	8.26	0	0	75	S.E.	1	2	1	1	2
26.7.70	11.37	2	1	110	N.W.	1	3	1	1	2
6.8.70	10.12	1	1	100	O.	1	1	1	1	1
7.8.70	15.14	0	0	200	S.	1	3	1	1	2
" " "	15.34	0	0	210	S.E.	1	3	1	1	2
11.8.70	19.54	1	1	275	S.E.	1	0	0	1	2
Cloud cover - 5										
15.7.70	15.28	1	1	220	S.W.	1	1	1	1	3
19.7.70	16.19	0	0	230	N.W.	1	0	0	1	2
" " "	16.27	0	0	230	N.W.	1	0	0	1	2
25.7.70	9.52	2	2	85	S.E.	1	0	0	1	2
" " "	10.03	0	0	90	S.E.	1	2	1	1	2
" " "	10.15	0	0	90	S.E.	1	1	1	1	2
26.7.70	7.38	1	1	60	N.W.	1	1	1	1	2
" " "	12.38	2	1	120	N.W.	1	1	1	1	2
29.7.70	16.58	0	0	235	N.W.	1	0	0	1	2
" " "	17.10	0	0	235	N.W.	1	0	0	1	2

7.8.70	14.00	0	0	185	O.	1	2	1	1	1
" " "	14.49	0	0	195	S.	1	2	1	1	1
9.8.70	20.41	2	2	285	W.	1	0	0	1	2
" " "	20.43	2	2	285	W.	1	0	0	1	2
11.8.70	12.49	4	3	0	S.W.	1	4	3	1	2
" " "	14.37	3	2	205	N.	1	3	1	1	2
" " "	15.04	0	0	210	N.	1	0	0	1	2
<u>Cloud cover - 6</u>										
13.7.70	12.16	2	2	135	N.E.	1	1	2	1	2
14.7.70	16.53	2	2	270	N.E.	1	2	2	1	3
17.7.70	9.27	0	0	80	N.	1	2	2	1	2
" " "	10.12	2	3	85	N.E.	1	2	2	1	2
" " "	16.05	2	2	230	N.W.	1	2	2	1	2
19.7.70	13.08	2	2	125	N.W.	1	2	1	1	2
20.7.70	14.18	0	0	120	S.W.	1	3	1	1	2
21.7.70	9.52	1	1	90	S.	1	1	1	1	2
21.7.70	10.07	1	1	90	S.	1	1	1	1	2
" " "	11.03	2	1	110	S.	1	2	1	1	2
22.7.70	17.32	1	1	245	S.E.	1	1	1	1	2
" " "	17.46	1	1	250	S.E.	1	1	1	1	2
" " "	17.47	1	1	250	S.E.	1	1	1	1	2
" " "	17.48	1	1	250	S.E.	1	1	1	1	2
25.7.70	12.50	2	1	135	S.	1	2	1	1	2
29.7.70	15.54	4	1	0	N.W.	1	4	2	1	2
31.7.70	16.11	3	2	0	N.W.	1	3	2	1	4
3.8.70	14.41	1	1	185	S.W.	1	1	1	1	2
" " "	15.19	2	1	195	S.W.	1	2	1	1	2

3.8.70	20.44	2	1	0	S.W.	1	2	3	1	2
7.8.70	8.33	0	0	85	S.	1	2	2	1	2
Cloud cover - 7										
13.7.70	8.08	2	2	75	N.E.	1	2	2	1	2
" " "	9.20	3	3	0	N.E.	1	2	3	1	2
" " "	11.46	1	2	130	N.E.	1	2	2	1	2
" " "	17.18	2	2	230	N.E.	1	2	2	1	2
" " "	21.07	1	2	300	N.E.	1	2	2	1	2
14.7.70	15.41	2	2	0	N.E.	1	2	2	1	3
17.7.70	8.18	2	2	60	N.	1	2	2	1	2
" " "	8.25	2	2	65	N.	1	2	2	1	2
18.7.70	13.00	2	3	0	N.W.	1	2	2	1	3
21.7.70	19.55	2	2	290	S.	1	2	2	1	2
22.7.70	6.07	1	2	35	S.W.	1	2	3	1	2
" " "	6.15	2	3	40	S.W.	1	2	3	1	2
25.7.70	17.31	2	1	250	S.E.	1	2	1	1	2
" " "	17.43	2	1	250	S.E.	1	2	1	1	2
" " "	18.02	2	2	255	S.E.	1	2	2	1	2
28.7.70	7.23	2	3	0	S.E.	1	2	3	1	2
" " "	7.46	2	2	65	S.E.	1	2	3	1	2
" " "	13.13	2	2	0	N.E.	1	2	2	1	2
" " "	13.26	2	2	0	N.E.	2	2	2	1	2
30.7.70	18.11	2	2	0	N.W.	1	2	2	1	2
" " "	20.14	1	1	285	N.W.	1	2	2	1	2
3.8.70	16.29	2	2	225	S.	1	2	2	1	2
" " "	16.48	2	2	230	S.	1	2	2	1	2
" " "	17.00	2	2	235	S.	1	2	2	1	2

3.8.70	17.01	2	2	235	S.	1	2	2	1	2
" " "	18.25	1	1	270	O.	1	2	2	1	1
6.8.70	17.09	1	1	245	N.E.	1	2	1	1	2
7.8.70	6.56	2	3	0	S.W.	1	2	2	1	2
" " "	7.43	2	3	75	S.	1	2	2	1	2
" " "	10.00	2	2	0	O.	1	2	2	1	2
" " "	10.36	2	2	0	O.	1	2	2	1	2
" " "	10.38	2	2	0	O.	1	2	2	1	2
Cloud cover - 8										
17.7.70	19.28	2	2	0	N.W.	1	2	2	1	2
" " "	20.35	2	3	0	N.W.	1	2	3	1	3
" " "	20.37	2	3	0	N.W.	1	2	3	1	3
18.7.70	14.34	2	3	0	N.W.	1	2	3	1	3
" " "	14.47	2	3	0	N.W.	1	2	3	1	3
" " "	15.11	2	3	0	N.W.	1	2	3	1	3
" " "	15.29	2	3	0	N.W.	1	2	3	1	3
" " "	20.28	2	3	0	N.W.	1	2	3	1	3
18.7.70	20.48	2	3	0	N.W.	1	2	3	1	3
22.7.70	9.42	2	2	0	S.W.	1	2	2	1	2
25.7.70	20.28	2	3	0	S.E.	1	2	3	1	2
28.7.70	10.24	2	3	0	S.E.	1	2	3	1	2
" " "	11.11	2	2	110	S.E.	2	2	3	1	2
6.8.70	19.37	2	2	275	O.	1	2	2	1	2
" " "	19.39	2	2	275	O.	1	2	2	1	2
" " "	20.27	2	2	0	N.E.	1	2	2	1	2
" " "	21.45	2	2	0	O.	1	2	2	1	2

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