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A SUMMARY OF ENVIRONMENTAL AND TUNA FISHING INFORMATION OF THE U.S. TRUST TERRITORY OF THE PACIFIC ISLANDS

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ABSTRACT

This paper provides a historical background and description of the islands within Micronesia and reviews much of the published information available on the climate, oceanographic climate, planktonic surveys, and tuna fisheries development in that region. Pre-World War II skipjack tuna, Katsuwonus pelamis, landings by the Japanese reached 33,000 metric tons (MT) in 1937. Attention is focused on the postwar development in the fisheries for skipjack tuna in Palau and by the Japanese southern water pole-and-line fleet, which landed 51,000 MT in 1971. The potential for further development within Micronesia is also discussed.

INTRODUCTION

The United States Trust Territory of the Pacific Islands and Guam are situated within reach of some of the most productive tuna fishing grounds in the world, e.g., off the eastern and southern coasts of Japan and around Papua New Guinea. The Trust Territory and Guam, however, are in a paradoxical situation; although they are constantly striving for ways to broaden their economic bases, they are not in a position to take full advantage of the fishery resources within their waters.

In sharp contrast is the tuna fishery in the eastern Pacific, where fishing pressure on yellowfin tuna, Thunnus albacares, has to be relieved. The fishermen in the eastern Pacific, therefore, must supplement their yellowfin tuna catches by fishing on tuna stocks capable of sustaining greater fishing pressure. Among the possibilities is the development of fisheries for skipjack tuna, Katsuwonus pelamis, yellowfin, and bluefin tunas, T. thynnus in the central and western Pacific Ocean.

For the ready reference of American tuna fishermen, it would be most useful to bring together a review of much of the published information available on the environment and tuna fishing in the Trust Territory region. Throughout this report, the words "Micronesia" and "Micronesian" are used to refer to both the Trust Territory and Guam and all the peoples within their boundaries.

HISTORICAL BACKGROUND

Micronesia has a varied and interesting history. In brief, the first contact with the islands of Micronesia by Europeans occurred during the 1500's, first by Magellan and then other occasional explorers (Nathan Associates, 1966). Although most of the islands had no additional contact in the centuries following, the Spanish continued to exert their influence in the Marianas. With the expansion of the copra trade, many islands within the Carolines also received attention and there was strong competition among traders of different nations from about 1875 to 1900.

German, Portuguese, British, and American vessels entered the competition to buy copra in Micronesia (Nathan Associates, 1966). In the last decade of the 19th century, however, the German traders achieved a position of dominance throughout the Carolines and Marshalls. They entered into an agreement with the high chiefs which gave Germany a protectorate over all the Marshalls. In 1899, after the Spanish-American War, the Germans bought from Spanish control all the Micronesian islands except Guam, which became a United States possession.

With the German administration came economic growth and political stability to Micronesia (Nathan Associates, 1966). Copra production increased and western goods became available to the Micronesians. The Germans also had some success in formalizing land ownership. Tools, new food products, and clothing were introduced and the mission schools that were established taught the Micronesians about the outside world.

Japan entered the copra trade on a small scale in 1889 but by 1907 was a significant influence within Micronesia (Nathan Associates, 1966). Entering World War I against Germany, Japan immediately proceeded to occupy the islands of Micronesia; in 1920, she obtained a mandate over these islands from the League of Nations.

In the 1920's and 1930's, Japan fully exploited the resources in Micronesia (Nathan Associates, 1966). Agricultural, fisheries, manufacturing, and processing industries were established with Japanese capital and management. Labor was imported from mainland Japan, Okinawa, and Korea. But with the intensification of war with China in the 1930's, Japan started a military buildup in Micronesia in preparation for World War II. Japanese and Okinawan immigrants outnumbered the Micronesians on larger islands where most of the military activities were concentrated. The Micronesians, however, participated at the fringes of these activities by taking advantage of the opportunity to sell various commodities to the immigrant population.

Despite the self-interest of the Japanese administration, the Micronesians reaped considerable benefits (Nathan Associates, 1966). Under the Japanese, the money economy replaced the traditional barter and gift exchanges and most of the people on the major islands became accustomed to a variety of manufactured and processed goods and many types of services. Schools taught the Japanese language to both Micronesian and Japanese immigrant children.

In 1944, the U.S. Armed Forces began occupying the islands of Micronesia (Nathan Associates, 1966). As a result of the intense fighting, villages on those islands where the Japanese established military bases were completely demolished. Not only the villages and business establishments but also most of the infrastructure--roads and causeways, electric and water systems, harbor and other waterfront facilities--were destroyed.

The U.S. Commercial Company, a subsidiary of the Reconstruction Finance Corporation, was assigned the task of supplying trade goods and reviving production and trade of copra, handicrafts, and other local goods after the American occupation (Nathan Associates, 1966). In 1947, the former mandated islands were established as a trusteeship under the United Nations (U.N.) Trusteeship Council and the U.S. was named trustee. The U.S. Navy Department established a civilian administration to manage the trusteeship.

The Trust Territory Government was established in 1951 and became a part of the Office of Territories of the U.S. Department of the Interior (Nathan Associates, 1966). Most of the Marianas, however, were transferred back and kept under U.S. Navy administration until 1962, at which time all the islands of the Marianas (excluding Guam) returned to the jurisdiction of the Trust Territory Government. Saipan and Tinian in the Marianas were virtually sealed off from the rest of the world from 1953 to 1962 because they were top security areas for the U.S. Navy (Tudor, 1972).

Because the limited financial resource of the Trust Territory Government was spread very thin, postwar recovery was very slow (Nathan Associates, 1966). Some progress was made in expanding the copra trade and agricultural production. In general, there was a settling down and adjustment of the Micronesians to their new economic and political environment under the Americans. An increased budget in 1962 brought a new buildup of schools, hospitals, and other facilities. Incomes increased and public services, particularly health and education, were rapidly expanded. Based on increased money flow, more Micronesians were employed by the government and there were more opportunities for creation and expansion of small businesses.

Divided into six districts--Palau, Yap, Truk, Ponape, Marshall Islands, and Mariana Islands--the Trust Territory is administered by the U.S. Department of the Interior through a High Commissioner who is headquartered at Saipan (Tudor, 1972). Each district, in turn, has a District Administrator, who is the immediate representative of the High Commissioner and who acts as the executive of the district government, administering the laws passed by his district's legislature.

DESCRIPTION OF THE AREA

The 2,141 individual islands within the Trust Territory, scattered in clusters over an expanse of ocean of some 3 million sq mi (7.8 million sq km) or about the size of the continental United States, make up 97 distinct island groups in three archipelagoes--the Mariana, Marshall, and Caroline Islands (Trust Territory of the Pacific Islands, 1956; Nathan Associates, 1966). With a combined land area of 706 sq mi (1,828 sq km), the territory extends about 1,140 mi (2,112 km) from Farallon de Pajaros at the upper tip of the Mariana chain (lat. 20°32'N) to Kapingamarangi (lat. 1°04'N) in the Carolines (Figure 1) (Trust Territory of the Pacific Islands, 1956). East to west, it spreads over roughly 2,400 mi (4,450 km) from Mili atoll in the Marshalls to Tobi in the Western Carolines. Beyond the territory's boundaries are Malaysia to the west, Melanesia ("black islands") to the south, and Polynesia ("many islands") to the east.

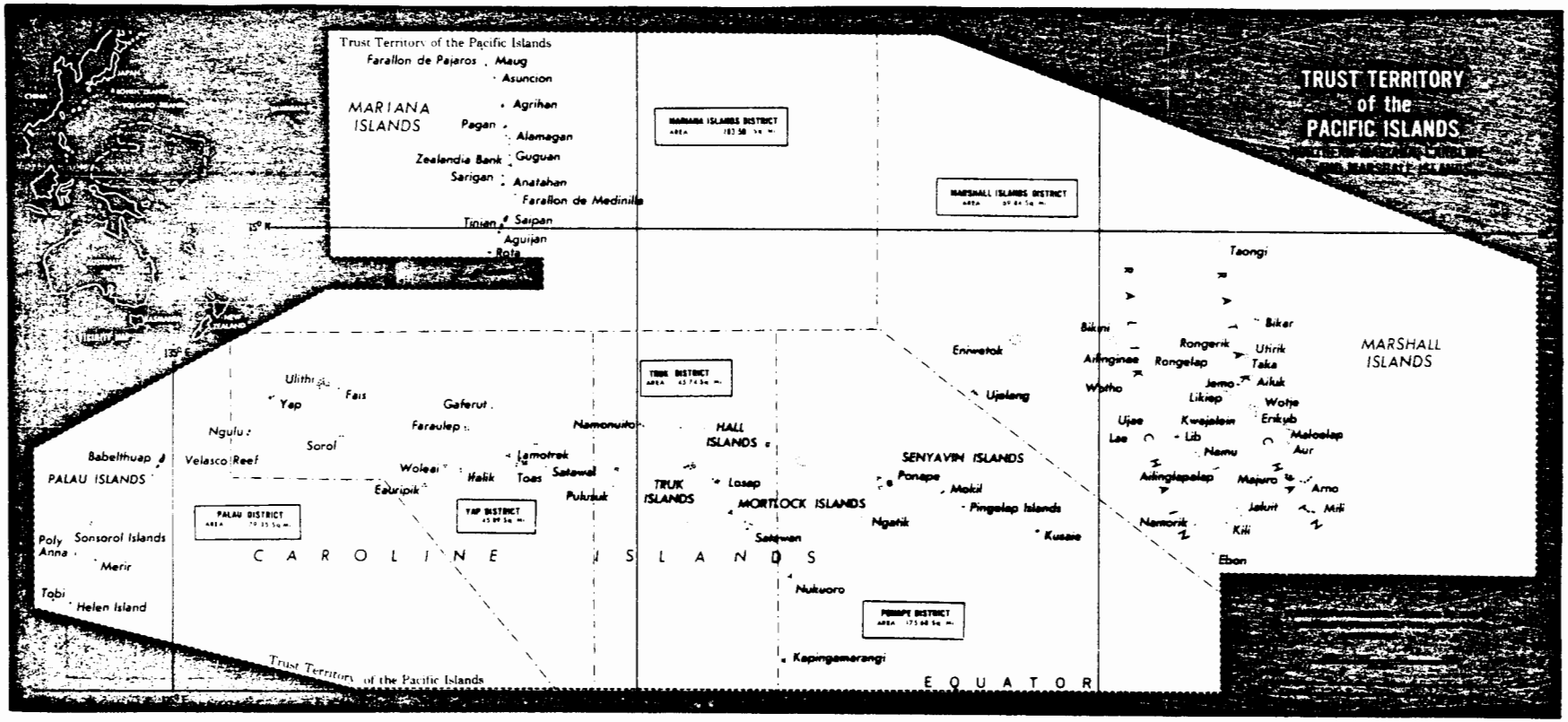

Figure 1.--The Mariana, Caroline, and Marshall Islands (U.S. Department of State, 1972).

Early explorers called the islands within the territory "Micronesia" meaning tiny isles (Trust Territory of the Pacific Islands, 1956). But the classifications "Trust Territory" and "Micronesia" are not entirely synonymous. There are two atolls--Nukuoro and Kapingamarangi--which lie farthest south near the equator that are considered Polynesian rather than Micronesian. The distinction is based not only on geographic location but also on ethnological factors.

Guam, ceded by Spain to the United States in 1898, is part of Micronesia but not of the Trust Territory (Trust Territory of the Pacific Islands, 1956). It has its own civil administration with a governor and elected congress.

The islands of Micronesia vary in size from small strips, some of less than an acre to large, high islands with up to 100 sq mi (260 sq km) or more of land area (Nathan Associates, 1966). Among the larger ones are Babelthuap (153 sq mi or 396 sq km) in the Palau group and Ponape (120 sq mi or 334 sq km) (Trust Territory of the Pacific Islands, 1956). The elevation of the islands varies considerably; low-lying coral atolls may be only 6 ft (2 m) above sea level whereas others such as Agrihan Island in the Marianas rise to 3,166 ft (965 m). Less than 20 of the islands are considered large enough to support sizable population concentrations (Nathan Associates, 1966). Only about 100 are large enough to support any permanent population.

MARIANA ISLANDS DISTRICT

The Mariana Islands District, shown in Figure 2, consists of 13 islands and one group of 3 islands called Maug (Tudor, 1972). The islands stretch north from Guam for about 350 mi (648 km). Guam, however, has been a U.S. territory since 1898 and is not included in the Trust Territory. Among the islands in this group, only Rota, Tinian, Saipan, Anatahan, Sarigan, Alamagan, Pagan, and Agrihan are inhabited.

The total land area in the group is about 184 sq mi (477 sq km). More than half of this area, however, comprises three principal islands--Saipan (47 sq mi or 122 sq km), Tinian (39 sq mi or 101 sq km), and Rota (33 sq mi or 85 sq km) (Trust Territory of the Pacific Islands, 1965). Unlike the Carolines to the south, which are predominantly coral islands, the Marianas are all high volcanic islands (Tudor, 1972). Of nine small volcanic islands in the northern portion of the chain, Pagan, Asuncion, and Farallon de Pajaros are still active volcanoes (Bowers, 1951). The southern islands are larger, coral-capped, terraced, and fringed with coral reefs.

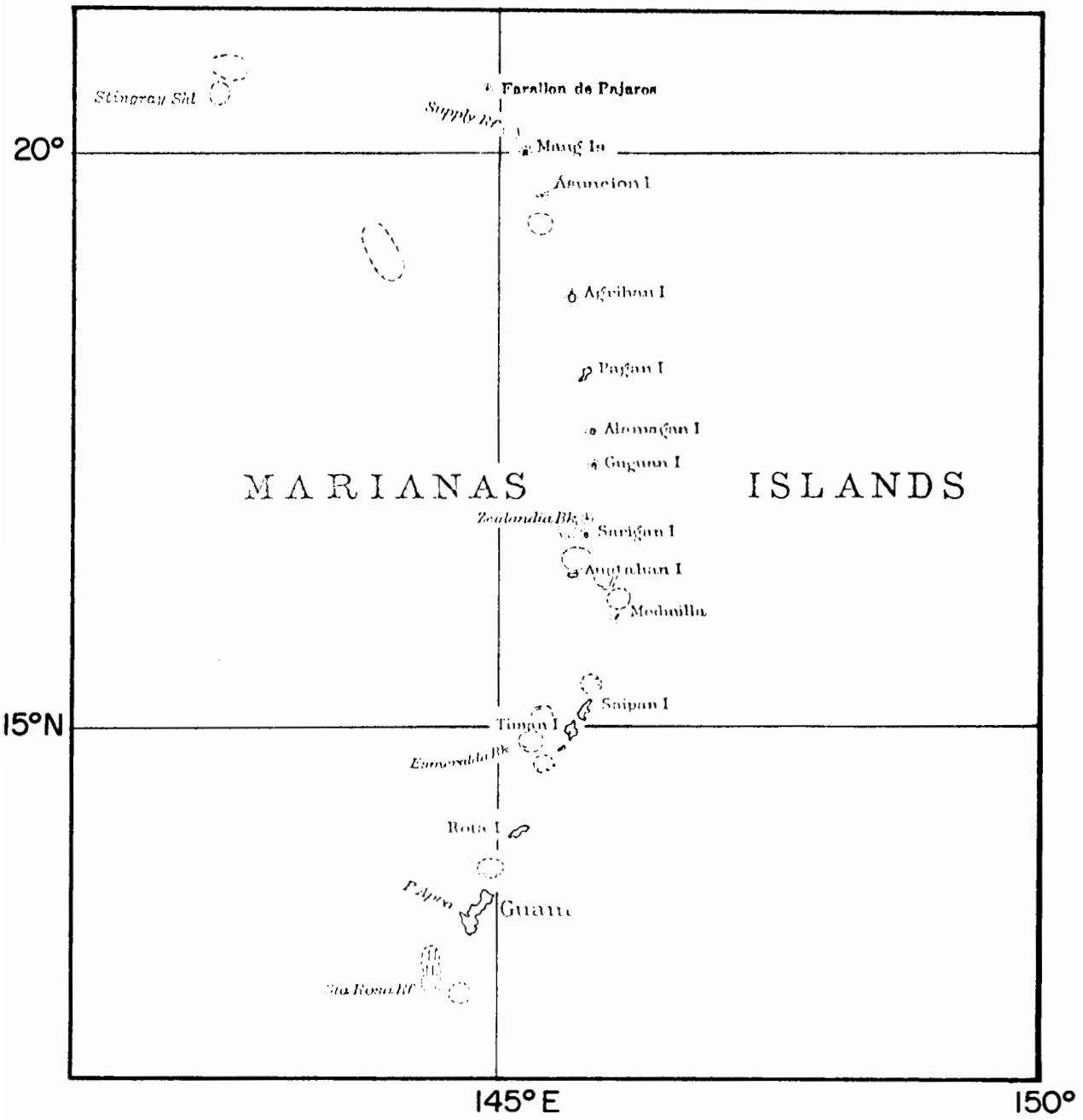

Figure 2.--The Mariana Islands (H. O. 5950).

Of the islands within this district, only Saipan, Tinian, and Rota are of any importance (Tudor, 1972). Under Japanese Mandate, these islands were turned into vast sugar plantations. The southern islands of the chain were strongly garrisoned by the Japanese in World War II.

On Saipan, shown in Figure 3, are located the district administration headquarters at Susupe and the Trust Territory headquarters at Capitol Hill (Tudor, 1972). This island, located at lat. 15°12'N and long. 145°43'E, is 12 mi (19 km) long by 5 mi (8 km) wide and covers 47 sq mi (122 sq km) (Bowers, 1951; Tudor, 1972). The largest island in the district, Saipan, has a lagoon along its west coast while the land area divides itself into four surface regions. There is a rugged northern upland which covers about two-thirds of the island, a southern plateau, a coastal lowland on the southwest, and Kagman Peninsula.

Tinian, to the south of Saipan and separated from it by a strait of about 3 mi (6 km), is 10 mi (16 km) long and 5 mi (8 km) wide and has 39 sq mi (101 sq km) of land (Bowers, 1951; Tudor, 1972). The island, shown in Figure 4, has no lagoon like Saipan but is steep with two plateaus separated from each other by a valley that has a northeast-southwest axis. It is located at lat. 14°58'N and long. 145°38'E.

Consisting of coralliferous limestone on a volcanic base, Rota, shown in Figure 5, is 10 mi (16 km) long and 3 mi (5 km) wide, covering about 32 sq mi (83 sq km). Situated at lat. 14°10'N and long.145°15'E, Rota is the only island in the Marianas, besides Guam, that has had a history of continuous occupancy by the Chamorros, the indigenous residents of the Mariana Islands.

GUAM

Guam is situated at the southern extremity of the Mariana Islands at lat 13°26'N and long 144°43'E (Tudor, 1972). A territory of the U.S. since 1898, Guam is peanut-like in shape, 28 mi (45 km) long and varying in width from 4 to 8 mi (6 to 13 km) (Bowers, 1951). It is the largest island in the Mariana chain, resembles the others in general formation, and has a land area of slightly over 200 sq mi (518 sq km). The island is divided into two sections, physiographically--a northern plateau and a higher southern mountainous area (Figure 6). The northern plateau is coral-capped, rises 200-600 ft (61-183 m) above sea level and has three low volcanic hills all under 900 ft (274 m) in altitude. A large proportion of the coastline ends abruptly in cliffs.

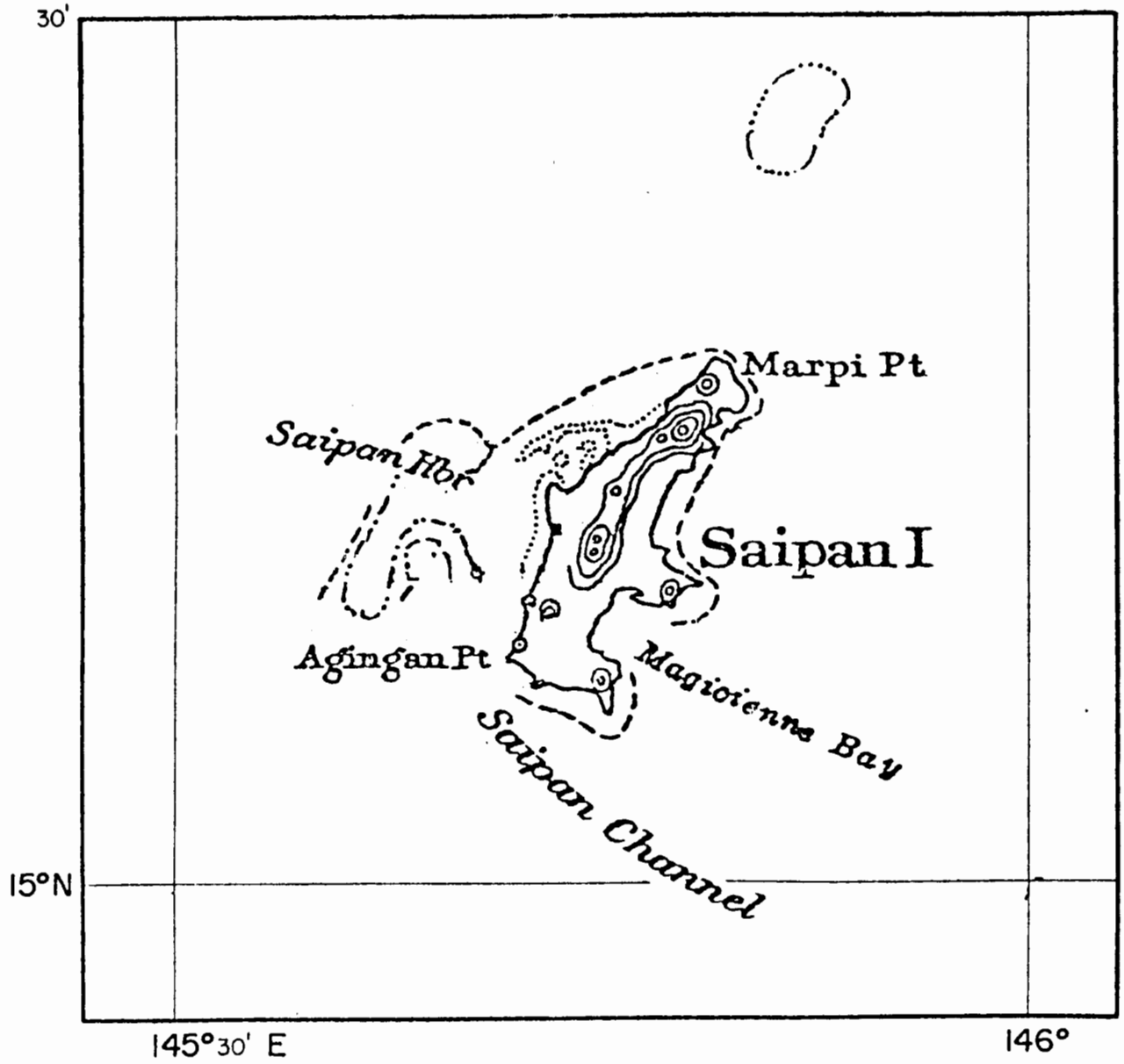

Figure 3.--Saipan Island (H. O. 5360).

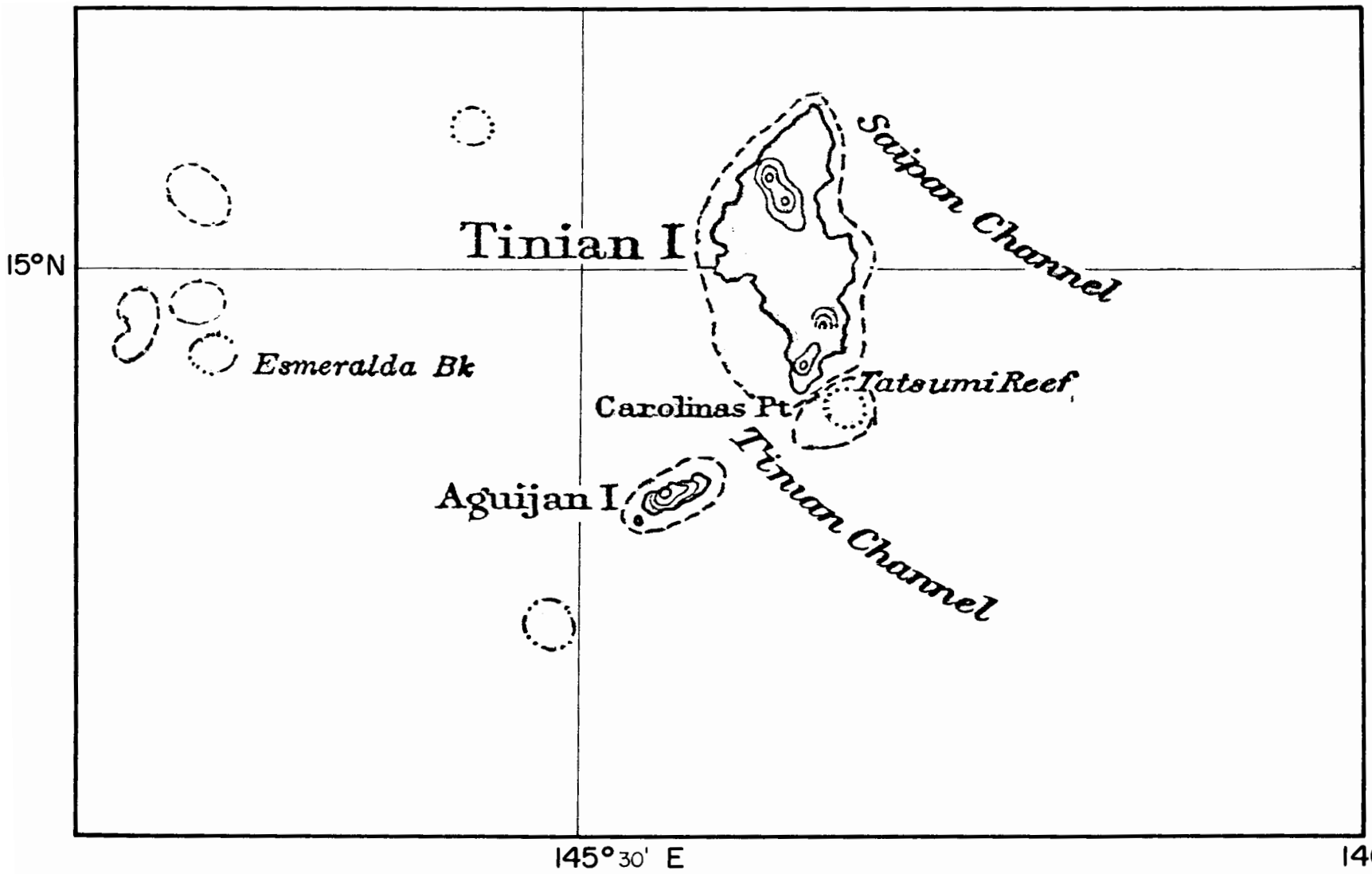

Figure 4.--Tinian Island (H. O. 5360).

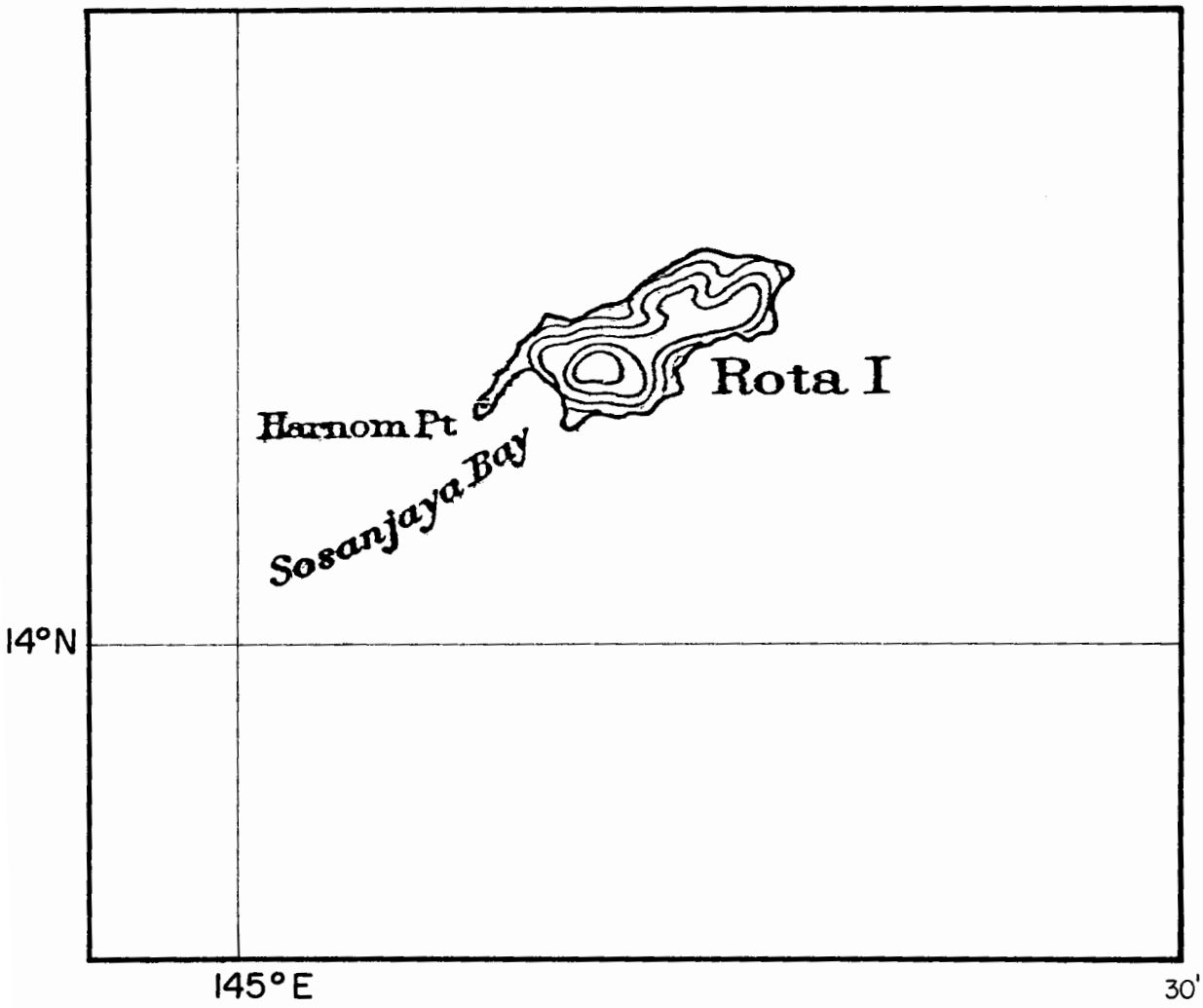

Figure 5.--Rota Island (H. O. 5360).

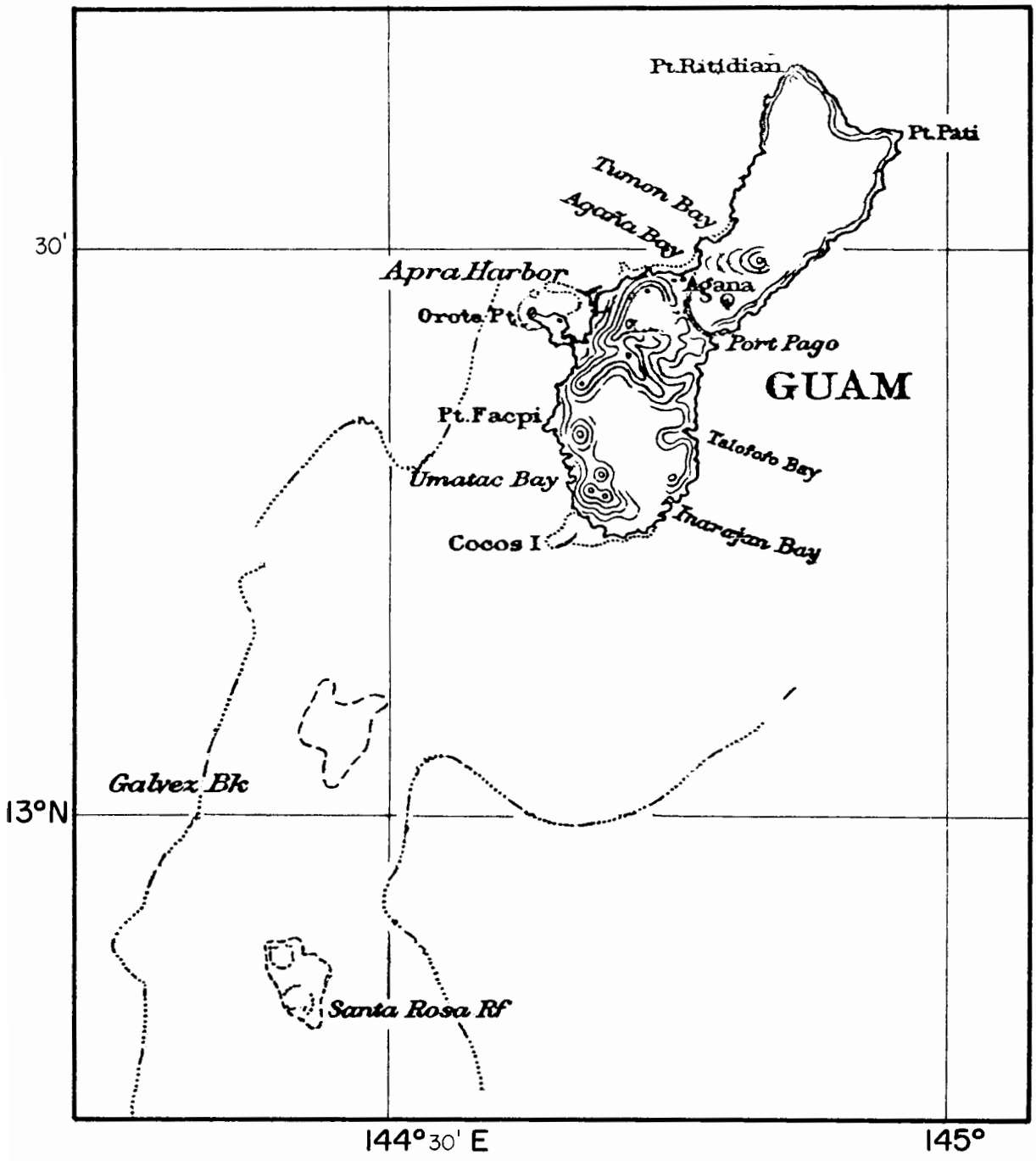

Figure 6.--Guam Island (H. O. 5417).

Guam was under the administration of the U.S. Navy until 1950 when the U.S. Congress enacted the Organic Act which placed the island under a civilian administration responsible to the U.S. Department of the Interior (Kim, 1974). Under this act, the Governor was appointed by the President with the advice and consent of the U.S. Senate. But in November 1970, Guam held its first election for Governor and Lieutenant Governor. Agana, the capital of Guam, is a modern city, having been entirely replanned and rebuilt following its complete destruction during World War II.

MARSHALL ISLANDS DISTRICT

The Marshall Islands, consisting of 28 low-lying coral atolls 5 single islands, and 867 reefs, lie between lat. 5° and 15°N and long. 162° and 173°E and are divided geographically and culturally into the Ratak (sunrise) chain and Ralik (sunset) chain (Mason, 1951; Trust Territory of the Pacific Islands, 1965; Tudor, 1972). Paralleling each other about 130 mi (241 km) apart, the Ratak chain comprises 13 atolls and 2 single islands whereas the Ralik chain is composed of 15 atolls and 3 single islands (Figure 7). Rising not more than a few feet above sea level, the islands have a total area of about 66 sq mi (171 sq km).

The important islands in the district are Majuro, Jaluit, and Kwajalein; Eniwetok and Bikini became well known after they were used in atomic bomb experiments.

Majuro, shown in Figure 8, is regarded as the capital of the Marshall Islands and the district headquarters are located there (Trust Territory of the Pacific Islands, 1965). Situated at lat. 7°05'N and long. 171°08'E, Majuro has an irregularly oval lagoon that measures about 28 mi (45 km) long and 11 mi (17 km) wide (Uchida and Sumida, 1973).

Jaluit, with a lagoon triangular in shape and measuring roughly 30 mi (48 km) long by 12 m (19 km) broad, has three deep passages through which vessels of any size can pass and anchor safely in 25-30 fm (fathoms) (46-55 m) of water (Figure 9) (Tudor, 1972). Jaluit lagoon is more than twice the size of Majuro lagoon. This atoll is located at lat. 6°00'N and long. 169°35'E.

Kwajalein, located at lat. 9°15'N and long. 167°30'E, became well known as a result of war operations (Figure 10). Having good accommodations for shipping, this atoll consists of 90 islets along a reef which encloses a 650-sq mi (1,684-sq km) lagoon, the largest in the world (Tudor, 1972). At present, Kwajalein islet, located at the extreme southern point of this triangular atoll, is a top secret anti-missile base for the U.S. and is under the jurisdiction of the U.S. Navy.

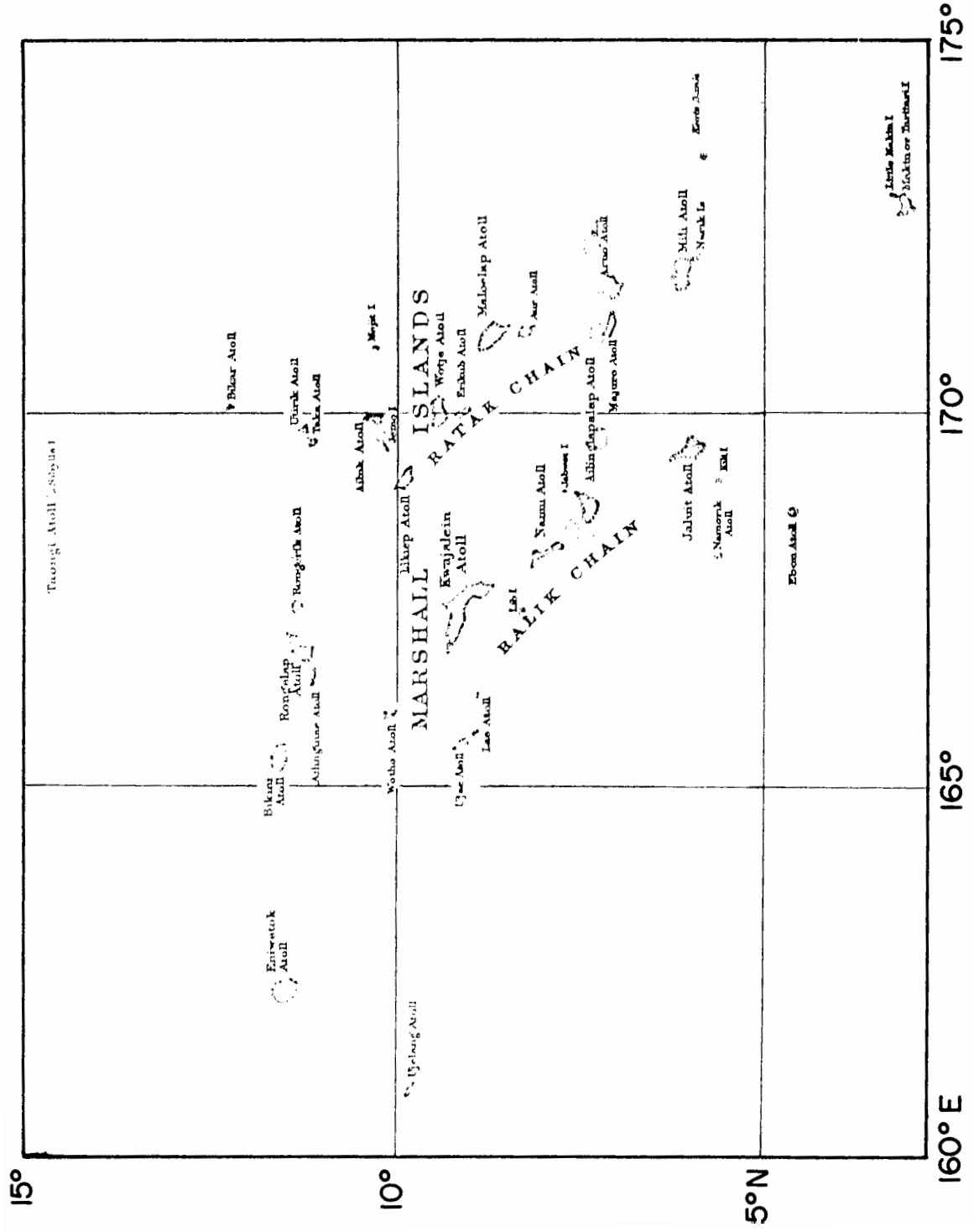

Figure 7.--The Marshall Islands (H. O. 5950).

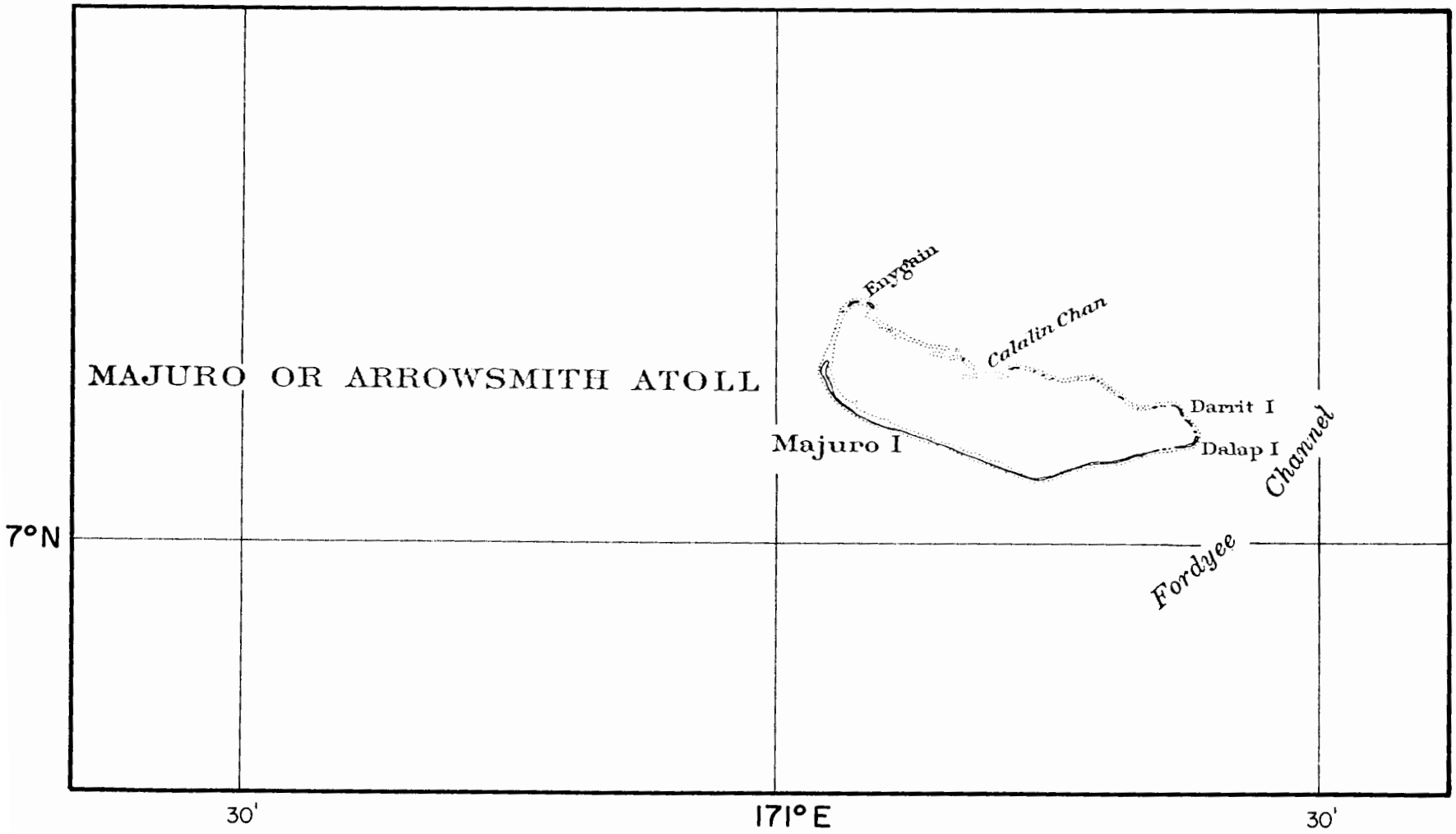

Figure 8.--Majuro Atoll (H. O. 5414).

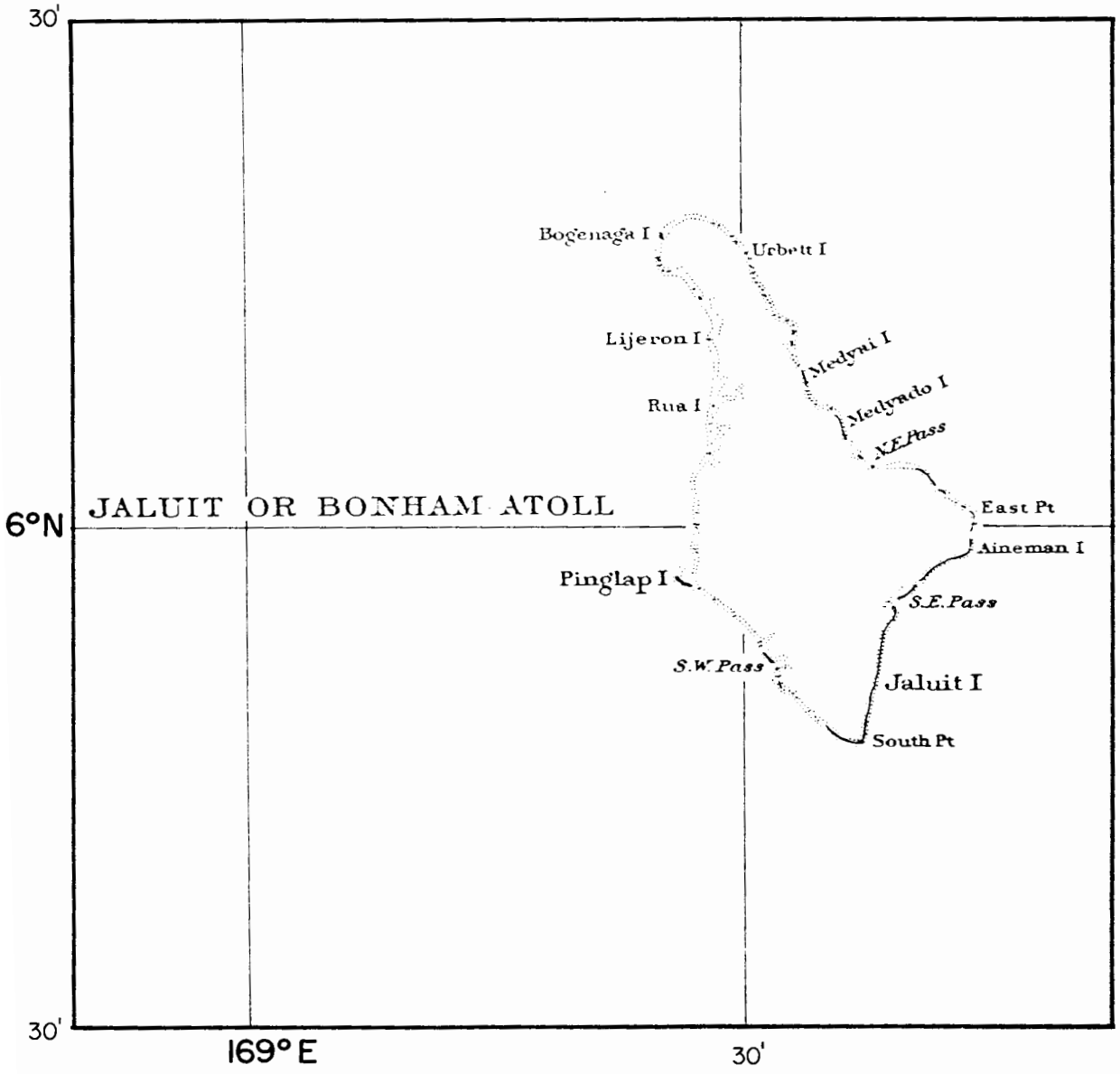

Figure 9.--Jaluit Atoll (H. O. 5414).

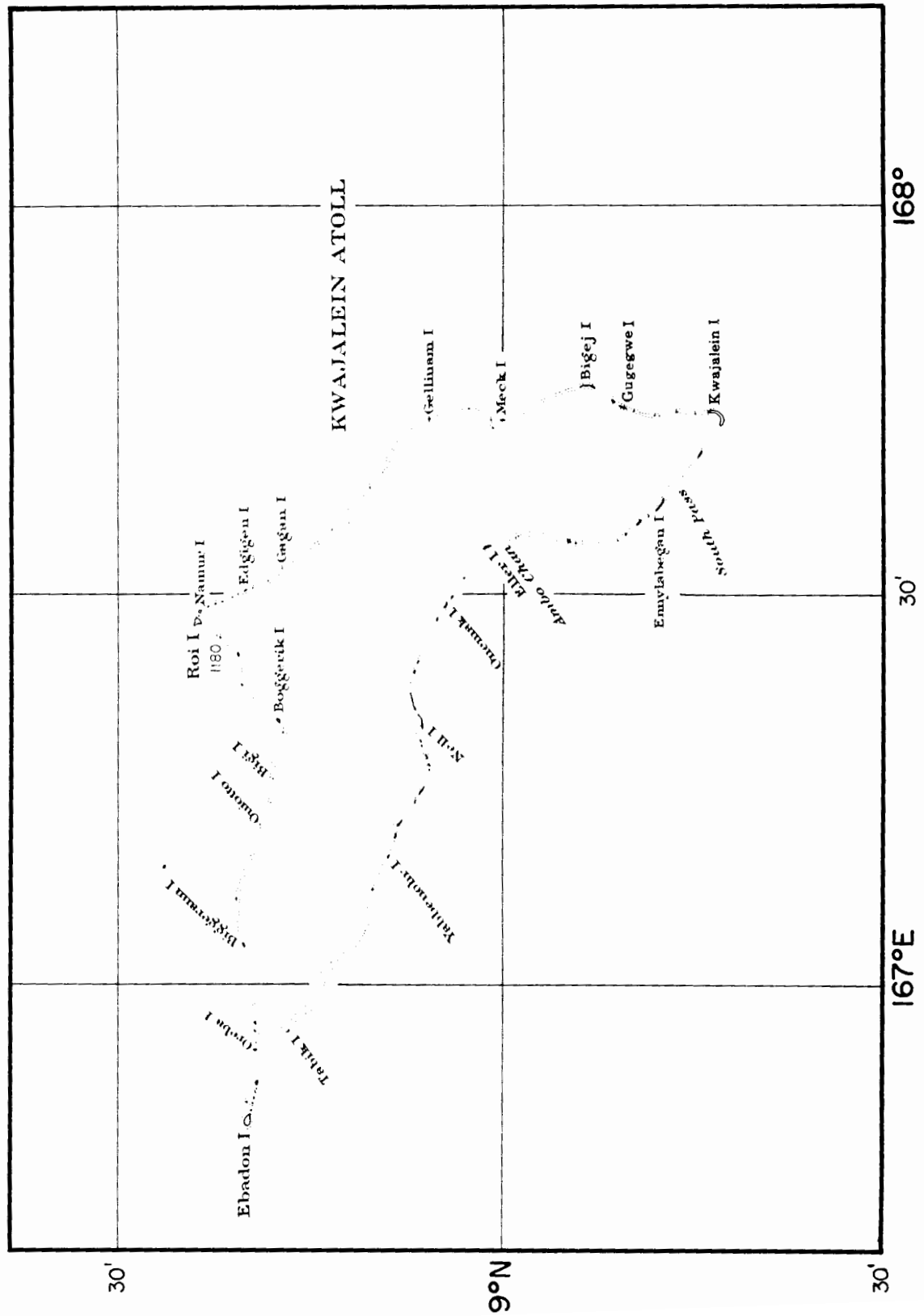

Figure 10.--Kwajalein Atoll (H. O. 5413).

DISTRICTS WITHIN THE CAROLINE ISLANDS

The Carolines lie in a vast chain just north of the equator between lat. 3°-10°N and long. 131°-163°E (Figures 11 and 12) (Manchester, 1951). Within the Carolines are 963 islands scattered over 1.3 million sq mi (4.5 million sq km). The total land area, however, is small and estimated to be about 830 sq mi (2,150 sq km). Included are volcanic islands with mountains and streams to tiny palm-clad islets and coral reefs only a few feet above sea level.

Politically, the islands are divided at long. 148°E into the Eastern and Western Carolines (Manchester, 1951). Administratively, the Western Carolines include the Palau and Yap Districts and the Eastern Carolines include the Truk and Ponape Districts. These administrative districts are named after the largest high islands within them.

Palau District

The Palau Islands, shown in Figure 13, comprise 200 islands scattered over an area about 125 mi (232 km) long and 25 mi (46 km) wide (Manchester, 1951; Tudor, 1972). They lie at the westernmost end of the Caroline chain at about lat. 7°30'N and long. 134°35'E. The islands are about 700 mi (1,300 km) southwest of Guam.

Rising abruptly from the sea, these volcanic islands are among the most beautiful in Micronesia. The principal islands in the group are Koror, which served as the administrative headquarters under the Japanese regime, Peleliu, and Angaur. Babelthuap at the north end of the group is the largest island in the Trust Territory, measuring roughly 27 mi (43 km) long and 8 mi (13 km) wide. It is very fertile, well-wooded, and produces many varieties of tropical fruits and vegetables (Tudor, 1972).

A large barrier reef about 70 mi (113 km) long fringes the eastern shores but widens on the western side of the main islands (Manchester, 1951). The reef is difficult to cross except in a few places. Outside the reef and to the north are the Kayangel Islands, which rise only a few feet above sea level. To the south, Angaur, a raised atoll, is important for its phosphate deposits.

Yap District

The Yap group (Figure 14) consists of four principal islands--Yap, Gagil-Tomil, Map, and Rumung--and about 10 small islands

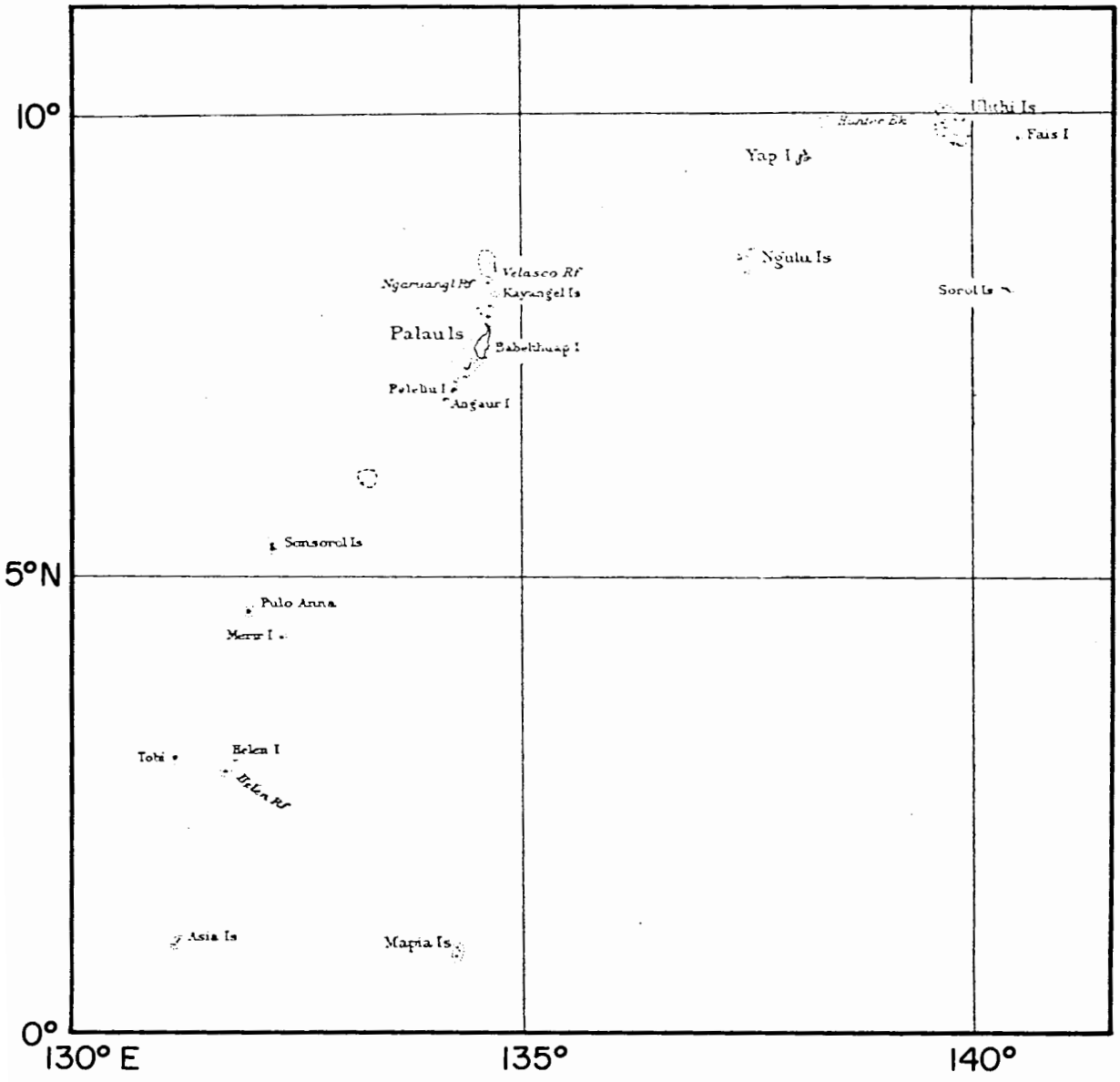

Figure 11.--The Caroline Islands west of long. 142°E (H. O. 5950).

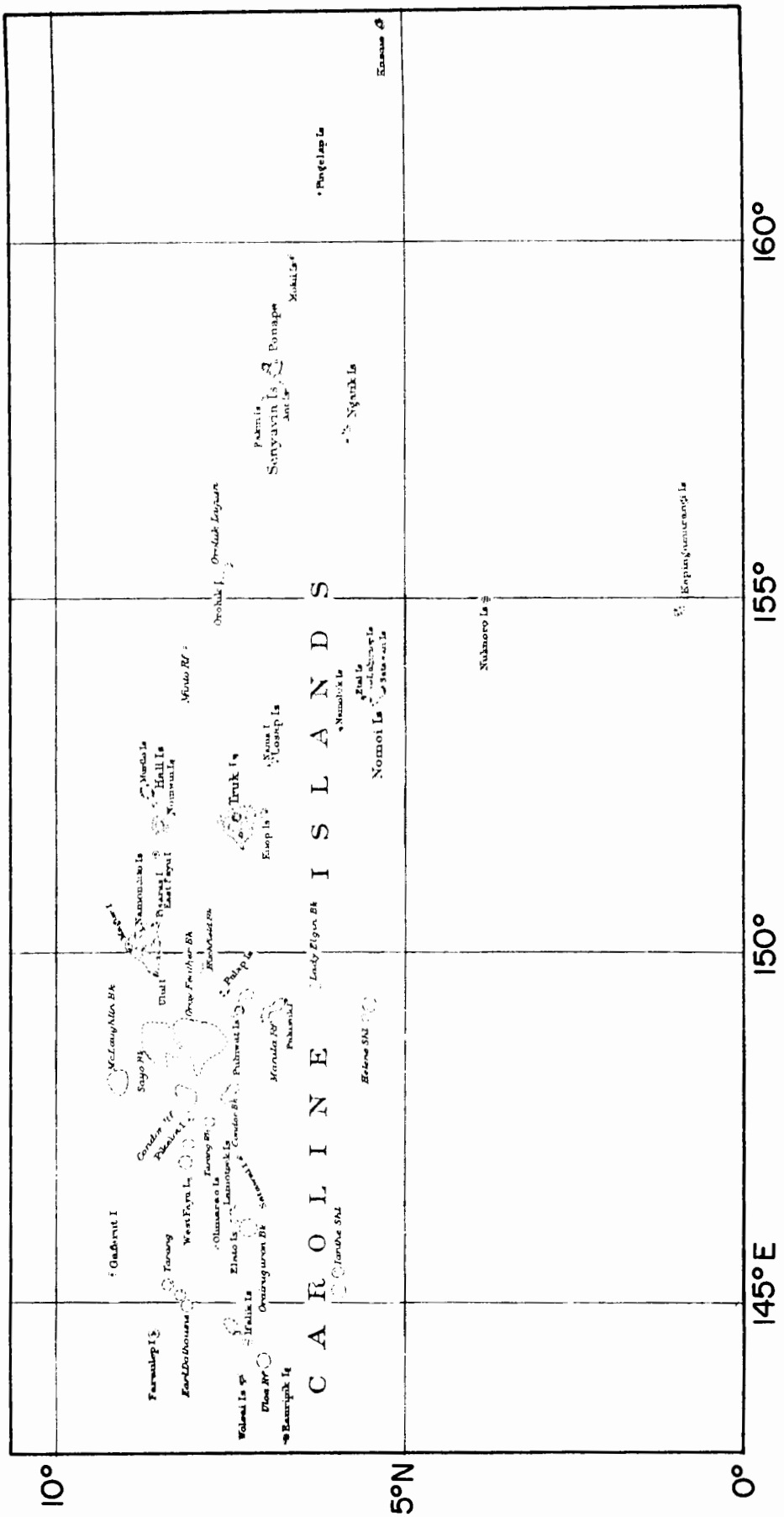

Figure 12.--The Caroline Islands east of long. 142°E (H. O. 5950).

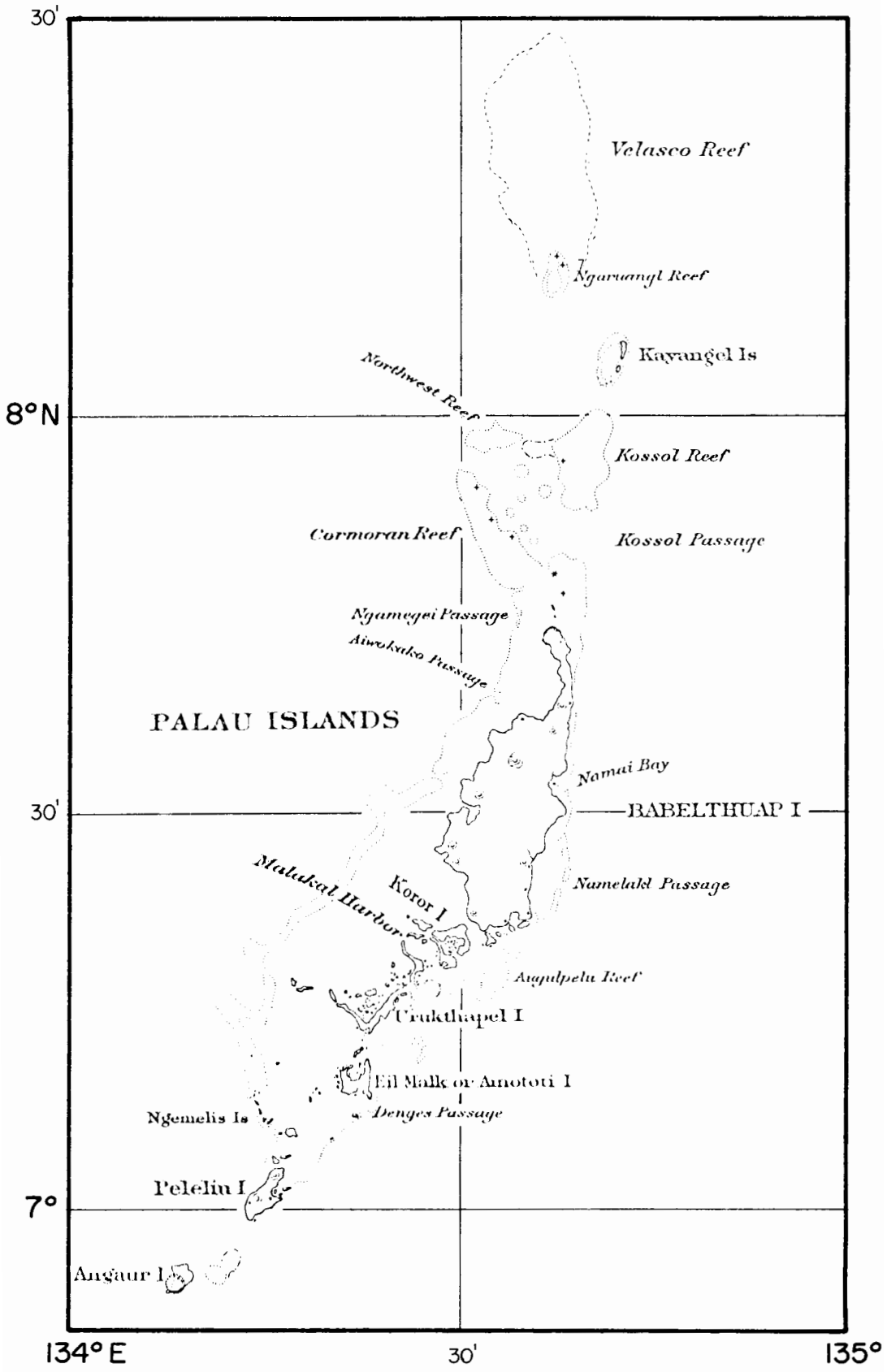

Figure 13.--Palau Islands (H. O. 5418).

(Manchester, 1951; Tudor, 1972). Located between lat. 9°25'-9°46'N and long. 138°03'-138°14'E, the group is situated on a triangular submarine platform and surrounded by a fringing reef. The reef varies in width from 0.5 mi (1 km) to 2 mi (3 km). The islands enclosed by the reef stretch 16 mi (26 km) long and 8 mi (13 km) wide. The main islands are narrowly separated from each other by lagoons. Land area has been estimated to be about 39 sq mi (101 sq km).

Yap is hilly and covered with magnificent forests of coconut and areca palms, bamboos, and crotons (Tudor, 1972). The largest of the individual islands in the group, Yap is about 12 mi (19 km) long and 3 mi (5 km) wide. The highest elevation is 585 ft (178 m) above sea level.

The Yap District headquarter is located in Colonia. Island groups included in the Yap District are Ulithi and Woleai, among others.

The Yapese are dignified, sensitive people who have retained many of their old customs and beliefs (Trust Territory of the Pacific Islands, 1965). Their stone moneys, bulky grass skirts, and loin cloths, have become the best known among the indigenous customs of Micronesia. Their famous stone moneys with holes through their centers were brought by sailing vessels from Palau and represent wealth.

Truk District

Truk District consists of Truk proper, 12 low-lying atolls, and 2 low islands. The Truk group, located 650 mi (1,204 km) southeast of Guam between lat. 7°07'-7°41'N and long. 150°04'-151°22'E, is commonly referred to as an "almost atoll" or "complex atoll" (Manchester, 1951; Trust Territory of the Pacific Islands, 1965). The group, shown in Figure 15, resembles a typical atoll in that it has a great barrier reef varying from 30 to 40 mi (48 to 64 km) in diameter, but there is a cluster of large, high islands inside the lagoon, the most important of which are Moen, Dublon, Fefan, Uman, Udot, Fanapenges (Falabeguets), and Tol. Tol is the largest of the islands and has the highest elevation at 1,483 ft (452 m). Elevation of the others varies from 950 ft (290 m) to a little over 1,000 ft (305 m). The lagoon is about 820 sq mi (2,124 sq km) whereas the land area of all the islands in the group is only about 39 sq mi (101 sq km) (Manchester, 1951).

There are 20 passes piercing the encircling reef, but only 4 are navigable. There are several fine harbors and anchorages within the reef, the chief one being enclosed by Dublon, Fefan, and Uman islands. Of the 40 islets on the encircling reef, only 1, Pis (pronounced peace) is permanently inhabited.

Figure 14.--Yap Islands (H. O. 5412D).

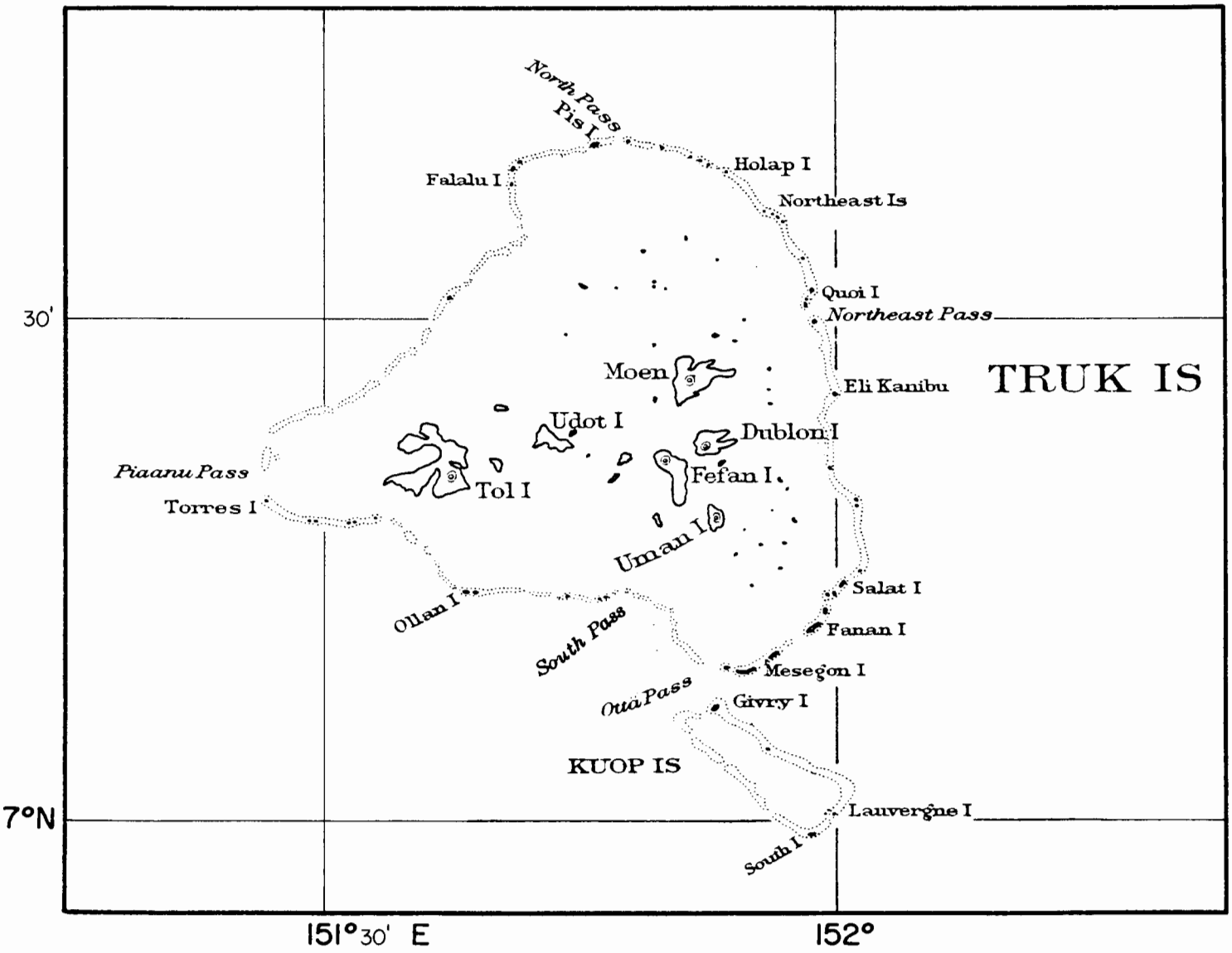

Figure 15.--Truk Islands (H. O. 5416).

Truk is actually a summit of a volcanic dome that rises from a submarine plateau (Manchester, 1951). The islands of the eastern part of the plateau are fairly stable, but there has been some subsidence as evidenced by drowned river valleys.

The most northerly atoll of the district is Manonuito, which is the world's second largest atoll (Tudor, 1972). Lying near the eastern side of the district are East Fayu and Hall Islands. To the west of Truk are Pulap and Puluwat and directly south lie Kuop, Nama, and Losap atolls. Near the district boundary to the southeast are Namoluk atoll and Mortlock Islands, comprised of about 100 islands arranged in three groups called Etal, Lukunor, and Satawan.

Ponape District

Ponape District, the most eastern among districts within the Carolines and including all islands east of long. 154°E, contains the high islands of Ponape and Kusaie and eight atolls (Manchester, 1951; Tudor, 1972). Ponape Island, located at lat. 6°53'N and long 158°14'E and shown in Figure 16, is a volcanic dome similar in origin to Truk but less advanced in subsidence. It rises gradually from the sea to a height of 2,579 ft (786 m). Second in size in the territory--only Babelthuap in the Palaus is larger--Ponape is about 14 mi (22 km) from north to south and 16 mi (26 km) from east to west. With a land area of 129 sq mi (334 sq km), the island is surrounded by 25 small islands of both coral and volcanic origin. This entire complex is surrounded by a barrier reef that encloses a narrow lagoon.

Colonia is the main town in Ponape and is the seat of the district administrative headquarters (Trust Territory of the Pacific Islands, 1965). The district includes the small groups of small islands called the Ant and Pakin groups and Ngatik (Tudor, 1972). Ponape, Ant, and Pakin are collectively known as Senyavin Islands. Isolated in the northwest of the district is Oroluk and about 100 mi (185 km) southeast of Ponape is the Mokil group, which includes Urak, Manton, and Mokil. Southeast of Mokil is the Pingelap group--Pingelap, Takai, and Tapulu--which are close together on one reef. Kusaie, often described as one of the most beautiful islands in the Pacific, is the farthest east of the Carolines.

CLIMATE

The climate in Micronesia can best be described as tropical and uniform. Because there are no large islands included in Micronesia,

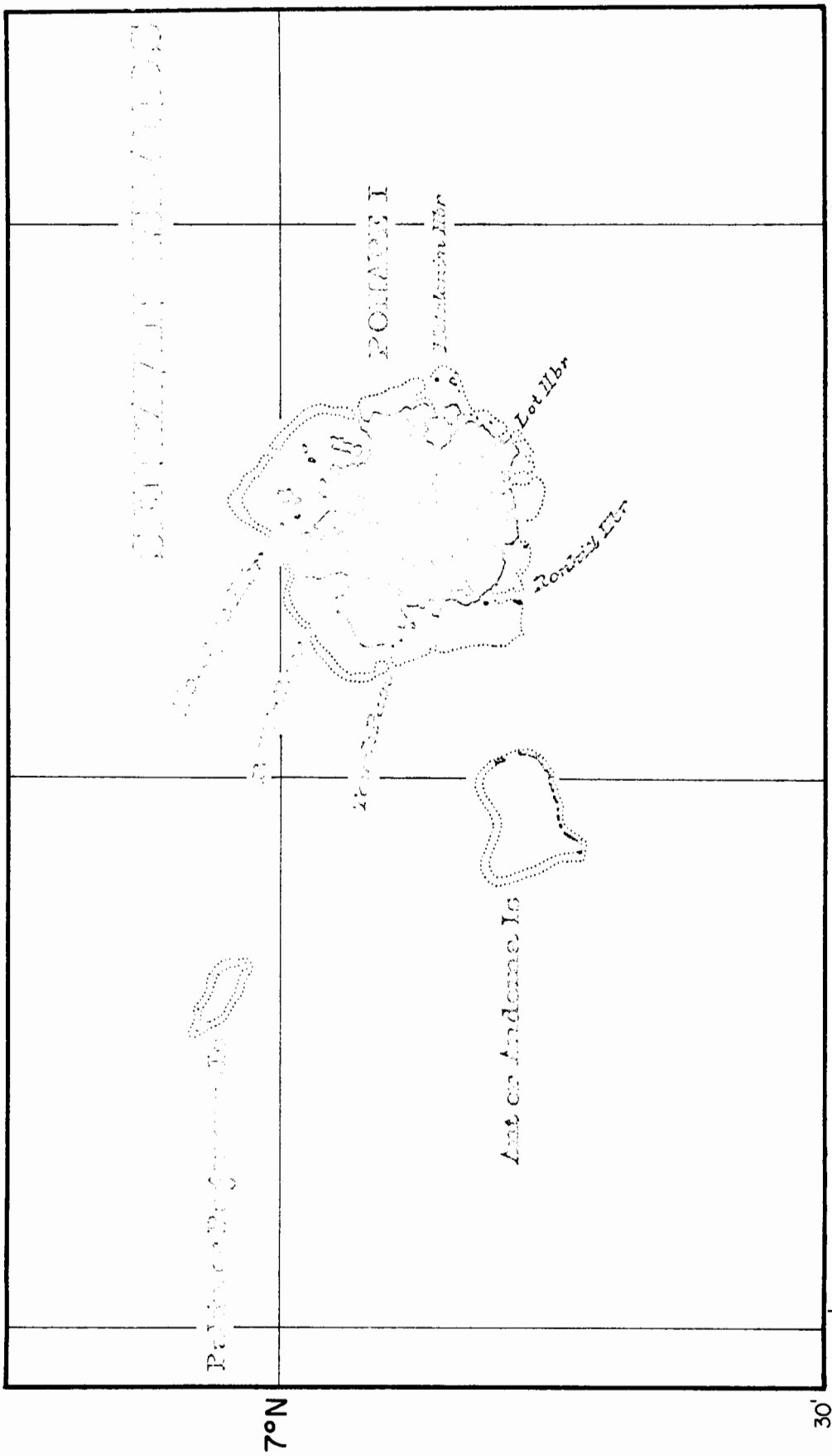

Figure 16.--Ponape Islands (H. O. 5415).

the climate is wholly marine to insular, tropical to the south and subtropical on the north (U.S. Weather Bureau, 1943). The mean annual air temperature over southern waters varies only by about 2°F (1°C) whereas over northern waters it is close to 15°F (8°C). Rainfall is heavy usually among the large island groups. Trade winds and monsoons (seasonal winds that blow from continental interiors to the ocean in winter and opposite in summer) exert their influence over Micronesia with a succession of winds much more pronounced over the Marianas and the Western Carolines than over more eastern waters. The reason is that the continental effects lessen with distance and the trades are the predominant winds.

In the sections that follow, detailed discussions of several weather elements are presented.

AIR TEMPERATURE

At sea in the western Pacific, the mean air temperature fluctuates only slightly from 80° to 84°F (27° to 29°C) all the way from the equator to lat. 15°N (U.S. Weather Bureau, 1943). Monthly variation in some areas near the equator scarcely exceeds 2°F (1°C); between lat. 10° and 15°N, the monthly variation may be as much as 4°F (2°C). Between lat. 15° and 20°N near long. 165°-170°E, the variation may be as much as 5°F (3°C) with a January-February average of 77°F (25°C) and that of August-September being 82°F (28°C).

Closer to the Asiatic continent at lat. 20°-25°N between long. 130° and 165°E, the January-March mean is 72°F (22°C) with February usually the coolest month (U.S. Weather Bureau, 1943). July is usually the warmest with temperatures averaging 83°F (28°C), making the annual range about 12°F (7°C). In the eastern sector of this belt between lat. 20°-25°N, the January-March mean is 74°F (23°C) whereas the July-September mean is 82°F (28°C). The annual range, therefore, is only 9°F (5°C), slightly less than to the west.

From lat. 25° to 30°N between long. 155° and 165°E, cooling becomes more apparent in the winter and spring (U.S. Weather Bureau, 1943). The lowest mean temperature, 64°F (18°C), is delayed until March. In summer, the temperature is only 3°F (2°C) lower than that near the equator.

Among the islands all the way from Jaluit at lat. 6°N to Wake Island at lat. 19°N, the mean annual temperature at near sea level ranges between 80° and 82°F (27° and 28°C) (U.S. Weather Bureau, 1943). At the Saipan Observatory, however, which is located 700 ft (213 m) above sea level, there is a record in these latitudes of a mean temperature as low as 78°F (26°C).

The U.S. Weather Bureau (1943) also reported that the monthly means at most stations in the western Pacific do not vary by more than 2°F (1°C) although there are exceptions. One is Saipan, where the February mean is 76°F (24°C) while the June mean is 80°F (27°C).

The mean daily temperature range, obtained as the difference between the annual means of the maximum and minimum temperatures, is 9°-11°F (5°-6°C) (U.S. Weather Bureau, 1943). At Palau, for example, the annual means of the maximum and minimum temperatures are 86° and 76°F (30° and 24°C), respectively. At other stations, they are as follows: Jaluit, 88° and 77°F (31° and 25°C); Ponape, 85° and 75°F (29° and 24°C); and Saipan, 83° and 74°F (28° and 23°C).

WIND DIRECTION AND VELOCITIES

The oceanic wind system between the equator and lat. 25°N consists of the monsoons and the northeast trades (U.S. Weather Bureau, 1943). West of long. 140°E, between the equator and lat. 5°N, the monsoonal succession of winds is fairly well defined. During the winter half of the year the northerlies, which include the westerlies to northeasterlies, are predominant, whereas during the summer half, the southerlies, which include the easterlies to southwesterlies, predominate. Between lat. 5° and 20°N, the northerly monsoon veers into more settled northeast trades from November to May. The summer winds in this region show the influence of the monsoons by turning into southerly and southwesterly winds. Figure 17 shows the average surface wind drift direction over the central and western Pacific Ocean.

Over the Marianas and central Carolines, the influence of the summer monsoon from Asia is insignificant (U.S. Weather Bureau, 1943). The northeast trades are predominant and strong except in summer. Farther eastward, the trades from northeast to east become increasingly dominant throughout the year.

In the latitudinal belt from the equator to lat. 5°N between long. 140° and 170°E, northeast and east winds are the most frequent annual winds (U.S. Weather Bureau, 1943). There is, however, a tendency for the frequency of these winds to increase from west to east. For example, in long. 140°-145°E, northeast and east winds constitute more than 60% of the observations annually. In the winter half of the year, some of the influence from monsoons persists; the result is that north, northwest, and west winds appear temporarily and overcome the trades. In the summer half of the year, the southeast trades cross the equator and partly replace the northeast winds. Although the east wind predominates at this time, southerly trades from southeast to southwest are rather frequent.

AVERAGE SURFACE WIND DRIFT DIRECTION, CONSTANCY AND FORCE

Symbols shown on charts 3 to 7

Prevailing winds move with the arrows
Direction and frequency:

81 percent or more

61 to 80 percent

41 to 60 percent

25 to 40 percent

Average velocity:

indicates predominance of Beaufort 0–3 (0 to 10 knots), indicates stronger winds, Beaufort 4 (11 to 16 knots) and higher, dominant 60% or more of the time.

CHART 3.—February.

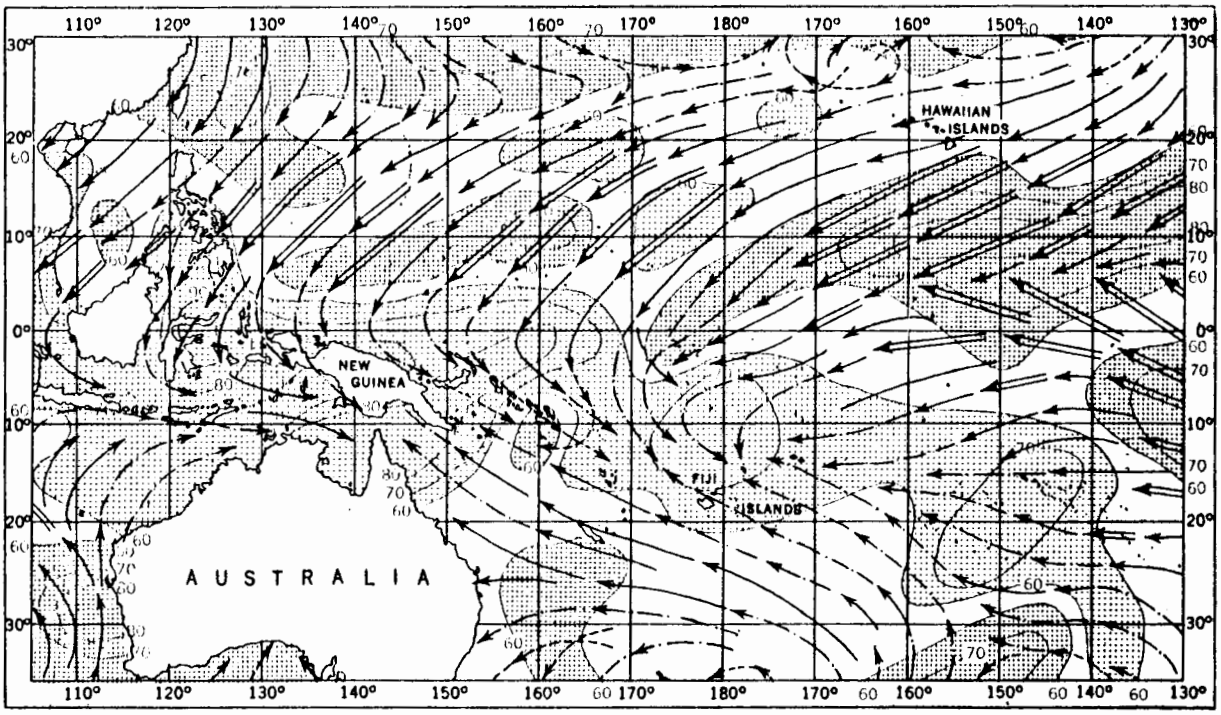

Figure 17.--Average surface wind drift direction, constancy, and force in the western Pacific Ocean (U.S. Weather Bureau, 1943).

CHART 4.—May.

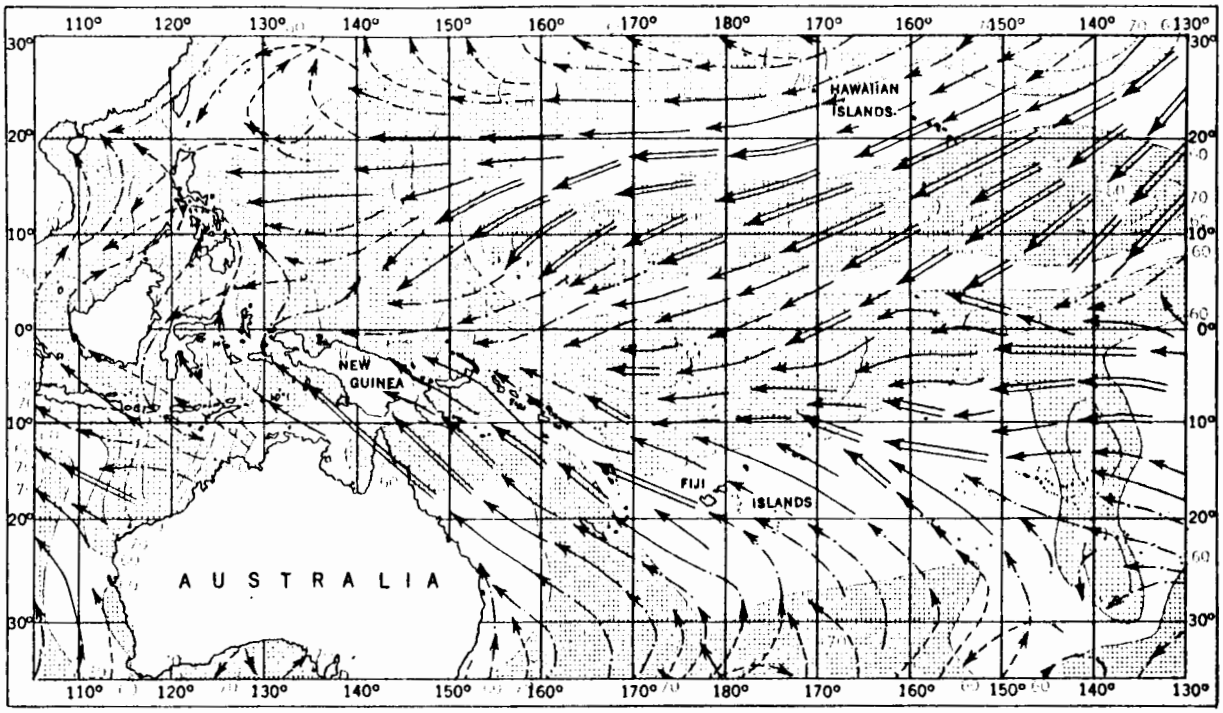

CHART 5.—July.

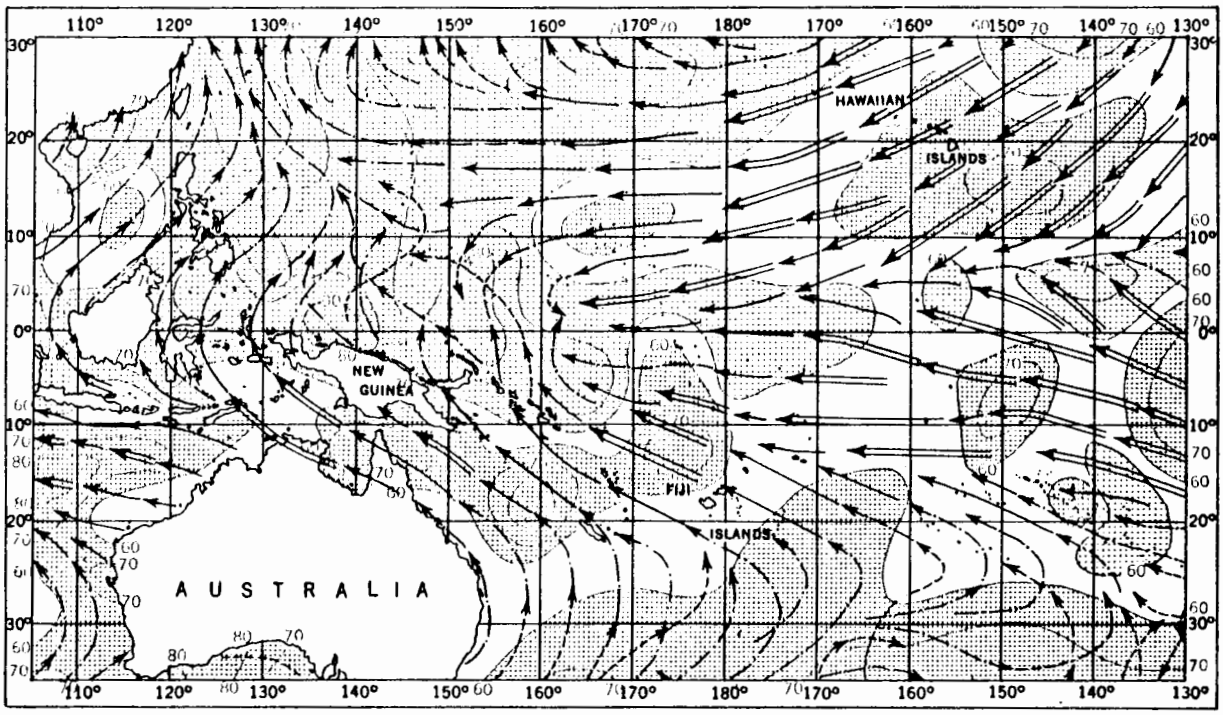

Figure 17.--Continued.

CHART 6.—October.

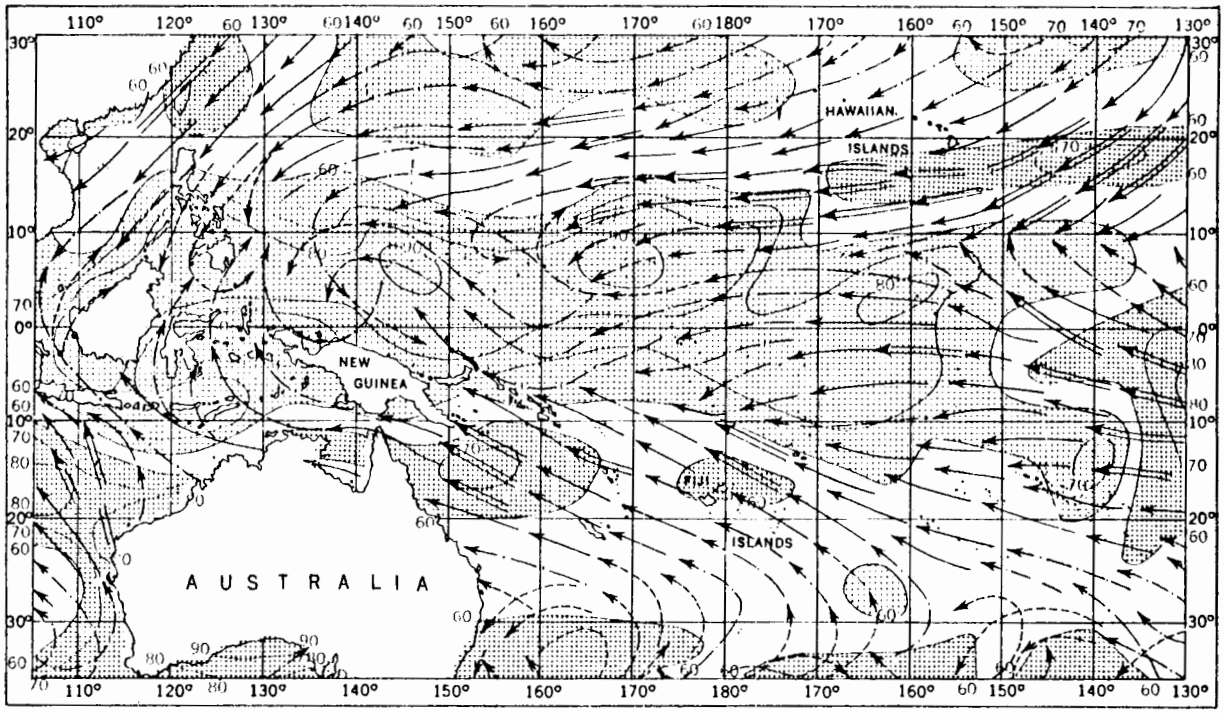

CHART 7.—December.

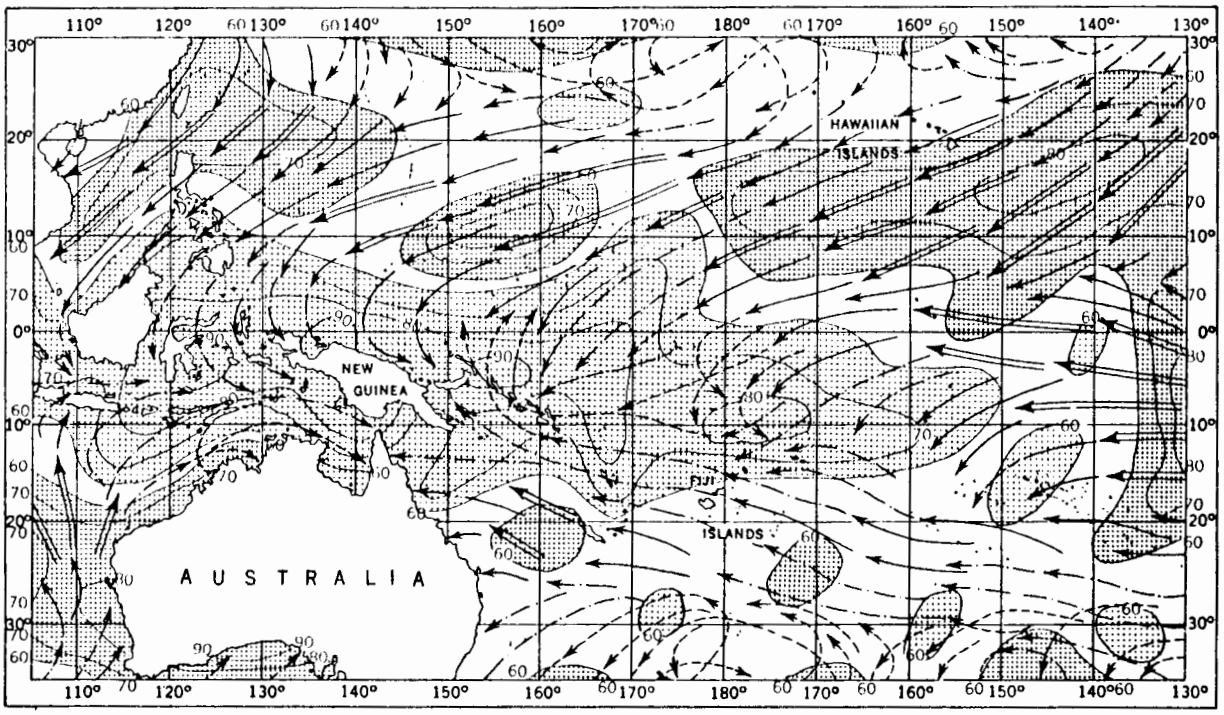

Figure 17.--Continued.

In the Marshalls, the northeast trades predominate in all months particularly in northern waters (U.S. Weather Bureau, 1943). Winds are strong and persistent in November-June in northern waters and from January to June throughout the Marshalls. Weaker trades predominate in the latter half of the year particularly in the southern Marshalls where there is some interposition of southerly to westerly winds.

In lat. 20° to 25°N between long. 140° and 165°E, the trades are less firmly established than they are between lat. 5° and 20°N (U.S. Weather Bureau, 1943). In winter, this area often has north and northwest winds whereas in summer southerly winds--southeast to south--occur frequently at the expense of the northeast winds.

The wind velocities in the western equatorial Pacific between the equator and lat. 5°N at long. 130° to 170°E are rather light with no real significant difference in spread from one season to another (U.S. Weather Bureau, 1943). West of long. 155°E, the mean speed is about 7 knots with frequent calms whereas toward the southeastern Carolines between long. 165° and 170°E, the mean rises to 9 knots with fewer calms. Figure 18 shows the distribution of wind forces in the western Pacific Ocean.

In lat. 5°-10°N between long. 130° and 175°E, the trades and monsoons blow briskly and the annual velocities rise from about 9 knots in the west to 11 knots in the extreme east (U.S. Weather Bureau, 1943). Here, seasonal differences are more marked; whereas the mean velocities of the summer period are generally between 6 and 9 knots, those of the winter period reach 10 knots or more.

In the more northerly latitudes in 10°-15°N between long. 130° and 175°E, the annual mean velocities are still higher, reaching 9 to 10 knots in the west and 12 to 13 knots in the east (U.S. Weather Bureau, 1943). In summer, velocities vary between 7 and 10 knots whereas winter velocities are 12 to 15 knots or more.

Approaching the stronger wind circulation projecting seaward from Asia at lat. 15° to 25°N between long. 130° and 170°E, the average velocities reach 11 knots in the west but are somewhat lower in the east, varying between 9 and 10 knots (U.S. Weather Bureau, 1943). West of the Marianas, the mean velocities range between 10 and 15 knots from October to March. At other times of the year, the monthly means are slightly lower, varying between 8 and 11 knots. The summer monsoon, which is very strong toward the Asiatic coast, carries some of its strength a considerable distance seaward in these latitudes. Over the Marianas and further east, both summer and winter winds are lighter.

Although the predominating wind throughout the year in Micronesia is the easterly trade winds, there are certain exceptions and they can best be discussed by examining the data collected at island weather observation stations. Data on monthly mean wind speed and prevailing direction are given for some island stations in Tables 1 to 8.

DISTRIBUTION OF WIND FORCES

Charts 8 to 12.—Explanation

First or upper figures.—Percentage of the total wind observations which record calms is shown to whole numbers in each 5° square.

Second figures.—Percentage of wind observations with Beaufort force 1 to 3, inclusive.

Third figures.—Percentage of wind observations with Beaufort force 4 to 6, inclusive.

Fourth figures.—Percentage of wind observations with Beaufort force 7 and 8.

Fifth or bottom figures.— Percentage with Beaufort force 9 or over.

0 Less than 0.5 percent.

* Denotes a square with less than 25 observations available for summarization.

CHART 8.—February.

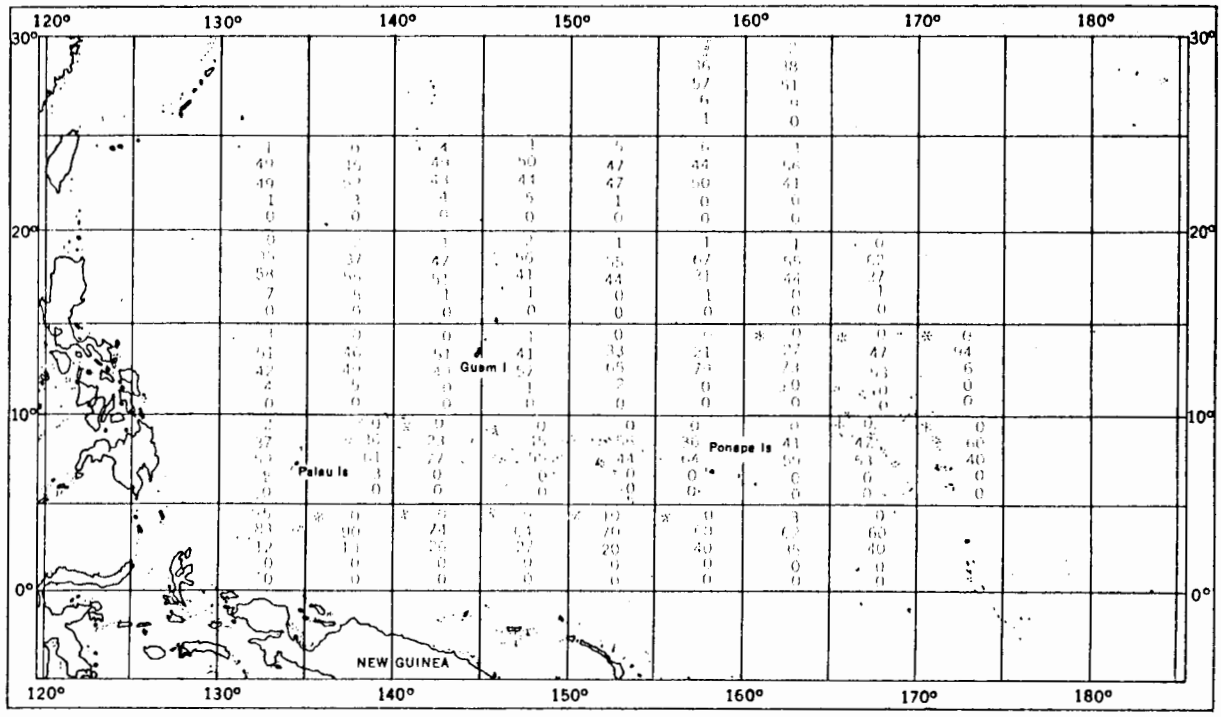

Figure 18.--Distribution of wind forces in the western North Pacific Ocean (U.S. Weather Bureau, 1943).

CHART 9.—May.

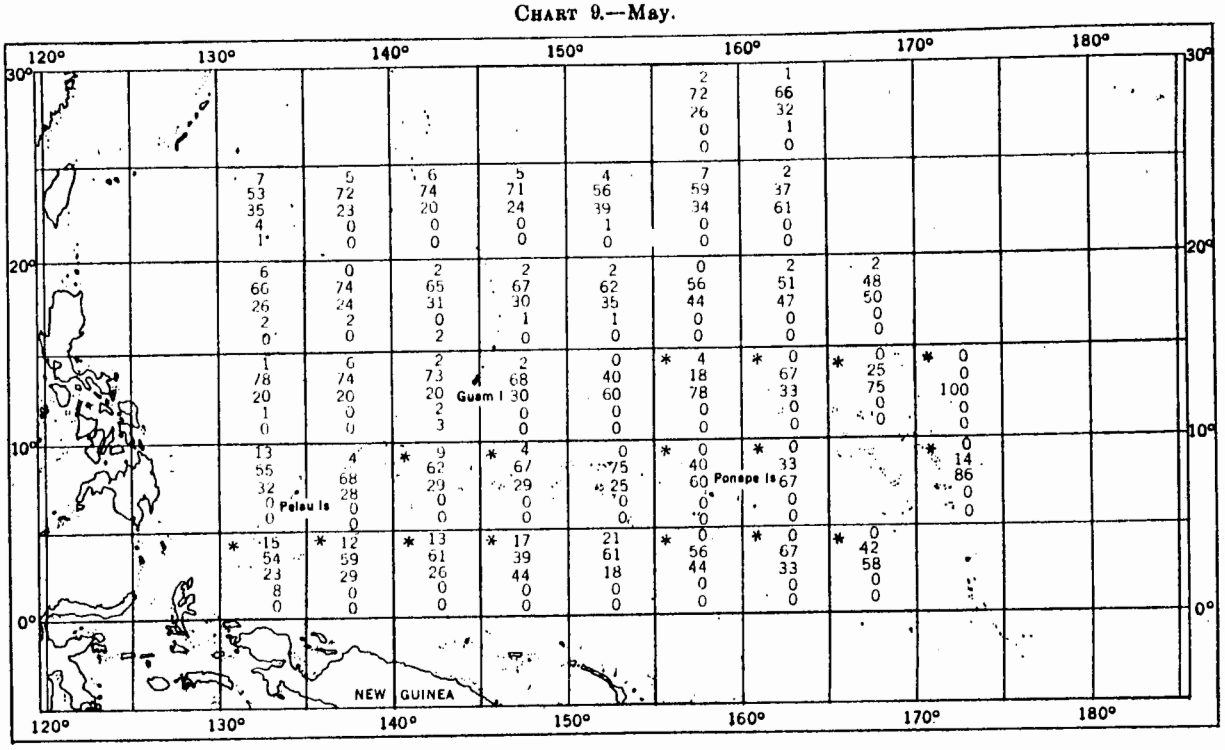

CHART 10.—July.

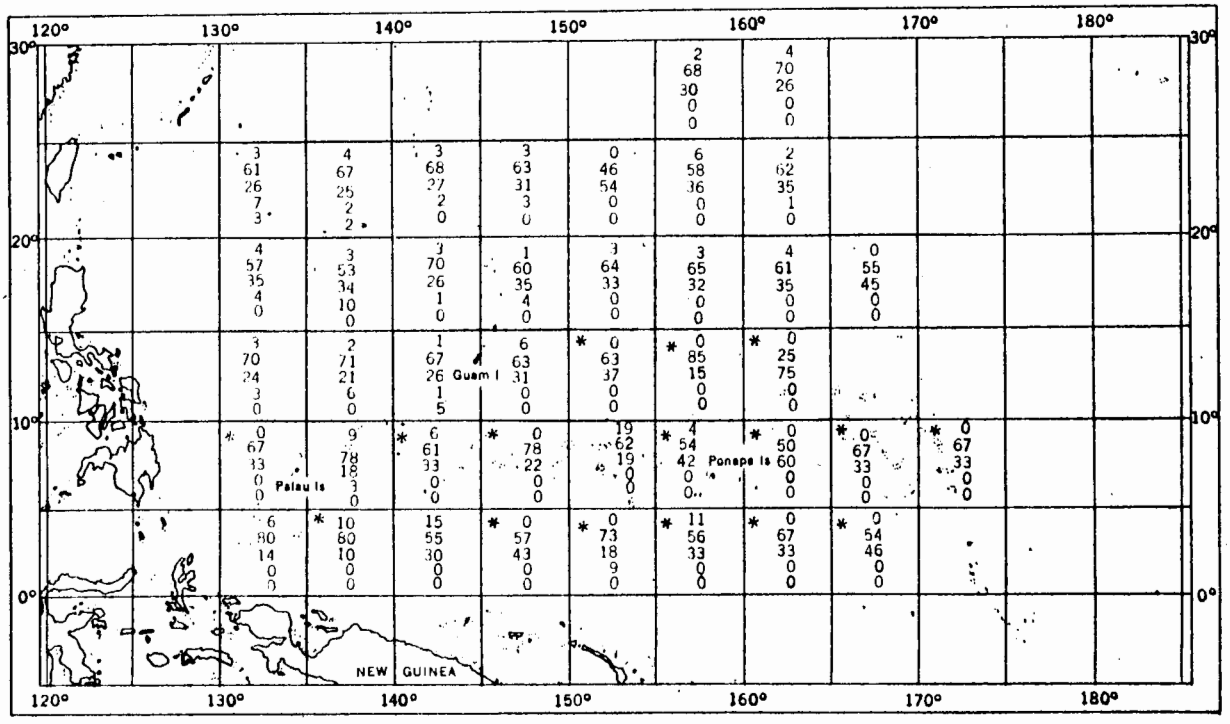

Figure 18.--Continued.

CHART 11.—October.

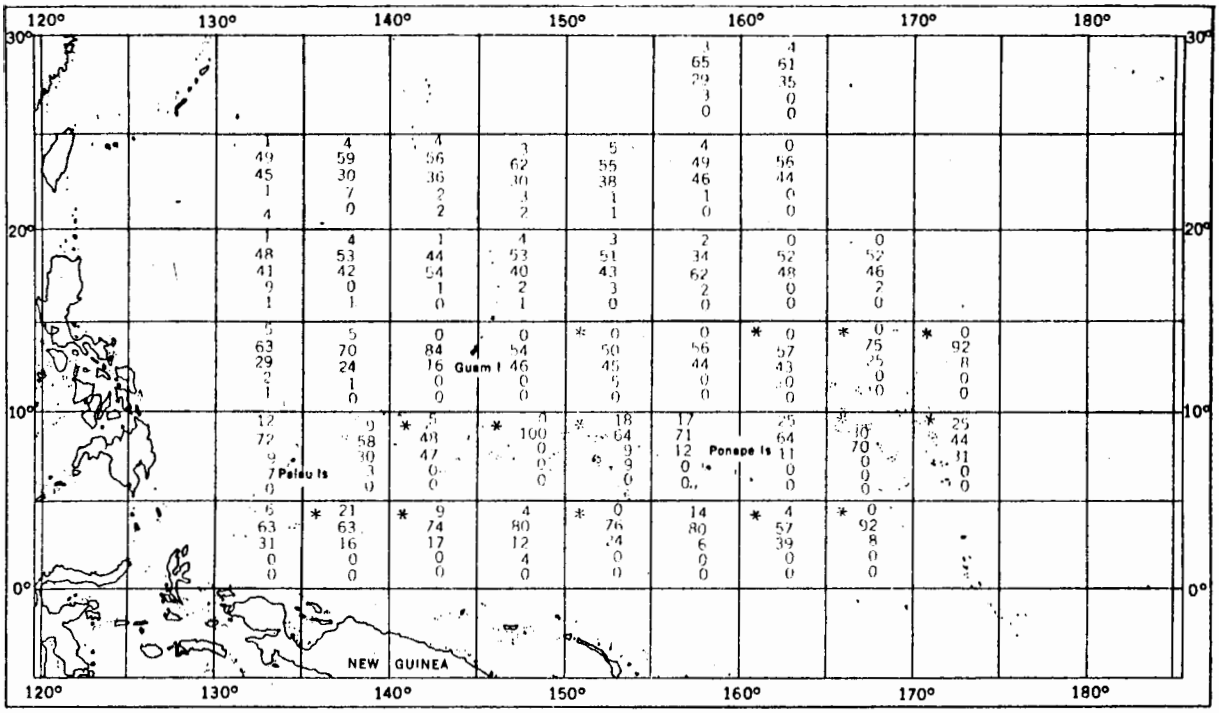

CHART 12.—December.

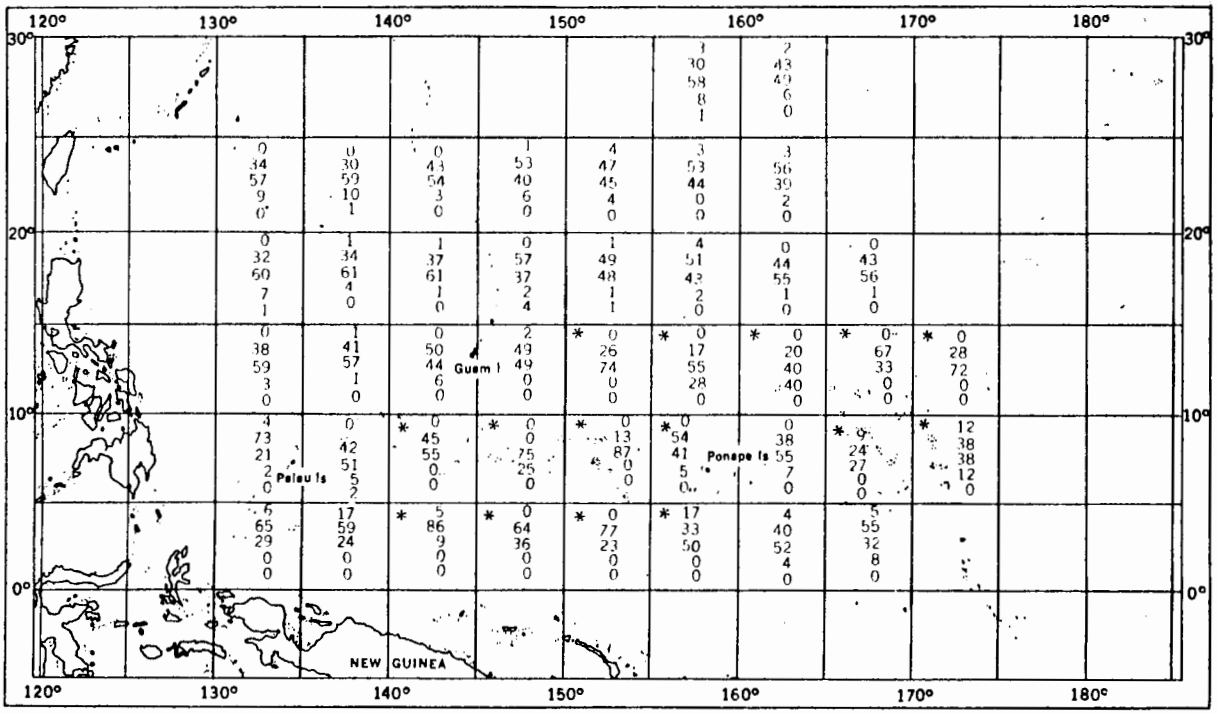

Figure 18.--Continued.

Table 1.--Normals, means, and extremes of meteorological observations at Koror, Palau, Caroline Islands 1941-70 (Environmental Data Service, 1973b).

Month	Temperature: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity: Hour 03 (Local time)	Hour 09	Hour 15	Hour 21	Wind &: Mean speed	Prevailing direction	Fastest mile: Speed	# Direction	Year	Pct of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max 90° and above	Max 32° and below	Min 32° and below	Min 0° and below	Average daily solar radiation: langleys
(a)	(b)	(b)	(b)	24		24		(b)	(b)	24		24		24		24	24		24		18	22	22	22	13	4	14	14		13	21	21	21	21	22	22	22	22	22	22	22	22	
J	86.4	74.9	81.2	91	1970+	70	1955	0	10.79	24.45	1956	2.11	1973	11.57	1955	0.0	0.0		0.0		90	81	76	88	8.5	NE	32	NE	1969	56	9.2	*	4	27	22	0	1	0	1	0	0	0	
F	86.5	75.0	80.7	92	1954	71	1972+	0	7.43	16.10	1964	1.24	1973	5.46	1965	0.0	0.0		0.0		90	81	75	86	8.7	ENE	30	SE	1968	61	9.1	*	4	24	19	0	1	0	1	0	0	0	
M	87.1	75.2	81.1	91	1971+	69	1953	0	7.79	21.98	1972	2.46	1955	6.17	1953	0.0	0.0		0.0		90	80	74	88	8.3	NE	73	S	1967	66	9.1	*	4	27	20	0	1	0	2	0	0	0	
A	88.1	75.8	81.9	93	1954	71	1950	0	8.69	16.94	1950	1.65	1948	5.33	1966	0.0	0.0		0.0		91	78	75	88	7.1	ENE	42	N	1969	69	8.9	*	6	24	19	0	2	0	6	0	0	0	
M	88.0	76.0	82.0	93	1972+	72	1971+	0	14.53	27.46	1954	8.25	1970	8.21	1958	0.0	0.0		0.0		92	81	78	90	6.3	E	29	SE	1968	58	9.0	*	5	26	24	0	4	0	9	0	0	0	
J	87.7	75.6	81.6	92	1973+	70	1948	0	13.75	22.67	1961	7.01	1968	5.82	1972	0.0	0.0		0.0		93	81	79	90	5.9	E	40	SW	1967	52	9.3	0	3	27	25	0	4	0	6	0	0	0	
J	87.1	75.2	81.1	93	1968+	70	1955+	0	16.19	34.82	1962	4.14	1964	8.23	1962	0.0	0.0		0.0		91	82	79	89	6.9	NW	34	W	1969	53	9.3	0	3	28	24	0	3	0	3	0	0	0	
A	87.0	75.4	81.2	93	1947	71	1967+	0	15.40	24.66	1952	8.92	1955	8.18	1962	0.0	0.0		0.0		91	81	78	88	6.5	SW	26	NE	1969+	53	9.4	*	3	28	24	0	4	0	3	0	0	0	
S	87.5	75.7	81.6	92	1967+	70	1950	0	12.99	20.79	1962+	6.75	1967	8.47	1949	0.0	0.0		0.0		89	81	78	88	6.9	W	34	N	1969	57	9.3	*	3	27	22	0	5	0	4	0	0	0	
O	87.9	75.9	81.9	92	1973+	71	1954+	0	12.59	19.59	1971	6.77	1951	6.18	1957	0.0	0.0		0.0		91	80	78	88	7.4	W	36	SW	1968	54	9.0	*	5	26	22	0	4	0	7	0	0	0	
N	88.0	75.8	81.9	92	1973+	70	1949	0	10.67	22.06	1958	4.70	1957	5.17	1967	0.0	0.0		0.0		92	80	77	89	6.6	NE	59	SE	1964	56	9.2	*	4	26	22	0	4	0	8	0	0	0	
D	87.2	75.4	81.3	92	1973	71	1958+	0	12.87	18.89	1948	6.32	1969	4.65	1962	0.0	0.0		0.0		91	81	77	89	7.6	ENE	50	N	1972	52	9.4	*	3	28	24	0	3	0	3	0	0	0	
YR	87.3	75.6	81.5	93	MAY 1972+	69	MAR. 1953	0	143.69	34.82	JUL. 1962	1.24	FEB. 1973	11.57	JAN. 1955	0.0	0.0		0.0		91	81	77	88	7.2	ENE	73	S	MAR. 1967	57	9.2	0	47	318	267	0	36	0	52	0	0	0	

Partial years data for 1947, 1949 and 1951 considered in extracting extremes of temperature and precipitation above.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological normals (1941-1970).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
— Below zero temperatures are preceded by a minus sign.
‡ ≤ 70° at Alaskan stations.

The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

To 8 compass points only.

Table 2.--Normals, means, and extremes of meteorological observations at Yap, Caroline Islands, 1941-70 (Environmental Data Service, 1973f).

Month	Temperature: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity (Local time): Hour 03	Hour 09	Hour 15	Hour 21	Wind &: Mean speed	Prevailing direction	Fastest mile: Speed	Direction #	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max. 90° and above	Max. 32° and below	Min. 32° and below	Min. 0° and below	Average daily solar radiation langleys
(a)	(b)	(b)	(b)	25		25		(b)	(b)	25		25		25		25	25		25		20	25	25	25	10	4	14	14		14	25	24	24	24	25	25	25	25	25	25	25	25	
J	85.3	75.6	80.4	90	1963+	69	1973	0	8.44	23.08	1955	2.14	1973	10.45	1958	0.0	0.0		0.0		87	78	76	85	10.5	NE	34	NE	1963	60	9.0	1	5	25	21	0	•	0	•	0	0	
F	85.5	75.6	80.5	92	1950	70	1969+	0	5.41	13.36	1962	1.00	1973	5.94	1962	0.0	0.0		0.0		86	78	75	84	11.0	NE	68	NE	1970	63	9.1	•	5	23	17	0	•	0	•	0	0	
M	86.2	75.8	81.0	90	1963+	69	1967	0	5.58	16.46	1950	1.38	1958	5.09	1963	0.0	0.0		0.0		86	76	74	84	10.1	NE	50	NE	1961	66	9.0	•	5	26	18	0	•	0	•	0	0	
A	87.2	76.3	81.7	97	1951	70	1967+	0	5.98	18.15	1956	1.82	1968	6.57	1962	0.0	0.0		0.0		87	76	74	85	8.6	NE	34	NW	1962	69	8.8	1	6	23	18	0	1	0	2	0	0	
M	87.5	76.2	81.8	93	1957+	70	1972+	0	10.03	18.23	1964	3.94	1968	10.06	1967	0.0	0.0		0.0		89	78	77	87	7.8	NE	33	E	1962	61	8.6	1	7	23	22	0	1	0	4	0	0	
J	87.6	75.8	81.7	94	1958	70	1967+	0	10.90	20.75	1952	3.40	1951	6.28	1953	0.0	0.0		0.0		91	79	77	88	6.1	NE	37	NE	1964	58	9.0	•	5	25	23	0	1	0	5	0	0	
J	87.2	75.2	81.2	96	1950	70	1971+	0	14.64	34.71	1969	4.99	1949	7.44	1969	0.0	0.0		0.0		92	80	78	89	5.8	SW	35	W	1962	52	9.3	1	3	27	25	0	2	0	4	0	0	
A	87.0	75.0	81.0	93	1957+	70	1971+	0	15.14	29.44	1953	5.13	1973	7.57	1970	0.0	0.0		0.0		91	81	79	89	5.5	SW	55	W	1962	53	9.4	•	3	28	25	0	2	0	5	0	0	
S	87.4	75.2	81.3	93	1956+	69	1961	0	13.09	19.57	1949	6.88	1953	5.87	1951	0.0	0.0		0.0		90	81	79	89	6.3	SW	34	SW	1965	52	9.3	•	5	25	24	0	3	0	5	0	0	
O	87.6	75.2	81.4	93	1957+	69	1971	0	12.42	21.16	1961	5.64	1972	5.32	1961	0.0	0.0		0.0		92	81	79	90	6.0	W	37	SW	1962	48	9.0	1	5	25	24	0	2	0	6	0	0	
N	87.3	75.7	81.5	93	1956+	69	1960	0	10.03	20.66	1960	1.96	1957	8.91	1960	0.0	0.0		0.0		90	80	79	89	7.5	NE	72	SW	1960	58	9.0	•	6	24	23	0	2	0	3	0	0	
D	86.1	75.9	81.0	94	1955	65	1973	0	9.88	17.05	1954	3.65	1957	5.05	1955	0.0	0.0		0.0		88	79	78	87	9.0	NE	72	SW	1960	55	9.0	1	6	24	23	0	2	0	1	0	0	
YR	86.8	75.6	81.2	97	APR. 1951	65	DEC. 1973	0	121.54	34.71	JUL. 1969	1.00	FEB. 1973	10.45	JAN. 1958	0.0	0.0		0.0		89	79	77	87	7.8	NE	72	SW	DEC. 1960+	58	9.0	6	61	298	261	0	16	0	36	0	0	0	

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological normals (1941-1970).
• Less than one half.
+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
— Below zero temperatures are preceded by a minus sign.
‡ ≦ 70° at Alaskan stations.

The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

To 8 compass points only.

% Data may be incomplete due to part time operation of station from June 1970 to date.

Table 3.--Normals, means, and extremes of meteorological observations at Truk, Caroline Islands, 1941-70 (Environmental Data Service, 1973e).

Month	Temperature: Normal: Daily maximum	Temperature: Normal: Daily minimum	Temperature: Normal: Monthly	Temperature: Extremes: Record highest	Temperature: Extremes: Year	Temperature: Extremes: Record lowest	Temperature: Extremes: Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Precipitation: Maximum monthly	Precipitation: Year	Precipitation: Minimum monthly	Precipitation: Year	Precipitation: Maximum in 24 hrs	Precipitation: Year	Precipitation: Snow, ice pellets: Mean total	Precipitation: Snow, ice pellets: Maximum monthly	Precipitation: Snow, ice pellets: Year	Precipitation: Snow, ice pellets: Maximum in 24 hrs	Precipitation: Snow, ice pellets: Year	Relative humidity: Hour 04 (Local time)	Relative humidity: Hour 10 (Local time)	Relative humidity: Hour 16 (Local time)	Relative humidity: Hour 22 (Local time)	Wind & Fastest mile: Mean speed	Wind & Fastest mile: Prevailing direction	Wind & Fastest mile: Speed	Wind & Fastest mile: Direction #	Wind & Fastest mile: Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets .1/2 inch or more	Thunderstorms	Heavy fog	Temperatures: Max: 90° and above	32° and below	Min.: 32 and below	0° and below	Average daily solar radiation - langleys
(a)	(b)	(b)	(b)	23		23		(b)	(b)	24		24		24		24	24		24		18	22	22	22	13	4	15	15		13	22	22	22	22	22	22	22	22	22	22	22	22	22	22	22	
J	85.2	76.9	81.0	91	1969	71	1963+	0	8.59	15.71	1951	0.96	1959	6.22	1965	0.0	0.0		0.0		82	76	76	81	10.4	NNE	35	E	1968	64	9.0	*	5	26	19	0	1	0	*	0	0	0	0		
F	85.3	76.9	81.1	91	1946	70	1963	0	6.40	11.80	1970	0.84	1950	6.59	1970	0.0	0.0		0.0		81	76	76	81	11.4	NNE	31	S	1962	61	9.2	*	3	25	17	0	*	0	0	0	0	0	0		
M	85.5	77.1	81.3	94	1946	71	1968	0	7.98	24.02	1967	2.30	1950	8.21	1972	0.0	0.0		0.0		83	76	76	81	10.6	NNE	28	SE	1961	68	9.2	*	3	28	18	0	1	0	0	0	0	0	0		
A	85.9	76.8	81.3	90	1958+	71	1967+	0	13.17	23.38	1956	5.62	1952	6.51	1967	0.0	0.0		0.0		85	79	78	84	9.5	NNE	40	NE	1971	63	9.1	*	4	26	21	0	1	0	*	0	0	0	0		
M	86.4	76.3	81.3	94	1946	71	1952	0	15.74	23.57	1955	8.41	1953	6.61	1962	0.0	0.0		0.0		87	80	80	86	8.3	NNE	78	S	1971	59	9.1	*	4	27	25	0	2	0	*	0	0	0	0		
J	86.8	75.8	81.3	93	1957	70	1965	0	12.59	21.72	1950	6.10	1966	7.61	1972	0.0	0.0		0.0		88	79	79	86	7.1	NNE	40	SW	1972	59	9.1	*	5	25	24	0	2	0	*	0	0	0	0		
J	86.5	75.0	80.7	92	1958	70	1968+	0	15.41	32.99	1962	7.49	1970	10.07	1962	0.0	0.0		0.0		91	80	79	88	7.4	SE	41	NW	1962	59	8.9	*	6	25	25	0	2	0	1	0	0	0	0		
A	86.8	75.0	80.9	92	1959+	70	1968+	0	13.44	20.42	1953	5.37	1949	4.91	1963	0.0	0.0		0.0		90	79	78	88	6.7	S	32	NW	1972+	63	8.9	*	6	25	25	0	1	0	1	0	0	0	0		
S	86.9	75.1	81.0	91	1966+	68	1973	0	13.07	21.17	1955	7.39	1949	5.16	1961	0.0	0.0		0.0		90	80	78	88	7.7	SW	50	SW	1972	60	9.0	*	5	25	23	0	2	0	1	0	0	0	0		
O	86.9	75.4	81.1	92	1960+	70	1953+	0	13.39	22.42	1955	4.17	1972	6.55	1968	0.0	0.0		0.0		89	79	78	87	7.8	S	40	S	1959	56	8.9	1	4	26	23	0	3	0	1	0	0	0	0		
N	86.7	76.0	81.3	91	1959	71	1962+	0	11.99	26.12	1962	5.20	1971	10.41	1962	0.0	0.0		0.0		88	79	79	86	7.8	NNE	45	N	1962	60	9.0	*	4	26	24	0	3	0	*	0	0	0	0		
D	85.8	76.8	81.3	91	1968	70	1968	0	13.92	34.89	1959	3.43	1957	14.92	1959	0.0	0.0		0.0		85	79	79	84	9.5	NNE	33	E	1971+	56	9.2	*	5	26	24	0	2	0	*	0	0	0	0		
YR	86.2	76.0	81.1	94	MAY 1946+	68	SEP. 1973	0	145.69	34.89	DEC. 1959	0.84	FEB. 1950	14.92	DEC. 1959	0.0	0.0		0.0		87	78	78	85	8.7	NNE	78	S	MAY 1971	61	9.0	1	54	310	268	0	21	0	5	0	0	0		

January - May 1946, August - December 1949, January - April and July - December 1951 data considered in extracting extremes of temperature.
January - May 1946, August - December 1947 and 1949, January - April and July - December 1951 data considered in extracting extremes of precipitation.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological normals (1941-1970).
* Less than one half.
+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
- Below zero temperatures are preceded by a minus sign.
‡ ≥ 70° at Alaskan stations.

The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

To 8 compass points only.

Table 4.--Normals, means, and extremes of meteorological observations at Ponape, Caroline Islands, 1941-70 (Environmental Data Service, 1973d).

Month	Temperature: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs	Year	Snow, ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs	Year	Relative humidity (Local time): Hour 05	Hour 11	Hour 17	Hour 23	Wind &: Mean speed	Prevailing direction	Fastest mile: Speed	Direction #	Year	Pct. of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max. 90° and above	32° and below	Min. 32° and below	0° and below	Average daily solar radiation - langleys
(a)	(b)	(b)	(b)	23		23		(b)	(b)	23		23		23		23	23		23		18	22	22	22	14	4	15	15		15	21	21	21	21	22	22	22	22	22	22	22	22	
J	85.8	75.5	80.6	90	1971+	69	1973+	0	11.75	26.67	1962	3.31	1973	5.04	1954	0.0	0.0		0.0		84	76	78	83	8.6	NE	28	SE	1965	48	9.0	•	5	26	22	0	1	0	•	0	0	0	
F	85.8	75.7	80.7	92	1950	67	1969	0	11.44	19.76	1964	1.71	1966	8.91	1968	0.0	0.0		0.0		83	77	77	82	9.6	NE	26	NE	1967	47	9.0	•	4	24	20	0	1	0	•	0	0	0	
M	86.3	75.4	80.8	95	1950	69	1971+	0	13.04	24.47	1968	6.36	1965	7.13	1967	0.0	0.0		0.0		86	77	79	85	8.4	NE	36	E	1959	54	9.1	•	4	27	22	0	1	0	1	0	0	0	
A	86.5	74.9	80.7	92	1953	68	1972	0	19.58	38.65	1959	6.07	1966	8.05	1959	0.0	0.0		0.0		89	79	81	88	7.3	NE	26	NE	1973	48	9.1	•	4	26	25	0	1	0	1	0	0	0	
M	86.8	74.6	80.7	92	1950	69	1964	0	19.43	33.46	1972	11.72	1953	7.00	1972	0.0	0.0		0.0		91	80	82	90	6.6	NE	29	SW	1972	46	9.0	•	5	26	28	0	2	0	3	0	0	0	
J	87.1	73.9	80.5	91	1968+	69	1964+	0	15.66	24.88	1969	9.60	1963	5.01	1973	0.0	0.0		0.0		93	79	80	91	5.6	NE	26	SW	1972	51	8.8	•	6	24	27	0	3	0	2	0	0	0	
J	87.2	72.9	80.0	91	1973+	68	1950	0	17.82	37.20	1965	9.40	1973	7.07	1965	0.0	0.0		0.0		95	79	80	94	4.9	E	23	SE	1962	49	8.7	•	6	25	27	0	4	0	3	0	0	0	
A	87.6	72.6	80.1	93	1959+	69	1971+	0	16.70	26.41	1953	10.06	1965	5.86	1953	0.0	0.0		0.0		96	79	80	94	4.5	ESE	32	NE	1973	53	8.6	•	8	23	27	0	3	0	5	0	0	0	
S	87.7	73.5	80.6	96	1950	68	1970+	0	16.76	29.53	1972	9.89	1971	6.99	1972	0.0	0.0		0.0		96	78	80	94	4.7	S	26	E	1970	51	8.7	1	5	24	25	0	3	0	6	0	0	0	
O	87.7	72.7	80.2	94	1957	68	1955	0	16.42	21.32	1973	7.98	1972	5.31	1973	0.0	0.0		0.0		95	78	79	93	4.8	ESE	28	SW	1972+	46	8.6	1	6	24	25	0	3	0	7	0	0	0	
N	87.3	73.4	80.3	92	1957+	66	1969	0	17.17	31.79	1957	4.55	1963	22.48	1957	0.0	0.0		0.0		93	79	81	91	5.6	NE	29	SW	1967	49	8.7	•	6	24	25	0	4	0	4	0	0	0	
D	86.6	74.7	80.6	91	1969+	68	1955	0	15.95	26.11	1959	2.40	1957	6.06	1954	0.0	0.0		0.0		88	78	80	86	7.7	NE	35	NE	1973	44	8.9	•	6	25	24	0	2	0	2	0	0	0	
YR	86.9	74.1	80.5	96	SEP. 1950	66	NOV. 1969	0	193.72	38.65	APR. 1959	1.71	FEB. 1966	22.48	NOV. 1957	0.0	0.0		0.0		91	78	80	89	6.5	NE	36	E	MAR. 1959	49	8.8	2	65	298	297	0	29	0	34	0	0	0	

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological normals (1941-1970).
• Less than one half.
+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
— Below zero temperatures are preceded by a minus sign.
‡ ≤ 70° at Alaskan stations.

The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North: i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

To 8 compass points only.

Table 5.--Normals, means, and extremes of meteorological observations at Majuro, Marshall Islands, 1941-70 (Environmental Data Service, 1973c).

Month	Temperature: Normal: Daily maximum	Daily minimum	Monthly	Extremes: Record highest	Year	Record lowest	Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs	Year	Snow, ice pellets: Mean total	Maximum monthly	Year	Maximum in 24 hrs	Year	Relative humidity: Hour 00 (Local time)	Hour 06	Hour 12	Hour 18	Wind &: Mean speed	Prevailing direction	Fastest mile: Speed	# Direction	Year	Pct of possible sunshine	Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset: Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets 1.0 inch or more	Thunderstorms	Heavy fog	Temperatures: Max 90° and above	32° and below	Min 32° and below	0° and below	Average daily solar radiation - langleys
(a)	(b)	(b)	(b)	18		18		(b)	(b)	19		19		19		19	19		19		17	18	18	17	14	4	15	15		13	17	17	17	17	19	19	17	18	19	19	19	19	
J	84.7	77.0	80.8	88	1961+	69	1958	0	8.96	21.97	1961	0.78	1973	9.57	1961	0.0	0.0		0.0		80	81	75	77	12.9	ENE	38	NE	1967	59	8.5	1	7	23	16	0	*	0	0	0	0	0	0	
F	85.1	77.3	81.2	88	1962	72	1963+	0	6.98	18.34	1957	0.40	1970	6.28	1957	0.0	0.0		0.0		80	80	74	77	14.0	ENE	35	E	1962	59	8.2	1	8	19	15	0	1	0	0	0	0	0	0	
M	85.3	77.1	81.2	88	1961+	70	1963	0	9.25	18.51	1955	1.73	1970	8.14	1972	0.0	0.0		0.0		81	81	75	78	13.3	ENE	36	NE	1959	62	8.4	1	7	23	18	0	1	0	0	0	0	0	0	
A	85.3	76.9	81.1	88	1973+	70	1955	0	10.31	31.10	1971	2.87	1970	6.63	1973	0.0	0.0		0.0		83	84	78	80	12.0	ENE	35	E	1963	55	8.6	1	6	23	22	0	1	0	0	0	0	0	0	
M	85.6	77.0	81.3	89	1963	71	1958	0	12.15	22.23	1956	4.93	1967	5.86	1962	0.0	0.0		0.0		84	85	78	81	11.0	ENE	38	E	1962	56	8.5	1	7	23	24	0	1	0	0	0	0	0	0	
J	85.4	76.6	81.0	89	1966	70	1958+	0	12.17	16.07	1968	7.54	1962	6.73	1972	0.0	0.0		0.0		84	84	78	80	9.6	ENE	38	NE	1964	52	8.6	*	7	23	24	0	2	0	0	0	0	0	0	
J	85.5	76.6	81.0	89	1969+	72	1973+	0	13.64	18.69	1964	5.34	1961	5.39	1971+	0.0	0.0		0.0		83	84	77	79	8.6	ENE	34	E	1973+	54	8.5	1	6	24	24	0	2	0	0	0	0	0	0	
A	86.0	77.0	81.5	91	1969	71	1955	0	11.78	16.72	1956	5.33	1959	4.01	1970	0.0	0.0		0.0		82	83	77	78	7.3	ENE	32	NE	1970+	61	8.3	1	8	22	23	0	2	0	*	0	0	0	0	
S	86.1	76.7	81.4	90	1969+	72	1969+	0	14.39	21.11	1964	6.83	1963	5.47	1972	0.0	0.0		0.0		82	84	76	78	7.2	E	36	E	1973	58	8.6	1	6	23	23	0	3	0	*	0	0	0	0	
O	86.0	76.6	81.3	91	1958	70	1967	0	16.00	24.26	1955	7.11	1969	7.19	1955	0.0	0.0		0.0		82	83	77	79	7.6	E	35	NW	1963	54	8.6	1	6	24	24	0	2	0	*	0	0	0	0	
N	85.6	76.8	81.2	89	1966	72	1973+	0	15.38	22.69	1962	4.53	1972	10.01	1957	0.0	0.0		0.0		82	83	77	80	9.0	E	36	E	1967	55	8.4	1	8	21	23	0	2	0	0	0	0	0	0	
D	85.2	77.0	81.1	88	1968+	70	1958	0	11.88	24.80	1968	2.28	1957	17.88	1972	0.0	0.0		0.0		81	82	76	79	12.6	ENE	38	E	1973+	51	8.6	1	7	23	21	0	1	0	0	0	0	0	0	
YR	85.4	76.9	81.2	91	AUG. 1969+	69	JAN. 1958	0	142.89	31.10	APR. 1971	0.40	FEB. 1970	17.88	DEC. 1972	0.0	0.0		0.0		82	83	76	79	10.4	ENE	38	E	DEC. 1973+	56	8.5	11	83	271	257	0	17	0	1	0	0	0	0	

March - December 1955 data considered in extracting extremes above.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological normals (1941-1970).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
- Below zero temperatures are preceded by a minus sign.
‡ ≤ 70° at Alaskan stations.

The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

To 8 compass points only.

Table 6.--Means, totals, extremes, and number of years various meteorological observations were made at Jaluit, Marshall Islands (U.S. Weather Bureau, 1943).

STATION: JALUIT, MARSHALL ISLANDS. POSITION: LATITUDE 5°55' N., LONGITUDE 169°38' E. ALTITUDE 20 FEET

Month	Air Temp. °F.					Relative humidity (percent)		Cloud amount (0-10)		Rainfall			1400		Wind									Predominant winds or calm	Average number of days with—		
	Mean			Extreme											Percentages of observations from—												
	Monthly	Maximum	Minimum	Maximum	Minimum	0700	1400	0700	1400	Av. amount (inches)	Number of rainy days [1]	Max., 24 hrs. (inches)	Mean velocity (knots) 0700	Mean velocity (knots)	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm		Fog	Gales	Thunder
January	82	86	77	98	72	85	78	6.6	6.5	10.2	16.7	6.9	13.4	11.5	2	67	18	7	1	1	*	0	4				0.4
February	82	87	78	97	72	82	77	5.7	6.4	8.5	13.0	3.2	13.4	11.9	2	59	24	9	2	*	0	0	4				0.8
March	83	88	78	95	71	81	77	5.8	6.8	14.2	18.2	6.0	12.9	12.3	*	65	23	8	*	0	0	0	4				1.2
April	82	87	78	94	71	83	79	6.8	7.1	15.8	20.4	8.2	11.5	9.6	2	44	34	12	2	1	*	*	5				1.1
May	82	87	77	94	71	83	80	6.3	7.1	16.6	23.1	4.1	9.6	8.8	1	39	38	9	2	1	*	1	9				1.4
June	82	87	77	93	72	82	79	6.0	6.9	15.3	21.6	6.9	9.6	9.2	1	45	37	7	1	1	1	0	7				1.8
July	82	88	77	95	71	82	77	6.6	6.8	15.4	22.1	11.1	6.7	5.6	1	34	32	13	2	1	*	2	15				2.1
August	82	88	77	94	71	81	75	6.1	6.5	12.0	19.9	6.0	5.2	4.8	1	31	30	15	3	2	1	1	16				2.1
September	82	88	77	95	71	80	75	5.8	6.5	13.1	20.0	4.7	5.2	4.4	1	14	20	29	10	3	1	1	21				1.8
October	84	90	77	97	72	80	73	5.9	6.6	12.2	20.2	7.3	6.7	7.0	4	15	26	29	6	4	2	2	12				1.5
November	82	88	77	98	70	81	77	6.6	7.0	11.9	19.8	3.7	8.8	8.7	4	36	28	19	3	2	*	1	7				1.6
December	82	87	77	98	72	84	78	6.5	7.0	13.6	19.8	7.6	12.3	11.5	3	61	21	8	1	1	*	1	4				0.9
Mean	82	88	77			82	77	6.2	6.8				9.6	8.8	2	42	28	14	3	1	*	1	9				
Total										159	235																16.7
Extreme				98	70							11.1															
Number of years	8	8	8	4	4	8	3	5	6	17	11	16	6	6					6								11

Authority: South Sea Bureau
Mitteilungen aus den Deutschen Schutzgebeiten Vol. 30, 1917
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*Less than 0.5 percent
[1]Days with .01 inch or more

Table 7.--Means, totals, extremes, and number of years various meteorological observations were made at Ujelang, Marshall Islands (U.S. Weather Bureau, 1943).

STATION: UJELANG, MARSHALL ISLANDS. POSITION: LATITUDE 9°46' N., LONGITUDE 160°58' E. ALTITUDE 33 FEET

Month	Air Temp. °F					Relative humidity (percent)		Cloud amount (0-10)		Rainfall			1400		Wind									Predominant winds or calm	Average number of days with—		
	Mean			Extreme											Percentages of observations from—												
	Monthly	Maximum	Minimum	Maximum	Minimum	0700	1400	0700	1400	Av. amount (inches)	Number of rainy days	Max., 24 hrs. (inches)	Mean velocity (knots) 0700	Mean velocity (knots)	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm		Fog	Gales	Thunder
January	81	84	77	90	72	81	77	4.6	4.2	2.1	13	2.4	19.5	19.5	0	50	48	1	0	0	0	0	1	----	----	1.5	----
February	81	85	77	91	72	82	76	4.6	4.0	1.8	13	2.1	19.5	19.1	0	45	54	1	0	0	0	0	0	----	----	.5	----
March	81	86	77	91	73	82	76	4.4	3.9	2.6	12	6.3	18.0	17.5	0	44	53	2	0	0	0	0	1	----	----	.0	----
April	82	86	77	91	73	84	78	4.9	4.8	5.3	17	5.7	16.4	15.4	0	31	62	5	1	1	0	0	0	----	----	.0	----
May	82	87	78	90	73	85	79	5.1	4.7	6.6	19	3.4	13.4	13.4	0	23	68	7	1	1	0	0	0	----	----	.0	----
June	82	87	78	90	73	85	79	5.0	4.8	7.1	21	7.1	12.3	12.4	0	25	67	7	0	0	0	0	1	----	----	.3	----
July	83	88	77	93	72	86	79	5.1	4.9	8.4	23	5.7	10.1	10.5	1	19	61	9	2	2	3	1	2	----	----	.0	----
August	83	88	77	94	71	87	78	4.8	4.8	8.5	22	4.5	7.5	8.8	4	13	44	13	5	7	6	3	5	----	----	.0	----
September	83	88	77	93	73	87	80	5.4	5.3	10.3	24	5.0	8.3	8.8	5	16	34	12	7	9	7	4	6	----	----	.0	----
October	83	88	77	95	73	87	80	5.3	5.3	10.4	23	5.2	9.6	10.1	4	18	44	11	5	6	6	3	3	----	----	.0	----
November	82	87	78	92	73	86	80	5.1	5.0	9.6	22	11.7	13.4	13.4	1	28	55	9	2	2	1	1	1	----	----	.0	----
December	82	86	78	90	72	82	78	4.7	4.4	4.9	19	3.9	19.5	19.5	0	42	56	2	0	0	0	0	0	----	----	.0	----
Mean	82	87	77	----	----	84	78	4.9	4.7	----	----	----	14.0	14.1	1	29	54	7	2	2	2	1	2	----	----	----	----
Total	----	----	----	----	----	----	----	----	----	77.4	228	----	----	----	----	----	----	----	----	----	----	----	----	----	----	2.3	----
Extreme	----	----	----	95	71	----	----	----	----	----	----	11.7	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Number of years	4-5	8	4	8		6-7	6-8	16	15	17	16	16	16	15	13-14											4	

Authority: Deutsch Uberseeische Meteorologische Beobachtungen
Mitteilungen aus den Deutschen Schutzgebeiten
Department of Agr. - Reed

Table 8.--Normals, means, and extremes of meteorological observations at Guam, Mariana Islands, 1941-70 (Environmental Data Service, 1973a).

Month	Temperature: Normal: Daily maximum	Temperature: Normal: Daily minimum	Temperature: Normal: Monthly	Temperature: Extremes: Record highest	Temperature: Extremes: Year	Temperature: Extremes: Record lowest	Temperature: Extremes: Year	Normal heating degree days (Base 65°)	Precipitation: Normal total	Precipitation: Maximum monthly	Precipitation: Year	Precipitation: Minimum monthly	Precipitation: Year	Precipitation: Maximum in 24 hrs	Precipitation: Year	Precipitation: Snow, ice pellets: Mean total	Precipitation: Snow, ice pellets: Maximum monthly	Precipitation: Snow, ice pellets: Year	Precipitation: Snow, ice pellets: Maximum in 24 hrs	Precipitation: Snow, ice pellets: Year	Relative humidity: Hour 04 (Local time)	Relative humidity: Hour 10 (Local time)	Relative humidity: Hour 16 (Local time)	Relative humidity: Hour 22 (Local time)	Wind & : c : Mean speed	Wind & : # : Prevailing direction	Wind & : Fastest mile: Speed	Wind & : Fastest mile: Direction #	Wind & : Fastest mile: Year	Pct. of possible sunshine	$: Mean sky cover sunrise to sunset	Mean number of days: Sunrise to sunset $: Clear	Partly Cloudy	Cloudy	Precipitation .01 inch or more	Snow, ice pellets .10 inch or more	Thunderstorms	% : Heavy fog	% : 90 and above	Temperatures: Max: 32 and below	Temperatures: Min: 32 and below	Temperatures: Min: 0 and below	Average daily Solar radiation langleys
(a)	(b)	(b)	(b)	17		17		(b)	(b)	17		17		17		17	17		17		3	6	6	5	6	7	15	15		12	3	3	3	3	17	17	11	11	17	17	17	17	
J	83.2	71.5	77.3	87	1962	58	1973	0	5.16	11.93	1970	1.99	1964	4.98	1970	0.0	0.0		0.0		88	78	77	87	8.2	E	31	E	1962	56	8.0	1	11	19	20	0	1	0	0	0	0	0	
F	83.3	71.3	77.3	88	1960	59	1959	0	4.26	9.47	1963	0.67	1960	3.49	1962	0.0	0.0		0.0		88	75	74	85	10.2	NE	36	NE	1962	60	8.0	1	9	18	18	0	0	0	0	0	0	0	
M	84.5	71.0	77.7	89	1965	54	1965	0	2.94	16.94	1971	0.59	1965	3.33	1972	0.0	0.0		0.0		86	76	74	86	9.0	E	29	NE	1972	67	7.6	1	13	15	18	0	0	0	0	0	0	0	
A	85.6	72.5	79.0	90	1960	59	1965	0	4.03	19.35	1963	0.50	1965	2.29	1962	0.0	0.0		0.0		90	73	72	87	8.9	E	64	SW	1963	66	7.8	1	10	19	20	0	1	0	*	0	0	0	
M	86.4	73.1	79.4	91	1970	62	1960	0	4.49	22.68	1971	0.90	1959	9.92	1971	0.0	0.0		0.0		92	72	72	89	8.3	E	47	E	1971	65	6.9	*	19	12	19	0	1	0	1	0	0	0	
J	86.7	72.9	79.8	91	1959+	63	1972	0	5.19	11.53	1958	1.52	1969	4.55	1958	0.0	0.0		0.0		92	76	75	90	6.4	E	30	SE	1970	62	7.5	1	13	16	23	0	2	0	2	0	0	0	
J	86.2	72.6	79.4	93	1966	66	1959	0	9.59	20.00	1972	4.74	1957	5.17	1969	0.0	0.0		0.0		94	79	79	92	5.1	E	34	E	1963	48	8.2	0	11	20	26	0	5	0	1	0	0	0	
A	86.1	72.2	79.1	91	1968+	67	1971	0	12.16	23.07	1967	3.87	1965	7.81	1971	0.0	0.3		0.0		96	81	79	94	4.8	E	32	W	1968	45	8.9	0	4	27	25	0	6	0	*	0	0	0	
S	85.8	72.4	79.1	95	1957	61	1958	0	14.08	22.28	1966	6.79	1969	7.48	1965	0.0	0.0		0.0		96	81	80	94	4.7	E	34	NE	1961	42	8.9	0	4	26	26	0	7	0	*	0	0	0	
O	85.6	72.3	78.9	91	1957	66	1968+	0	14.40	25.32	1969	6.89	1965	9.38	1969	0.0	0.0		0.0		95	80	80	93	6.2	E	44	W	1968	44	8.2	1	9	21	25	0	3	0	*	0	0	0	
N	85.3	73.2	79.2	89	1970+	62	1957	0	8.51	18.14	1957	2.08	1973	7.26	1957	0.0	0.0		0.0		91	79	80	91	7.8	E	80	NE	1962	51	7.7	0	14	16	24	0	2	0	0	0	0	0	
D	84.1	72.9	78.5	89	1966	61	1967+	0	5.85	16.19	1963	2.51	1967	6.09	1963	0.0	0.0		0.0		88	78	78	88	9.1	E	35	SW	1963	51	7.2	1	16	14	23	0	*	*	0	0	0	0	
YR	85.1	72.3	78.7	95	SEP. 1957	54	MAR. 1965	0	90.66	25.32	OCT. 1969	0.50	APR. 1965	9.92	MAY 1971	0.0	0.0		0.0		92	77	77	90	7.4	E	80	NE	NOV. 1962	55	7.9	7	135	223	207	0	27	*	4	0	0	0	

% Data through 1964 with station operating less than 24 hours daily, plus data for January 1970 through June 1971 based on 22 hourly observations per day. Beginning July 1971, data were based on observations at intervals of 3 hours. In 1972, the station operated less than full time with changes in schedule during the year.

(a) Length of record, years, based on January data. Other months may be for more or fewer years if there have been breaks in the record.
(b) Climatological normals (1941-1970).
* Less than one half.
\+ Also on earlier dates, months, or years.
T Trace, an amount too small to measure.
— Below zero temperatures are preceded by a minus sign.
‡ ≤ 70° at Alaskan stations.

The prevailing direction for wind in the Normals, Means, and Extremes table is from records through 1963.

Unless otherwise indicated, dimensional units used in this bulletin are: temperature in degrees F.; precipitation, including snowfall, in inches; wind movement in miles per hour; and relative humidity in percent. Heating degree day totals are the sums of negative departures of average daily temperatures from 65° F. Cooling degree day totals are the sums of positive departures of average daily temperatures from 65° F. Sleet was included in snowfall totals beginning with July 1948. The term "ice pellets" includes solid grains of ice (sleet) and particles consisting of snow pellets encased in a thin layer of ice. Heavy fog reduces visibility to 1/4 mile or less.

Sky cover is expressed in a range of 0 for no clouds or obscuring phenomena to 10 for complete sky cover. The number of clear days is based on average cloudiness 0-3, partly cloudy days 4-7, and cloudy days 8-10 tenths.

Solar radiation data are the averages of direct and diffuse radiation on a horizontal surface. The langley denotes one gram calorie per square centimeter.

& Figures instead of letters in a direction column indicate direction in tens of degrees from true North; i.e., 09 - East, 18 - South, 27 - West, 36 - North, and 00 - Calm. Resultant wind is the vector sum of wind directions and speeds divided by the number of observations. If figures appear in the direction column under "Fastest mile" the corresponding speeds are fastest observed 1-minute values.

c Data through 1964 and January 1970 to date — data for incomplete years not included.
To 8 compass points only.
$ For period 1968-1970.

At Palau Islands, which are located near the western edge of Micronesia, the northeast trades prevail in December-March (Table 1) ([U.S.] Environmental Data Service (EDS), 1973b). Winds are generally light to moderate at this time. In April, the frequency of northeast winds decreases while the frequency of east winds increases. By May, the predominant winds are from the east with southeast winds just as frequent as northeast ones. In June, the directions most frequently observed are east and southeast (U.S. Weather Bureau, 1943). From July to October, the south to west monsoons are prevalent. Winds are west-southwesterly with the Intertropical Convergence Zone (ITCZ) in the vicinity of Koror at this time (EDS, 1973b). By November, Koror is usually near the heart of the zone and this is reflected in the high frequency of calm periods and of light winds from all directions. Calms are frequent in all months except February-March. Winds are light in January-March, averaging 5.5 knots, and in June with an average of 3 knots.

East of Palau, the ITCZ lies near Yap during the northern summer particularly as it moves northward in July and returns southward in October (Table 2) (EDS, 1973f). The southwest monsoon gradually replaces the northeast trades in July and becomes well established by August (U.S. Weather Bureau, 1943). At this time, there are frequent periods of calm and light variable winds; however, heavy shifting winds can also occur particularly during periods of heavy showers or thunderstorms. The northeasterly wind gradually replaces the southwest monsoon in September-October. From November through June, Yap is under the influence of the northeast trade winds.

In the vicinity of Truk, the climate is primarily influenced by the northeasterlies from about November to June (Table 3) (EDS, 1973e). In April, however, the trades are beginning to diminish in strength and by July, Truk is influenced by lighter and more variable winds of the doldrums. In July-October, the island frequently comes under the influence of the ITCZ, which has moved northward into this vicinity. Also during this period, moist southerly winds are most frequent and humidity is often oppressively high.

The trade wind regime is unsteady at Ponape, resulting in frequent calms particularly in April-December (U.S. Weather Bureau, 1943). In January-March the wind velocity averages 7 knots but in July-October the wind speed diminishes to 3 knots during the monsoon (Table 4) (EDS, 1973d). Northeast to east trades prevail from December to April but in May-June southerly winds increasingly interrupt the trade winds. July-October winds are from the southwest but by November the trades gradually return and predominate.

At Majuro, the trade winds prevail throughout the year (EDS, 1973c). As in Truk and Ponape, Majuro comes under the influence of the ITCZ as it moves across the area during the summer and the trade winds are frequently interrupted (Table 5).

At Jaluit in the southern Marshalls, the trades from northeast to east strongly predominate from about December to June (Table 6) (U.S. Weather Bureau, 1943). During the remainder of the year, although the northeast to east trades continue to predominate, there are frequent periods of southeasterly and southerly winds. In June-December, winds are very light, averaging 1 to 3 knots, but in other months they vary between 5 and 8 knots.

In the northern Marshalls at Ujelang, wind velocity is higher than at Jaluit (U.S. Weather Bureau, 1943). In winter, the winds average 19 knots but gradually decrease to 8 or 9 knots by August-September (Table 7). The prevalent wind is from the east and northeast. Southeast to westerly winds interrupt the trades about half of the time in August-October.

At Guam in the Marianas, wind conditions vary markedly and define the seasons (EDS, 1973a). In winter, the dominant winds are easterly and east-northeasterly (Table 8). Although 70% of the annual winds are from the northeast to east, this figure may rise to 90% in December-April (U.S. Weather Bureau, 1943). In July-October, the trades, blowing out of the east, are often interrupted by southeast to southwest winds. The trades are most constant during the dry months of January-April (EDS, 1973a). During the wet season from mid-July to mid-November, there is often a weakening of the trades. And because Guam is situated near the dividing line of the Asiatic summer monsoon and the northeast trades, the prevailing wind direction in August-September is southwesterly in some years and northeasterly in others (U.S. Weather Bureau, 1943). Monthly wind velocity averages 3 to 7 knots with winter winds strongest. Variable winds are light.

RAINFALL

The atmosphere over the tropical oceans is saturated with moisture at all times, and any significant decrease in temperature to which the air masses are subjected will cause rain (Wiens, 1962). Islands with high and wide surfaces fronting the prevailing winds are likely to have more rainfall on the windward side, while on the leeward side moisture deficiency may occur. This windward-leeward difference in rainfall is reflected in differences in vegetation. Thus, it is difficult to describe patterns of average annual rainfall among the high volcanic Pacific islands.

Generally, the high average annual rainfalls are those occurring in tropical areas where differences in vertical temperature are largest (Wiens, 1962). The volume of air uplifted to bring about rain increases with the velocity of the wind carrying the moisture. There

are large geographical differences in the potential for precipitation because some parts of the Pacific have higher average wind velocities than others. Therefore, the western tropical Pacific is likely to have higher rainfall because of the higher frequency of typhoon occurrences. Figure 19 shows the frequency of rain or showers, thunderstorms, and squalls over the western Pacific Ocean.

Rainfall varies not only among areas in the Pacific but also among years (Wiens, 1962). The ITCZ is an area in which large-scale rising air masses bring comparatively large volumes of rain regardless of orography. However, this zone must not be looked upon as a fixed area which invariably gets high rainfall. Great fluctuations in annual rainfall are recorded on some of the low-lying atolls in the tropical Pacific. For example, Fanning Island, not far from the equator, recorded 208 in. (528 cm) of rainfall in 1905 but received only 28 in. (71 cm) in 1950.

In Micronesia, drizzle, the least common of all the types of sea rainfall, occurs occasionally in low latitudes (U.S. Weather Bureau, 1943). In higher latitudes, it is more frequent and is observed in 1%-2% of the monthly observations.

Rain and showers in Micronesia occur more frequently and they represent 15%-20% or more of the annual observations made between the equator and lat. 10°N (U.S. Weather Bureau, 1943). Based on island observations in the Caroline and Marshall groups, this latitudinal belt has the heaviest and most frequent rainfall. Ships' observations also showed that the area bounded by the equator and lat. 5°N between long. 140° and 145°E is the wettest locality. Seasonal differences in rainfall are not clearly discernible over the vast oceanic extent near the equator and this is reflected on the islands within this belt where wet or dry seasons are not as sharply differentiated as they are farther north.

This belt of heavy annual rainfall of 100 in. (254 cm) or more stretches from Palau through the other islands of the Caroline group to the southern Marshalls (U.S. Weather Bureau, 1943). Narrowing somewhat toward the Marshalls, this rainfall belt marks the ITCZ, the meeting zone of the North and South Pacific trade winds in the east and the easterly and westerly monsoons in the west. Orographic influences on rainfall are entirely lacking on islands that are low and small but are distinctly perceptible on high islands.

Rainfall in the Caroline Islands is shown by meteorological data collected at Palau, Yap, Truk, Ponape, and Kusaie. Palau is an example of high volcanic islands with orographic influences on rainfall. At Koror, Palau, precipitation is heavy with an average of 144 in. (366 cm) per year in 1941-70 and 150 in. (381 cm) or more in a year is not

FREQUENCY OF RAIN AND SHOWERS—THUNDERSTORMS AND SQUALLS

Charts 18 to 22.—Explanation

First or upper figures.— Percentage of rain and showers.
Second or middle figures.—Percentage of thunderstorms.
Third or lower figures.—Percentage of squalls.
*Denotes a square with less than 25 observations available for summarization.

The values given are percentages, in whole numbers and tenths, of observations (1879–1933) which recorded these elements.

For example.—In February in the square 5° N. to 10° N. and 130° E. to 135° E., 25.6 percent of all observations showed rain and showers, 4.6 percent recorded thunderstorms, and 11.6 percent recorded squalls.

CHART 18.—February.

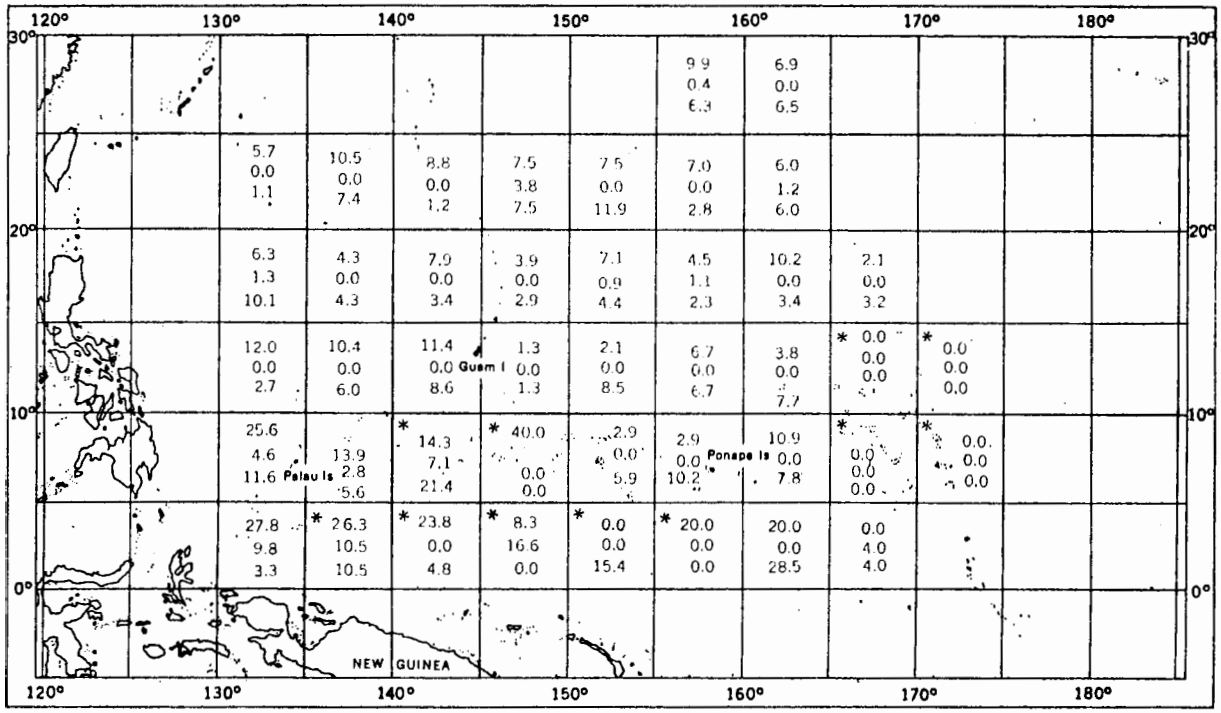

Figure 19.--Frequency of rain and showers, thunderstorms, and squalls in the western North Pacific Ocean in February (U.S. Weather Bureau, 1943).

CHART 19.—May.

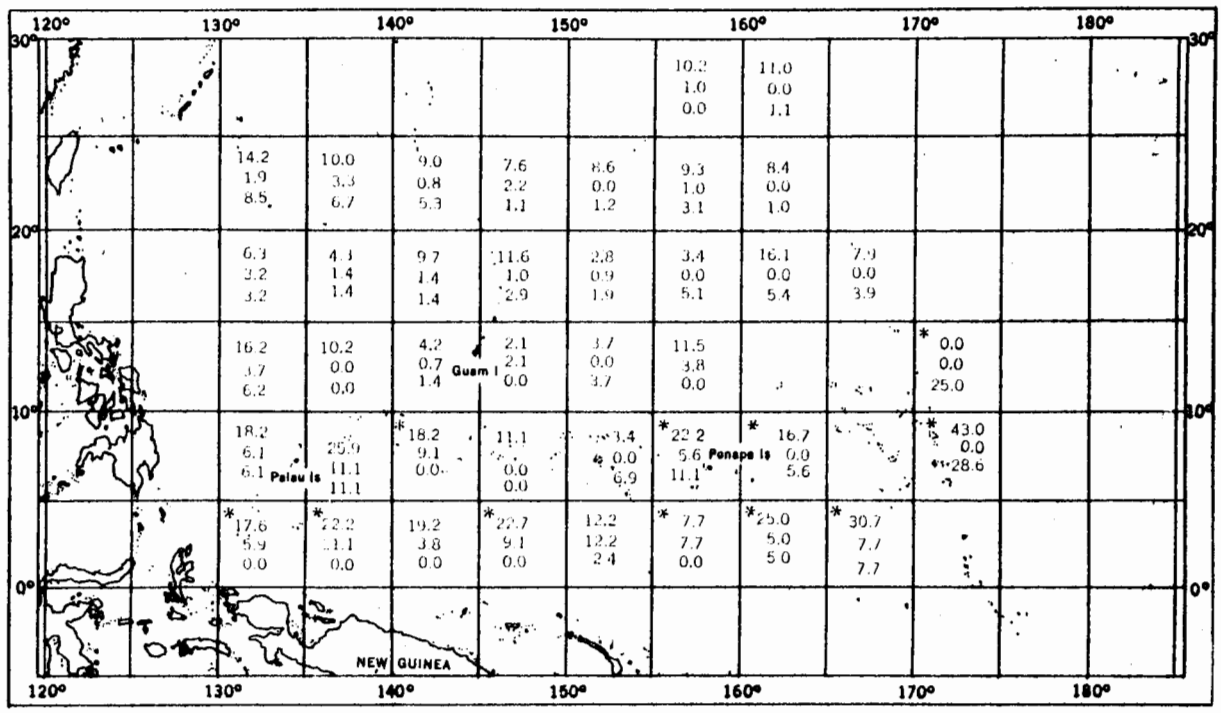

CHART 20.—July.

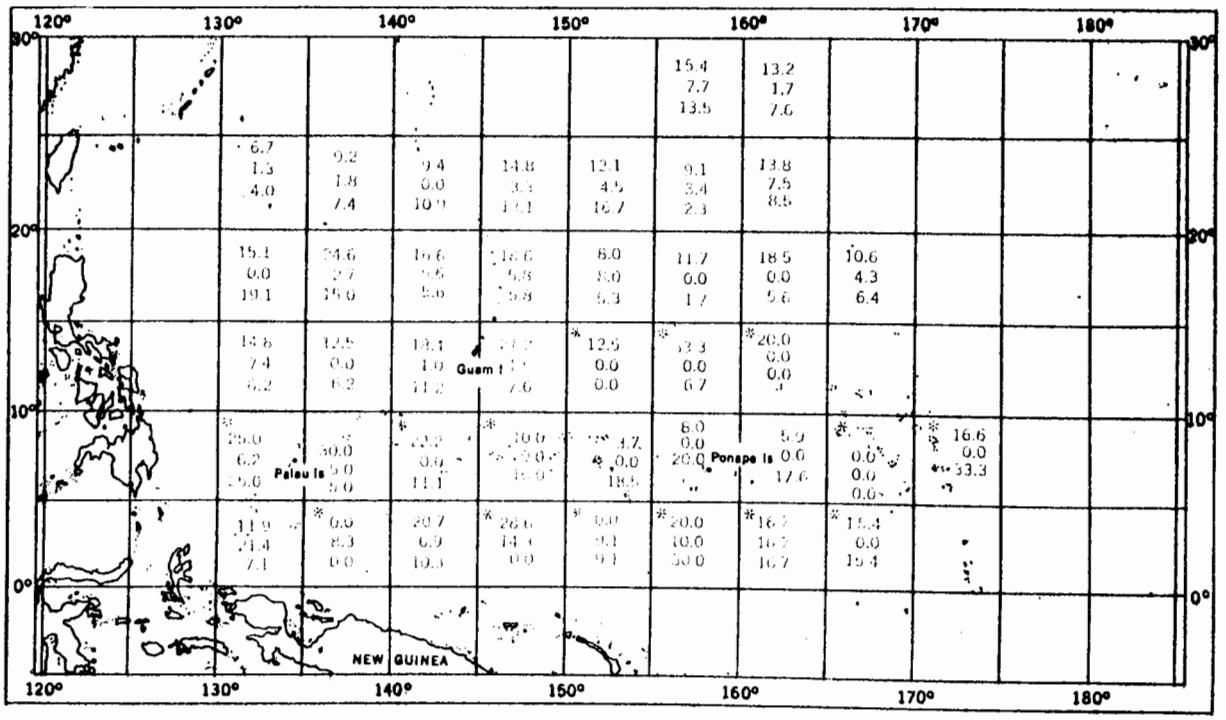

Figure 19.--Continued.

CHART 21.—October.

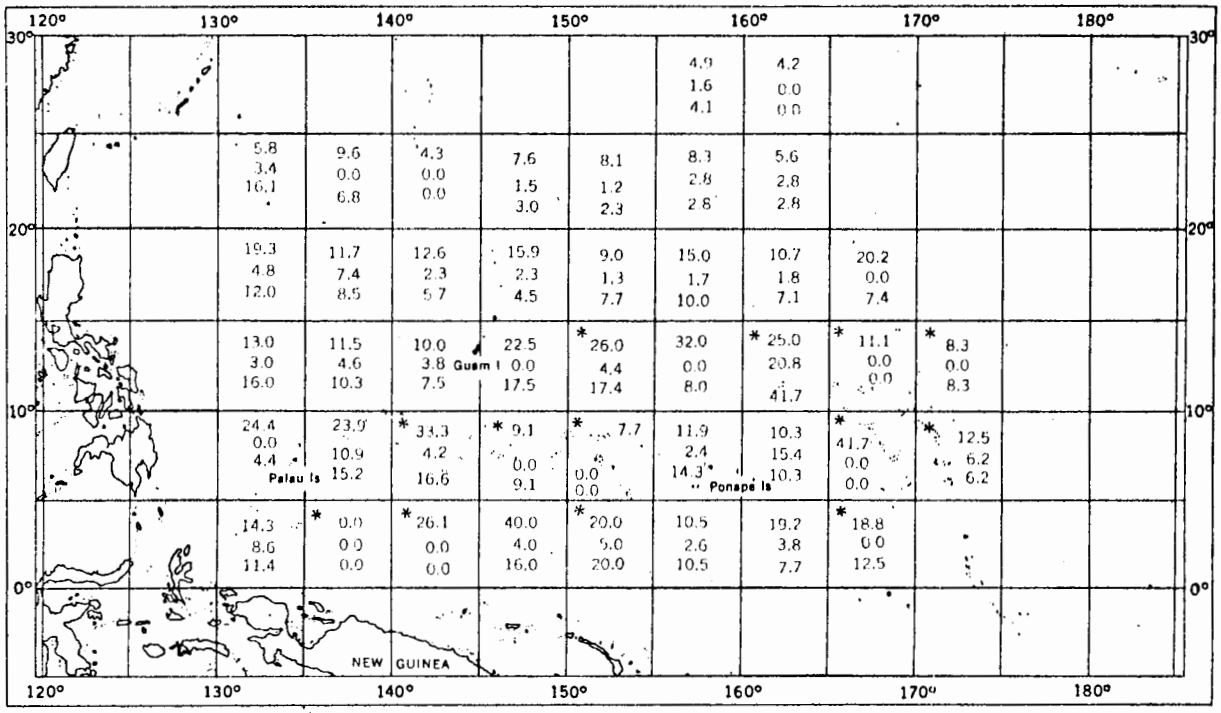

CHART 22.—December.

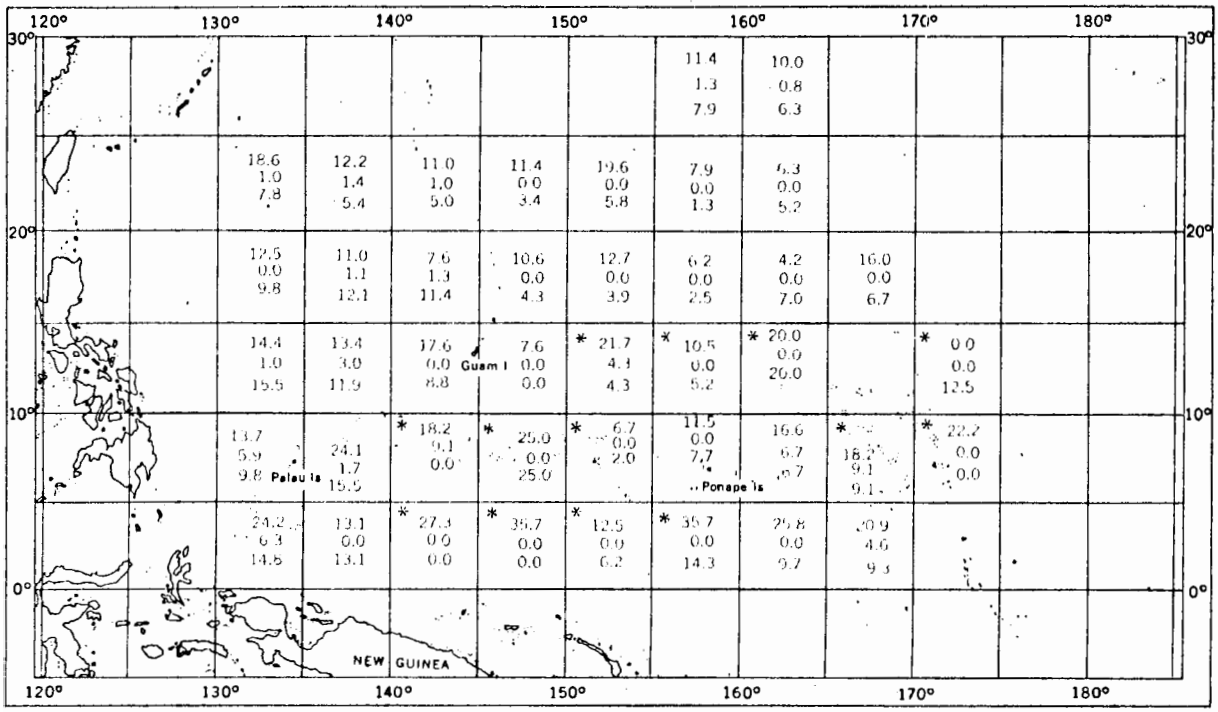

Figure 19.--Continued.

unusual (Table 1) (EDS, 1973b). Monthly rainfall is highly variable from year to year with monthly differences sometimes as much as 15-20 in.(38-51 cm). In all months except February, March, and April (Figure 20), which are the driest months of the year, normal precipitation exceeds 10 in.(25 cm). Rainfall, heaviest in December-January, decreases sharply when the ITCZ moves well south of the islands. Usually, sometime in June, the ITCZ moves northward across Koror, bringing with it heavy rainfall and thunderstorms. During this period, there may be as much as an inch (3 cm) of rain in 15-30 min. Because the ITCZ usually remains slightly north of Koror from July to October, heavy rainfall persists. The convergence zone is almost directly over Koror in November and this is reflected in the high frequency of calms and light winds and continued heavy rain.

Yap, which is 2° north of the 0°-10° latitudinal belt of heavy rainfall, is within the sweep of westerly summer monsoons (U.S. Weather Bureau, 1943). During the northern summer, the ITCZ lies near Yap as it moves northward and southward from July to October (EDS, 1973f). At this time, showers, interspersed with heavier showers and thunderstorms predominate. In 1941-70, the mean annual rainfall was 122 in.(310 cm). According to Table 2 and Figure 20, February-April are the driest months. In other months, normal rainfall exceeds 8 in. (20 cm), with July being the wettest. Cloudless days are rare at Yap. From May through December, a common daily occurrence is to have the morning's fair-weather clouds build up into towering cumulus by late afternoon followed by evening and early morning showers. In such showers visibility may be less than 5 mi (9 km).

Lamotrek atoll, which is in the Yap District but geographically located between the Yap and Truk groups, has an average annual rainfall of 104 in.(264 cm) (U.S. Weather Bureau, 1943). Table 9 and Figure 20 show that summer is the wettest period with the highest monthly rainfall of over 13 in.(33 cm) occurring in August. Late winter and early spring are the dry season with February usually the driest month of the year with an average rainfall of 6 in.(15 cm).

In 1941-70, rainfall at Truk averaged 146 in.(371 cm) annually (Table 3) (EDS, 1973e). At Truk, the relatively dry period from January to March, when monthly rainfall averages 8 in.(20 cm) or less, is the most pleasant time of the year (Figure 20). February is the driest month with an average of only 6 in.(15 cm) and 17-19 days of measurable rain. In April-December, monthly averages vary between 12 and 16 in. (30 and 41 cm) with 21-25 rainy days per month. Rainfall varies widely from month to month as well as from year to year in amount and in seasonal distribution. Even in the dry season from January to March, monthly rainfall has been as much as 24 in.(61 cm) in some years; however, dry spells are not uncommon, and rainfall has been observed to be less than an inch (3 cm) at this time of the year. Annually, rainfall at Truk has been as low as 120 in.(305 cm) and as high as 180 in.(457 cm).

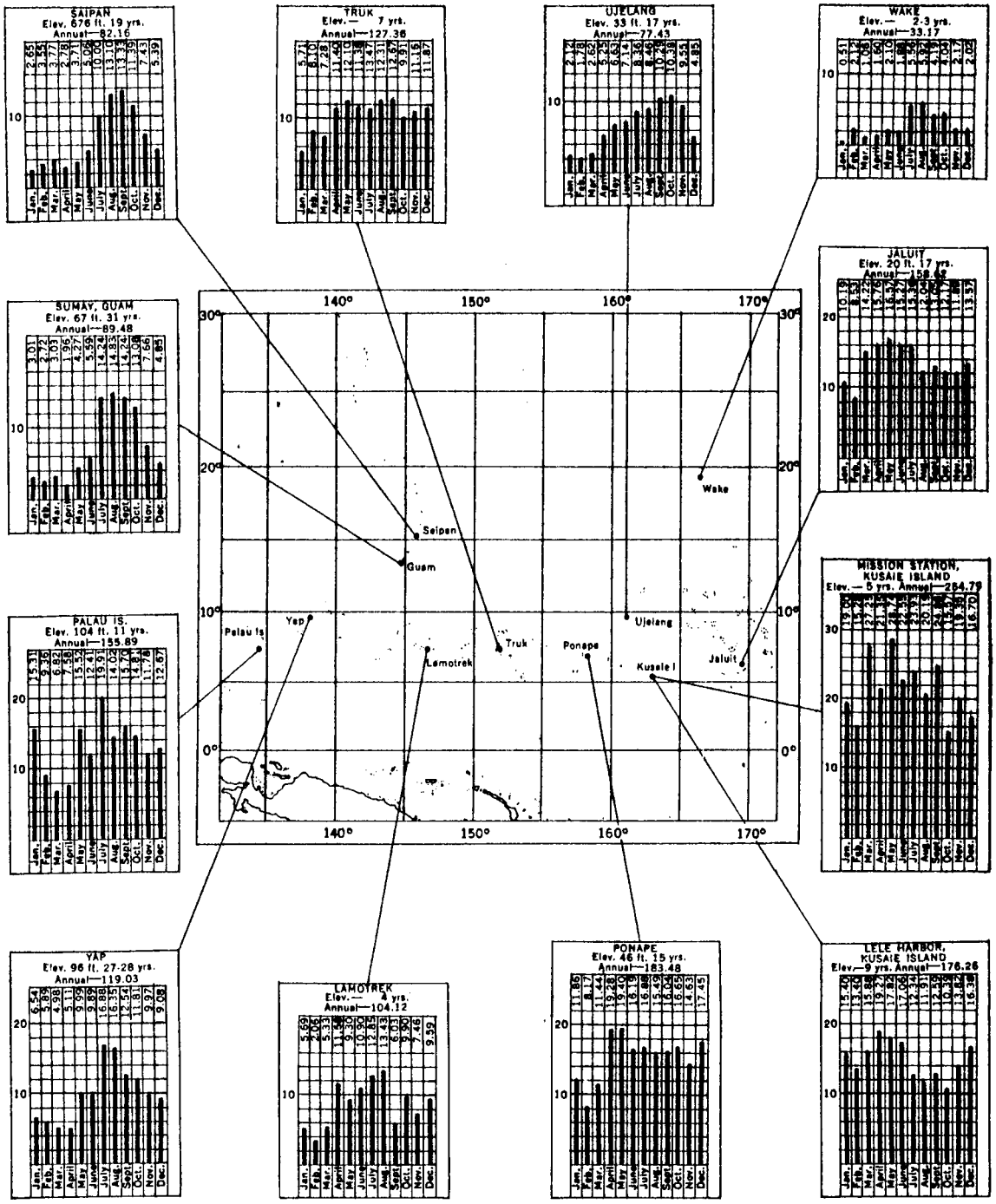

Figure 20.--Seasonal distribution of rainfall. The rainfall profiles shown are based on average monthly rainfall recorded in inches (U.S. Weather Bureau, 1943).

Table 9.--Monthly means, totals, extremes, and number of years rainfall observations were made at Lamotrek, Caroline Islands (U.S. Weather Bureau, 1943).

STATION: LAMOTREK, CAROLINE ISLANDS. POSITION: LATITUDE 7°27' N., LONGITUDE 146°24' E.

Month	Air Temp. °F					Relative humidity (percent)		Cloud amount (0-10)		Rainfall			Wind										Predominant winds or calm	Average number of days with—		
	Mean			Extreme											Percentages of observations from—											
	Monthly	Maximum	Minimum	Maximum	Minimum					Av. amount (inches)	Number of rainy days [1]	Max. 24 hrs. (inches)	Mean velocity (knots)	Maximum velocity (knots)	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm		Fog	Gales	Thunder
January	---	---	---	---	---	---	---	---	---	5.7	13	1.9	---	---												
February	---	---	---	---	---	---	---	---	---	2.1	6	1.6	---	---												
March	---	---	---	---	---	---	---	---	---	5.3	8	2.9	---	---												
April	---	---	---	---	---	---	---	---	---	11.6	8	4.7	---	---												
May	---	---	---	---	---	---	---	---	---	9.3	13	3.2	---	---												
June	---	---	---	---	---	---	---	---	---	10.9	18	3.0	---	---												
July	---	---	---	---	---	---	---	---	---	12.9	18	2.5	---	---												
August	---	---	---	---	---	---	---	---	---	13.4	16	3.6	---	---												
September	---	---	---	---	---	---	---	---	---	6.0	14	3.2	---	---												
October	---	---	---	---	---	---	---	---	---	9.9	10	2.2	---	---												
November	---	---	---	---	---	---	---	---	---	7.5	12	4.1	---	---												
December	---	---	---	---	---	---	---	---	---	9.6	12	6.1	---	---												
Mean	---	---	---	---	---	---	---	---	---				---	---												
Total	---	---	---	---	---	---	---	---	---	104	148	---	---	---												
Extreme	---	---	---	---	---	---	---	---	---	---	---	6.1	---	---												
Number of years										4	4	4														

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[1] Days with .01 inch or more

At Ponape, rainfall is heavy and frequent throughout the year, with an annual average of 194 in.(493 cm) in 1941-70 (Table 4) (EDS, 1973d). April and May are the wettest with an average of more than 19 in.(48 cm) per month (Figure 20). Rainfall is high even during the driest period--January-March--with averages of nearly 12 in. (30 cm) in each month. The result is that measurable rain is observed on about 300 days a year. Orographic rainfall due to moist air rising over the steep and rugged terrain of the island adds to the total rainfall received during the trade wind season as well as when the area comes under the influence of the ITCZ.

Orographic influence on rainfall is also well demonstrated at Kusaie in the extreme southeastern Carolines (Tables 10 and 11). Data from U.S. Weather Bureau (1943) show that at Mission Station on the west coast of the island, the mean annual rainfall was 255 in. (648 cm) with over 20 in.(51 cm) falling monthly from March to September (Figure 20). In drier months, the monthly rainfall varied between 15 and 19 in.(38 and 48 cm). Mountains separate the west from the east coast where at Lele Harbor rainfall averaged 176 in.(447 cm). Monthly rainfall here varied between 19 in.(48 cm) in April and 10 in.(25 cm) in October. The wet seasons at Kusaie are in December and in March-June; dry periods are in late summer to autumn and in February.

In the Marshalls, rainfall is shown by meteorological data collected at Ujelang, Jaluit, and Majuro.

Ujelang, located in a zone where the northeast trades are more settled and prevalent, has a mean annual rainfall of 77 in.(196 cm) (U.S. Weather Bureau, 1943). Table 7 and Figure 20 show that the dry season is in January-March with minimum rainfall usually in February. In February-March, drought conditions have resulted in some years because total rainfall was extremely low, varying between 0.3 and 0.4 in.(0.8 and 1.0 cm). There is a gradual increase in rainfall from April culminating in September-October when the mean rainfall is greater than 10 in.(25 cm) in each month.

Unlike Ujelang, which is a zone of strong prevailing northeast trades, Jaluit is located in an area where the interchange of northerly and southerly trade winds is relatively strong (U.S. Weather Bureau, 1943). The result is that Jaluit has a mean rainfall of 159 in. (404 cm) per year or more than twice the mean at Ujelang. The height of the rainy season is in March-July, but Table 6 and Figure 20 show that average rainfall of 10 in.(25 cm) or more occurs in all months except February. The wettest month of May has an average rainfall of 17 in.(43 cm) but the amounts over the years have been extreme, varying from 8 in.(20 cm) to 36 in.(91 cm). Even February, the driest month, has had extremes of 2 in.(5 cm) and 16 in.(41 cm).

Table 10.--Monthly means, totals, extremes, and number of years rainfall observations were made at Kusaie, Mission Station, Caroline Islands (U.S. Weather Bureau, 1943).

STATION: KUSAIE, MISSION STATION, CAROLINE ISLANDS. POSITION: LATITUDE 5°19' N., LONGITUDE 162°59' E.

Month	Air Temp. °F.					Relative humidity (percent)		Cloud amount (0-10)		Rainfall			Wind											Predominant winds or calm	Average number of days with—		
	Mean			Extreme											Percentages of observations from—												
	Monthly	Maximum	Minimum	Maximum	Minimum					Av. amount (inches)	Number of rainy days [1]	Max. 24 hrs. (inches)	Mean velocity (knots)	Maximum velocity (knots)	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm		Fog	Gales	Thunder
January	---	---	---	---	---	---	---	---	---	19.0	21	3.3	---	---	---	---	---	---	---	---	---	---	---	---	---	---
February	---	---	---	---	---	---	---	---	---	15.3	20	4.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---
March	---	---	---	---	---	---	---	---	---	27.3	26	5.4	---	---	---	---	---	---	---	---	---	---	---	---	---	---
April	---	---	---	---	---	---	---	---	---	21.4	25	3.0	---	---	---	---	---	---	---	---	---	---	---	---	---	---
May	---	---	---	---	---	---	---	---	---	28.7	27	4.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---
June	---	---	---	---	---	---	---	---	---	22.6	25	3.9	---	---	---	---	---	---	---	---	---	---	---	---	---	---
July	---	---	---	---	---	---	---	---	---	23.9	28	4.1	---	---	---	---	---	---	---	---	---	---	---	---	---	---
August	---	---	---	---	---	---	---	---	---	20.2	23	6.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---
September	---	---	---	---	---	---	---	---	---	24.9	21	10.4	---	---	---	---	---	---	---	---	---	---	---	---	---	---
October	---	---	---	---	---	---	---	---	---	15.6	20	4.5	---	---	---	---	---	---	---	---	---	---	---	---	---	---
November	---	---	---	---	---	---	---	---	---	19.4	21	8.4	---	---	---	---	---	---	---	---	---	---	---	---	---	---
December	---	---	---	---	---	---	---	---	---	16.7	20	3.3	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Mean	---	---	---	---	---	---	---	---	---																	
Total	---	---	---	---	---	---	---	---	---	255	280															
Extreme	---	---	---	---	---	---	---	---	---			10.4	---	---												
Number of years										10	10	10														

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[1] Days with .01 inch or more

Table 11.--Monthly means, totals, extremes, and number of years rainfall observations were made at Kusaie, Lele Harbor, Caroline Islands (U.S. Weather Bureau, 1943).

STATION: KUSAIE, (LELE HARBOR) CAROLINE ISLANDS. POSITION: LATITUDE 5°20' N., LONGITUDE 163°01' E.

Month	Air Temp. °F					Relative humidity (percent)		Cloud amount (0-10)		Rainfall			Wind											Predominant winds or calm	Average number of days with—		
	Mean			Extreme											Percentages of observations from—											
	Monthly	Maximum	Minimum	Maximum	Minimum					Av. amount (inches)	Number of rainy days [1]	Max. 24 hrs. (inches)	Mean velocity (knots)	Maximum velocity (knots)	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm		Fog	Gales	Thunder
January										15.4	19	5.5														
February										13.4	16	6.7														
March										15.9	21	6.3														
April										19.3	21	6.9														
May										17.8	22	5.8														
June										17.1	22	5.9														
July										12.3	21	4.1														
August										11.9	21	6.9														
September										12.6	18	4.3														
October										10.4	16	5.0														
November										13.8	20	5.4														
December										16.4	22	5.3														
Mean																										
Total										176	239															
Extreme												6.9														
Number of years										9	9	9														

Authority: Mitteilungen aus den Deutschen Schutzgebeiten
Monthly Weather Review - Supplement 28 - Reed

[1] Days with .01 inch or more

At Majuro, located roughly 110 mi (204 km) northeast of Jaluit, rainfall is also heavy with monthly averages of 10 in.(25 cm) or more in most months (EDS, 1973c). Table 5 shows that January-March are relatively drier than April-December when the rainfall averages are 10 in.(25 cm) more each month. The height of the wet season is in October-November when the island usually receives over 15 in.(38 cm) of rain each month.

Northward of the 0°-10° latitudinal belt, between 10° and 15°N, rainfall lessens, but 10%-15% of the ships' reports show continued rain and showers (U.S. Weather Bureau, 1943). Between lat. 15° and 20°N, rain and showers were reported in 10%-12% of the observations. The annual frequency of rain and showers between lat. 20° and 30°N decreased further to 8%-10% of the observations. Seasonal differences in rainfall within these various latitudinal belts are not sufficiently pronounced at sea to warrant special attention.

Meteorological data were available from two island stations--Guam and Saipan--in the Marianas.

At Guam, although temperature and humidity vary only slightly throughout the year, rainfall and wind conditions vary markedly (EDS, 1973a). The variations in the latter two weather elements define the two primary and two secondary seasons on Guam. The dry season, which extends from January through April, and the wet season, which extends from mid-July to mid-November are the primary ones (Table 8 and Figure 20). The secondary seasons are transitional ones, which may be either rainy or dry depending on the nature of the particular year. These are from May to mid-July and mid-November to December. Table 8 shows that the mean annual rainfall on Guam is 91 in.(231 cm). On the windward or east side of the higher mountains, the mean annual average is about 95 in.(241 cm), whereas along the western coast of the southern half of Guam, the rainfall is lower averaging 80 in.(203 cm). Usually, rainfall in the dry season accounts for about 15% of the annual total whereas that in the wet seasons contributes 55%.

Saipan, some 2° north of Guam and dominated by its high peaks, has a mean annual rainfall of 82 in. (208 cm) (U.S. Weather Bureau, 1943). Table 12 and Figure 20 show that the rainy season on Saipan is in July-October when monthly averages vary between 10 and 13 in. (25 and 33 cm). The dry season, which has rainfall averaging 3 to 4 in. (8 to 10 cm) monthly, is in January-May. The greatest monthly rainfall on record at Saipan, reaching 25 in. (64 cm), occurred in October. The lowest October amount was 4 in. (10 cm).

Table 12.--Monthly means, totals, extremes, and number of years various meteorological observations were made at Saipan Island (Garapan), Marianas group (U.S. Weather Bureau, 1943).

STATION: SAIPAN ISLAND (GARAPAN) MARIANAS GROUP. POSITION: LATITUDE 15°14' N., LONGITUDE 145°46' E. ALTITUDE 676 FEET

Month	Air Temp. °F.					Relative humidity (percent)		Cloud amount (0-10)		Rainfall			Wind										Predominant winds or calm	Average number of days with—		
	Mean			Extreme											Percentages of observations from—											
	Monthly	Maximum	Minimum	Maximum	Minimum	0600	1400	0600	1400	Av. amount (inches)	Number of rainy days [1]	Max. 24 hrs. (inches)	Mean velocity (knots)	Maximum velocity (knots)	N.	NE.	E.	SE.	S.	SW.	W.	NW.	Calm		Fog	Gales [2]	Thunder
January	76	80	72	84	68	85	73	7.2	7.8	2.7	12.4	1.4	5.3												0	1.8	0.1
February	76	80	72	85	69	84	70	7.1	7.4	3.6	11.3	2.1	4.6												0	1.3	0.0
March	77	82	72	85	68	87	71	6.3	7.1	3.8	12.8	6.1	4.9												0	2.2	0.2
April	78	83	73	86	71	87	69	6.6	6.1	2.8	13.6	2.8	4.8												0	1.7	0.4
May	79	84	75	87	69	89	72	6.6	7.2	3.7	12.9	5.3	5.4												0	2.7	0.7
June	80	84	75	87	71	88	71	6.7	6.8	5.1	16.7	3.7	4.5												0	1.7	1.1
July	79	84	75	88	71	91	78	8.5	8.3	10.0	23.5	8.2	4.5												0	5.7	3.7
August	79	84	75	87	69	91	77	8.3	8.6	13.1	22.6	8.9	3.7												0	2.0	2.6
September	79	84	75	89	71	91	79	8.1	8.6	13.3	21.9	5.4	3.7												0	3.5	3.9
October	79	84	75	87	71	91	79	7.4	7.7	11.4	21.8	6.1	4.5												0	4.0	2.8
November	79	83	75	85	72	89	78	7.1	7.3	7.4	19.3	13.1	5.4												0	4.2	1.4
December	78	82	74	84	70	86	75	6.4	7.0	5.4	19.0	3.0	5.5												0	3.2	0.5
Mean	78	83	74	----	----	88	74	7.2	7.5	----	----	----	4.7														
Total	----	----	----	----	----	----	----	----	----	82.2	208	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Extreme	----	----	----	89	68	----	----	----	----	----	----	13.1	----	----	----	----	----	----	----	----	----	----	----	----	0	34.0	17.4
Number of years	6	6	6	6	6	6	6	6	6	19	13	19	6												6	6	6

Authority: Mitteilungen aus den Deutschen Schutzgebeiten, Banden Meteorological obs. in Japan

[1]Days with .01 inch or more

[2]Winds of 22.4 M.P.H. or more

TROPICAL STORMS

In tropical seas, thunderstorms are more likely to occur at night than during daytime (U.S. Weather Bureau, 1943). On large islands that promote well-developed daytime convection, thunderstorms are likely to form also in the afternoon but these islands are still subject to thunderstorms that move in at night from the sea.

By far the greatest threat to fishing activities at sea in the western Pacific is tropical cyclones or typhoons. According to the U.S. Weather Bureau (1943), the greatest number of tropical cyclones of the western North Pacific originate in or pass through some parts of the area bounded by the equator and lat. 30°N and between long. 130° and 170°E (Figure 21). A few originate in the China Sea or north of lat. 30°N.

Most of the typhoons in this region are first observed between lat. 7° or 8°N and 20°N from long. 125° to 155°E (U.S. Weather Bureau, 1943). The Marshalls and extreme eastern Carolines are far less likely to experience the effects of typhoons than the Western Carolines and the Marianas. South of lat. 7°N, typhoons are rare. Table 13 shows the total and average monthly and annual numbers of typhoons in 1901-40 in the western North Pacific. The annual numbers can vary considerably.

The movements of typhoons are varied but generally there are three main divisions (U.S. Weather Bureau, 1943). These are storms that move west to northwest toward the Philippines, those that move west or north toward the China coast or southern Japan, and those that remain at sea and finally pass north to northeast toward the seaward side of Japan (Figure 22). For storms that originate west of long. 150°-160°E, the primary direction is west to northwest.

Typhoons advance at an average rate of 6-12 knots especially on their early westward course (U.S. Weather Bureau, 1943). They may reach speeds of up to 20 knots. At the point of recurve, a typhoon usually slows down and if the bend in the track is sharp, the speed may be imperceptible for a day or two. When moving freely again in a northeasterly direction, the typhoon may have speeds exceeding 25-30 knots.

The advancing speed of typhoons should not be confused with wind velocity, which is related to the steepness of the pressure gradient between the inner and outer parts of the typhoon (U.S. Weather Bureau, 1943). If the gradient is flat, the winds may not be very strong, but if the difference is large, winds of 65 knots may be expected. Actual velocities of 100 knots have been recorded on land instruments.

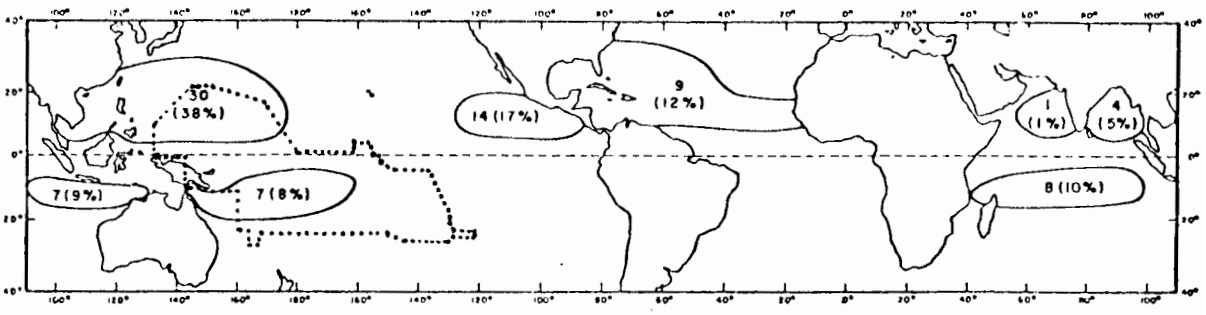


Figure 21.--Average annual number (and percent of global total) of tropical cyclones of significant intensity in each development area. South Pacific Commission Area including Micronesia is shown by dotted line (adapted from Atkinson, 1971 by Hickman, 1973).

Table 13.--The total and average number of typhoons observed in the western North Pacific Ocean (U.S. Weather Bureau, 1943).

	Jan.	Feb.	Mar.	Apr.	May	June	July
Total No. Observed	16	8	11	16	29	40	128
Average per month	0.4	0.2	0.3	0.4	0.7	1.0	3.2

	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Total No. Observed	169	142	130	67	46	802
Average per month	4.2	3.6	3.2	1.7	1.2	20.1

Table 14.--Characteristic properties of zonal currents through the section at long. 137°E in January 1967, RV Ryofu Maru (Masuzawa, 1967).

Current		Range	Width (mile)	Difference of sea surface (dyn. cm)	Geostrophic flux ($km^3 \cdot hr^{-1}$)
Kuroshio		Ry 3031-Ry 3035 33°30′N-31°20′N	130	− 117	+ 273
Kuroshio Countercurrent		Ry 3035-Ry 3038 31°20′N-28°54′N	146	+ 47	− 162
Subtropics		Ry 3038-Ry 3045 28°54′N-21°58′N	416	− 16	+ 0.3
North	Northern part	Ry 3045-Ry 3052 21°58′N-14°54′N	424	+ 10	− 79
Equatorial	Southern part	Ry 3052-Ry 3060 14°54′N-06°58′N	476	+ 45	− 145
Current	Whole	Ry 3045-Ry 3060 21°58′N-06°58′N	900	+ 55	− 224
Equatorial Countercurrent		Ry 3060-Ry 3065 06°58′N-02°04′N	294	− 28	+ 234
Equatorial Undercurrent?		Ry 3065-Ry 3070 02°04′N-00°43′S	167	...	...

KEY TO THE STORM TRACKS SHOWN ON CHART

The lines and arrowheads indicate the tracks and directions followed by the centers of various typhoons and tropical storms which have traversed the eastern North Pacific Ocean in or near the area covered by this Weather Summary. Both normal and abnormal tracks are represented. The open circles indicate the successive positions of the storm center at Greenwich noon of the dates entered nearby.

The Roman numerals in the chronological listing below correspond to those given on the chart.

No.	Date	Begins near Lat. °N.	Long. °E.
I	Dec. 31, 1930–Jan. 5, 1931	9	146
II	Feb. 11–17, 1927	5	143
III	Mar. 20–30, 1925	12	150
IV	Apr. 21–25, 1929	7	137
V	May 19–31, 1930	5	145
VI	May 5–10, 1925	17	141
VII	June 8–11, 1921	16	145
VIII	July 21–27, 1918	20	150
IX	July 6–16, 1940	8	145
X	July 28–Aug. 7, 1939	23	145
XI	Aug. 14–19, 1930	20	145
XII	Aug. 13–22, 1940	13	150
XIII	Aug. 1–14, 1941	10	154
XIV	Sept. 3–10, 1930	15	155
XV	Sept. 12–14, 1930	8	149
XVI	Sept. 26–Oct. 2, 1930	12	154
XVII	Sept. 22–27, 1935	18	149
XVIII	Oct. 16–21, 1921	15	144
XIX	Oct. 14–19, 1928	9	151
XX	Nov. 21–29, 1928	4	156
XXI	Dec. 15–21, 1909	3	146
XXII	Dec. 17–25, 1935	9	148

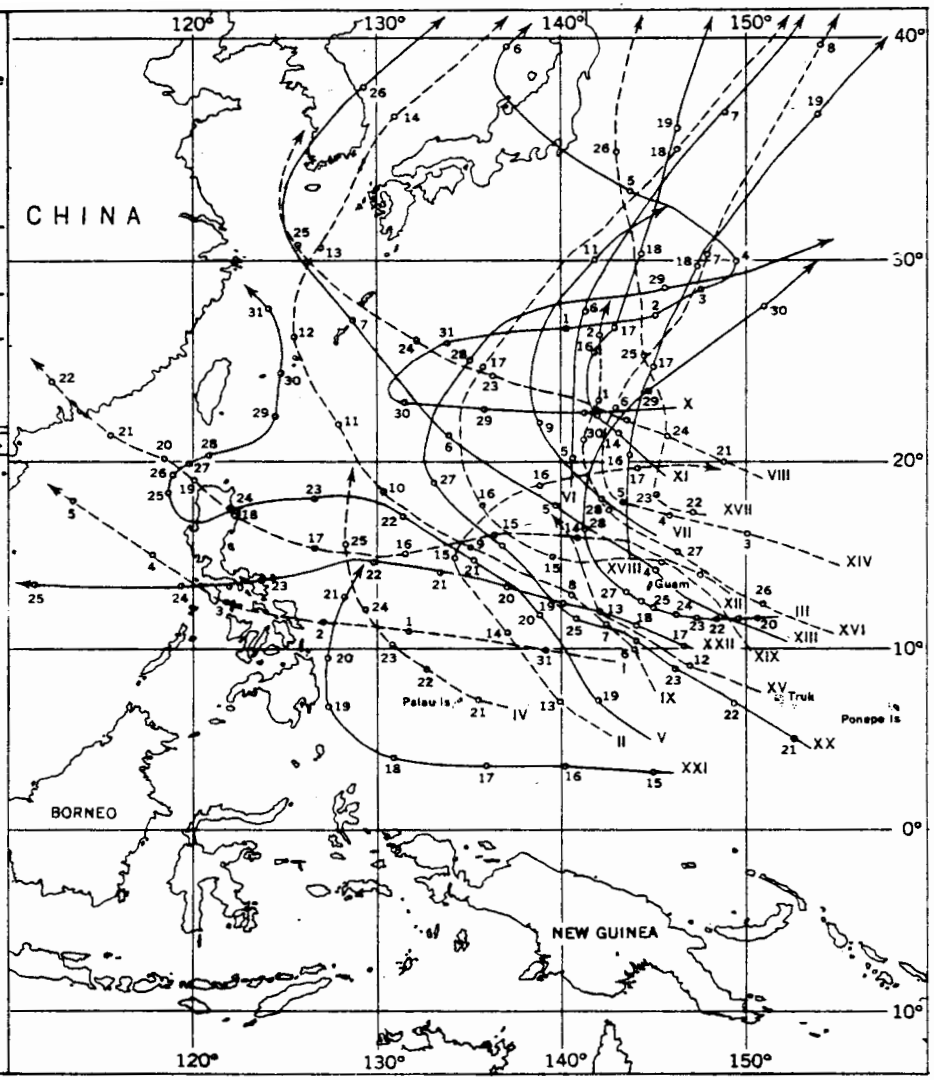


Figure 22.--Selected tracks of typhoons of the western North Pacific (U.S. Weather Bureau, 1943).

Typhoons vary in diameter (U.S. Weather Bureau, 1943). Some are small, perhaps less than 50 mi (93 km) across, but others have diameters of 300 to 500 mi (556 to 926 km) or more. The center or eye of the typhoon is rarely less than 6-7 mi (11-13 km) and not much larger than 20-25 mi (37-46 km).

Among the Carolines and Marianas, typhoons usually approach from the east or southeast, but rarely from the south (U.S. Weather Bureau, 1943). Most likely, the storms cross the Marianas in July-October and the Western Carolines in May-June and November-December.

Data from individual islands or island groups within Micronesia show the frequency and season of thunderstorms and typhoons. In Palau, which averages 22 storms per year, there is usually 1 per month in January-April and 2-3 monthly in May-December (U.S. Weather Bureau, 1943). Thunderstorms usually occur more frequently after June because at this time the ITCZ moves northward across the islands. Palau lies just below the beginning of the typhoon belt and rarely has real typhoons.

Thunderstorms are relatively infrequent at Yap (EDS, 1973f). They occur in association with the ITCZ as it moves northward in July and southward again in October in the vicinity of Yap; therefore, June to November is the period of most frequent storms (U.S. Weather Bureau, 1943; EDS, 1973f). In August-December, the average is about two per month. Tropical cyclones are more prevalent further to the northwest. June-December is when typhoons occur in greatest frequency although fully developed ones are uncommon near Yap. Most of the typhoons near Yap pass to the north, then move westward or northwestward away from the island.

Between July and November, Truk and Ponape are frequently under the influence of the ITCZ which has moved northward into the vicinity of these island groups, and during this period tropical disturbances and moist southerly winds are most frequent (EDS, 1973d, 1973e). Truk and Ponape are located within the spawning grounds of typhoons, but the major typhoon tracks in the western Pacific lie well to the north and west. Typhoons Lola in November 1957 and Ophelia in January 1958 caused extensive damage to crops and housing on Ponape (EDS, 1973d). At Truk, these two typhoons brought winds of 70 mi/h (113 km/h) and caused widespread damage to buildings, crops, and coconut palms. Damages to coastal structure by storm-generated waves were also extensive (EDS, 1973e). On 1 May 1971, typhoon Amy moved directly over Truk lagoon. Winds from the south measured 78 mi/h (126 km/h) and a peak gust from the northeast was 113 mi/h (182 km/h). Rainfall totaled 8 in.(20 cm). Homes and other buildings suffered extensive damage and 75%-80% of the crop was destroyed.

At Majuro, tropical storms are very rare; the last typhoon recorded from this atoll occurred in January 1914 (EDS, 1973c). At Jaluit, according to U.S. Weather Bureau (1943) reports, about 17 thunderstorms usually occur in a year with an average of 2 per month in June-September.

During the rainy season on Guam, which extends from mid-July to mid-November, there is frequently a breakdown of the trades (EDS, 1973a). On some days during these periods, the weather is dominated by westerly moving storm systems that bring heavy showers or steady torrential rain. Also, there are occasional typhoons which bring not only tremendous rains but also violent winds producing flooding of the low-lying coastal areas. The probability of having one or more typhoons pass sufficiently close to Guam to produce high winds and heavy rains is about one in three. In the past 50 years, typhoons have passed close to Guam in every month but their most frequent occurrence is in July-December. A typhoon that moves directly across Guam occurs once in about 8 years.

THE OCEANOGRAPHIC CLIMATE

In Micronesian waters, not only meteorological but also oceanographic properties show little apparent seasonal variation. In the following sections, we discuss sea-surface temperatures, thermocline depth, surface currents, and chemical properties of water surrounding the islands and atolls within the Trust Territory.

SEA-SURFACE TEMPERATURE

Figure 23 shows the monthly mean sea-surface temperature in the Pacific Ocean. According to LaViolette and Seim (1969), who computed monthly mean temperatures from data collected in various regions of the Pacific, the surface temperature data collected in Trust Territory waters show little variation throughout the year. In the Marshalls, the surface temperature throughout the year varied between 73° and 91°F (23° and 33°C). Temperatures were usually lowest in March-April and highest in September-October. Observations made in the Western Carolines and Marianas showed that the minimum temperature was about 75°F (24°C) and the maximum observed value slightly above 84°F (29°C). Temperatures were usually lowest in February and highest in August-September. The monthly variation of sea-surface temperature in selected regions of the western Pacific is shown in Figure 24.

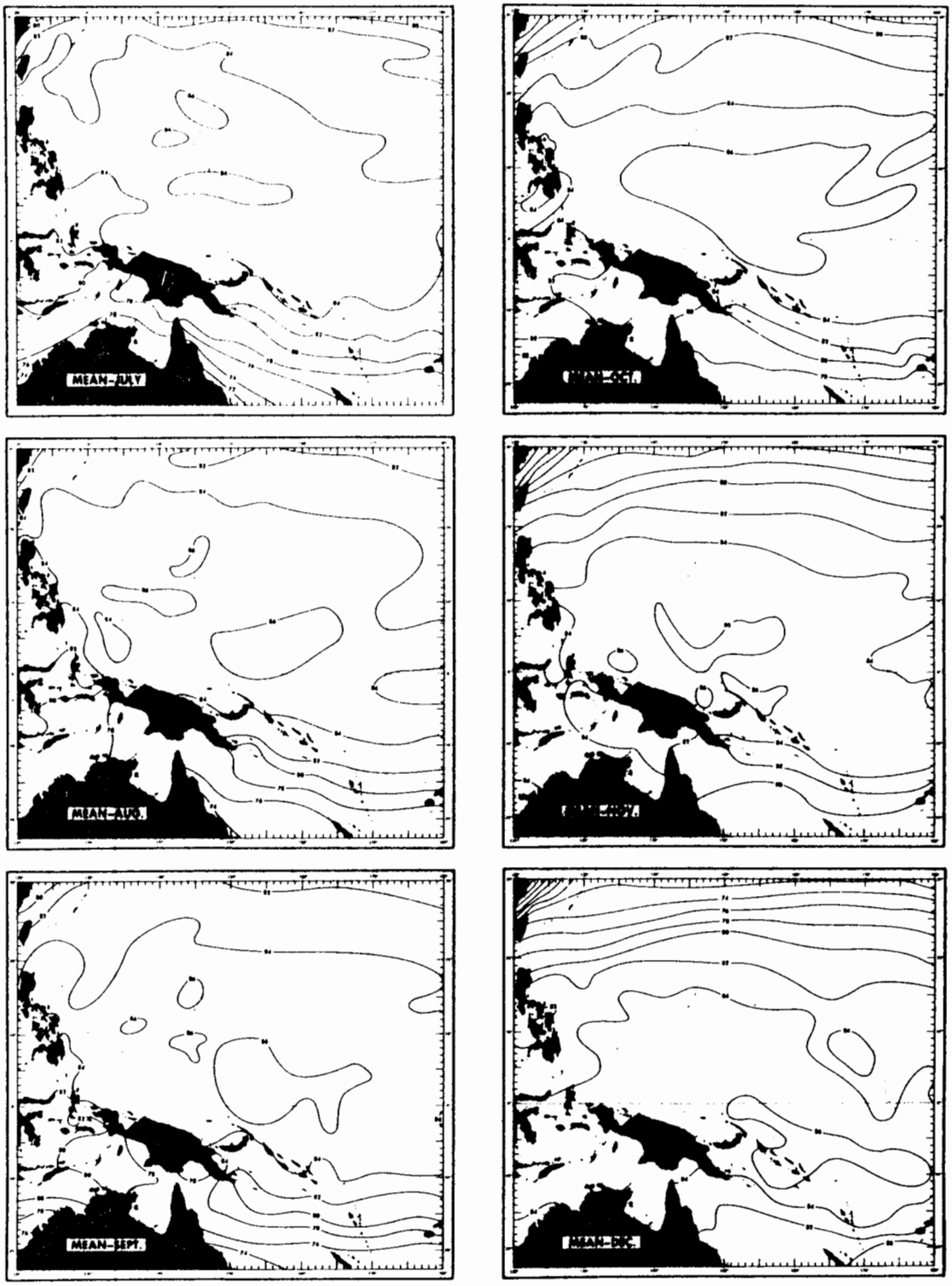


Figure 23.--Monthly charts of mean sea-surface temperature (LaViolette, 1970).

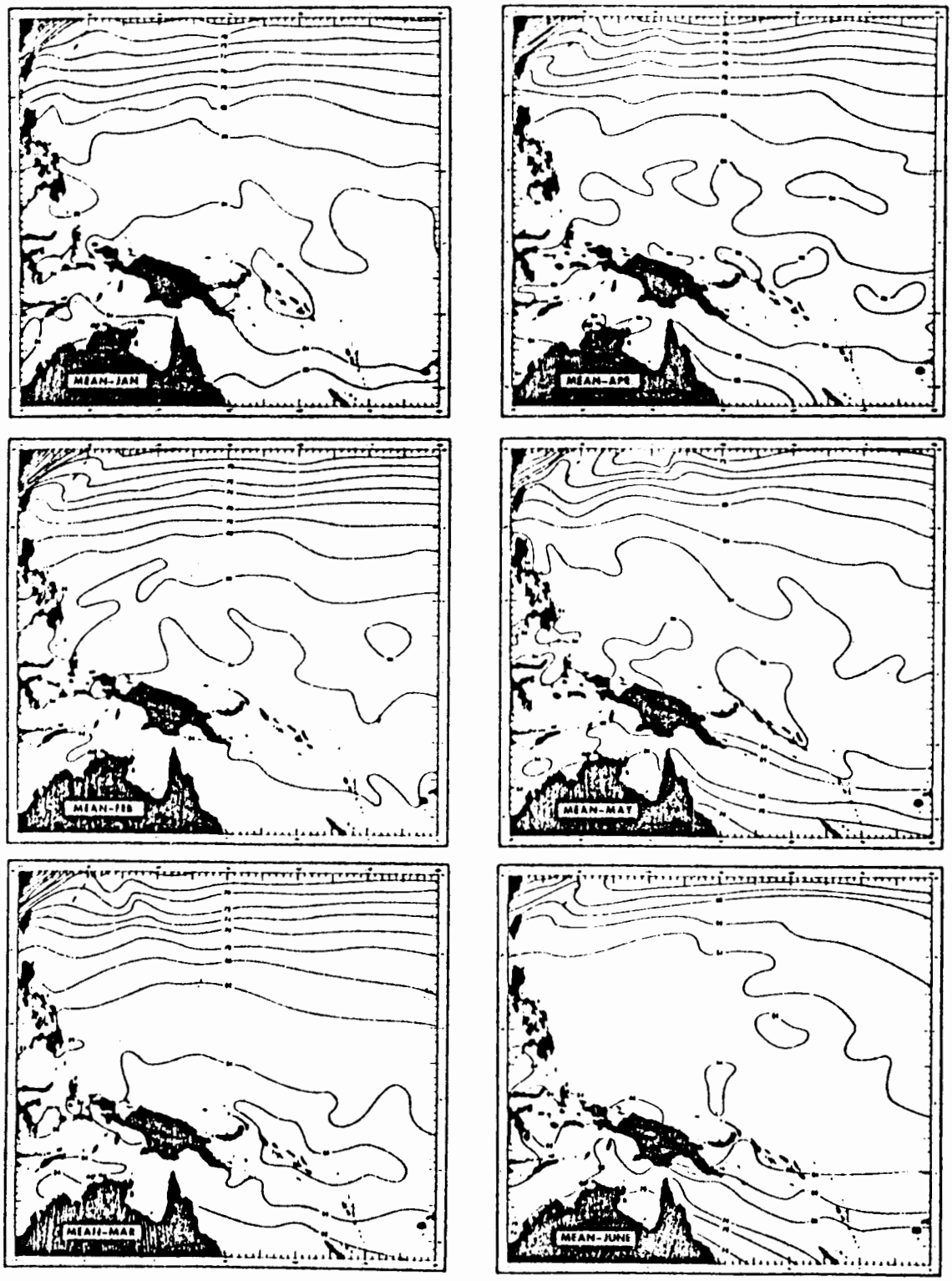


Figure 23.--Continued.

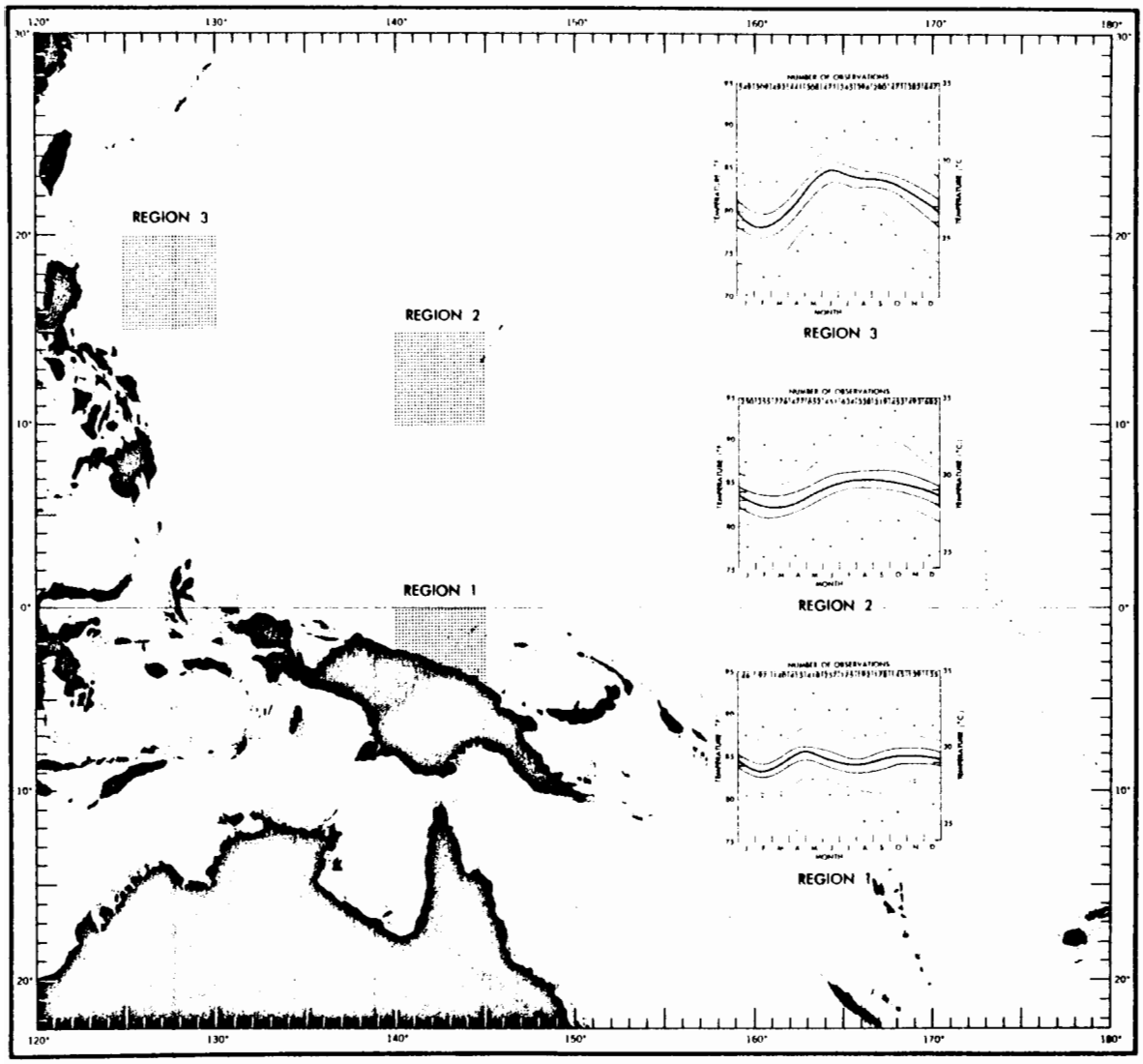


Figure 24.--Monthly variation of sea-surface temperature in selected regions. Dots represent the absolute extreme value reported; the inner (shaded) and outer (unshaded) envelopes represent 50% and 95% of the data observed (LaViolette, 1970).

Figure 23 also shows the latitudinal movement of the surface isotherms with season. Whereas the 78°-84°F (26°-29°C) isotherms are within the Micronesian area in March, they are displaced by the 84°-86°F (29°-30°C) isotherms by August.

The horizontal distribution of surface temperatures for the Marshall Islands area is shown in Figure 25. Mao and Yoshida (1955), in discussing some of the notable features, mentioned that the surface temperature in this area usually decreases slowly with increasing latitude. In summer, they detected somewhat lowered surface temperature at or near the equator and believed that intensive upwelling associated with equatorial divergence occurred (Figure 25). In the winter, however, the feature was not evident.

A tongue of cool water has its origin from the northeast and may be associated with the ascending motion in the northern boundary of the countercurrent. The temporal and spatial variation in the position of this tongue of cool water may be due to changes in wind pattern.

SURFACE CURRENTS

Two regions of trade wind current, one in each hemisphere, exist in the Pacific Ocean. These currents have a persistent westward drift during the entire year. The tangential stress of the trade winds, which embrace the major part of the world's ocean and blow persistently is responsible for the trade wind regions being the centers of action for surface circulation (Dietrich, 1963).

Schemes of the major oceanic circulation in the western Pacific in winter and summer are shown in Figures 26 and 27. In the western Pacific, not all the North Equatorial Current is directed north toward Japan or south into the South Pacific (Wiens, 1962). Some flows into the seas and basins of Indonesia and the Philippines to form local circulations. South of Palau, there is a major reversal of current direction and an eastward flow or countercurrent starts between the westward flowing North and South Equatorial Currents. The countercurrent, which extends nearly all the way across the Pacific, actually lies north of the equator, shifting latitudinally with the season. In February-March, the countercurrent flows south of the Western Carolines and between Ponape and Kusaie in the Eastern Carolines. Continuing eastward, the countercurrent then passes between the Marshalls and the northern Gilberts.

The westward flowing North Equatorial Current breaks up into complex gyrals and cross currents as it flows among the various islands and atolls that lie in its path (Wiens, 1962). The seasonal monsoon

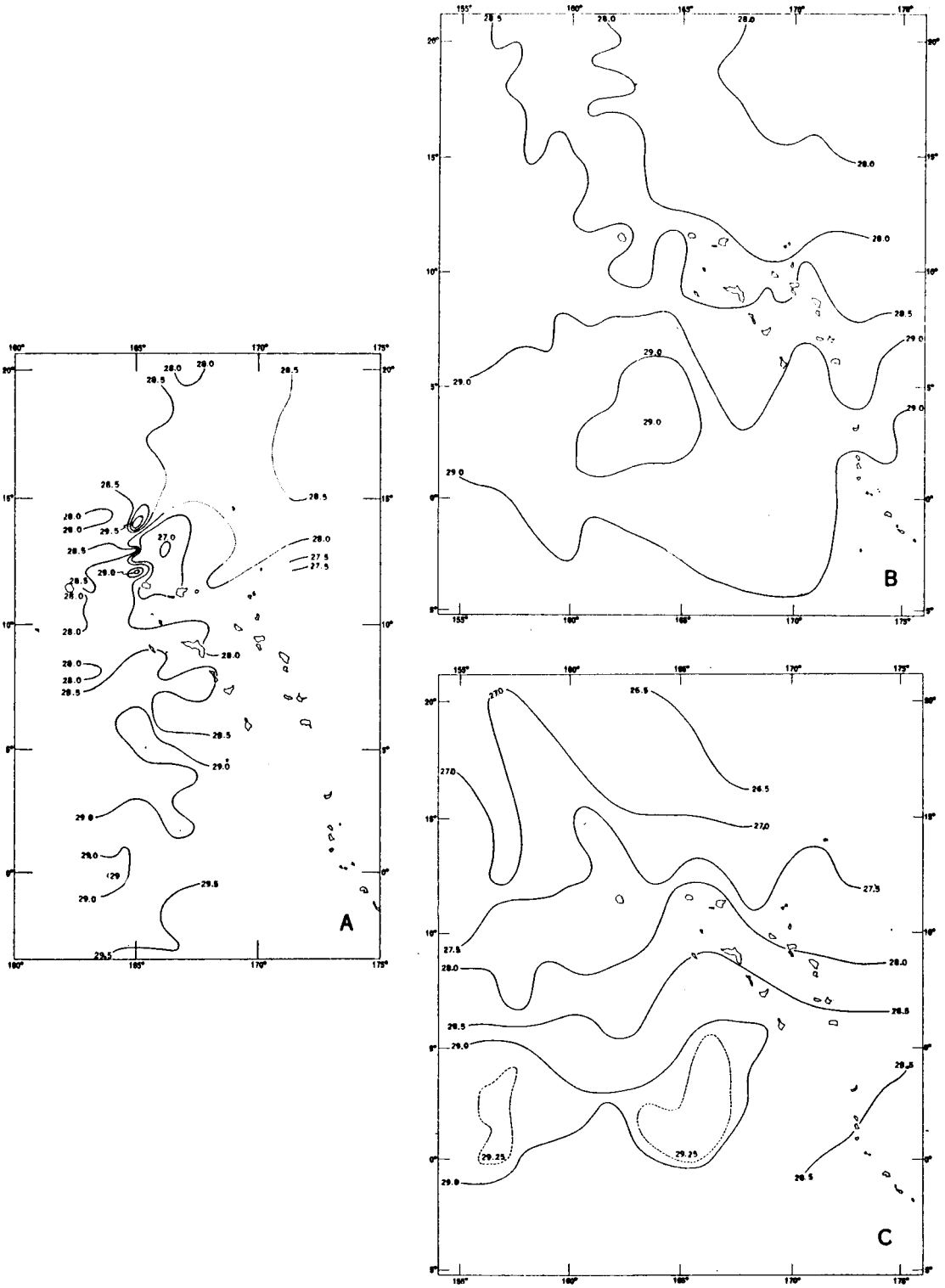


Figure 25.--Horizontal distribution of temperature at the surface. A. From Crossroads data, March to August 1946. B. From Japanese data, 1933-41 summer season. C. From Japanese data, 1933-41 winter season (Mao and Yoshida, 1955).

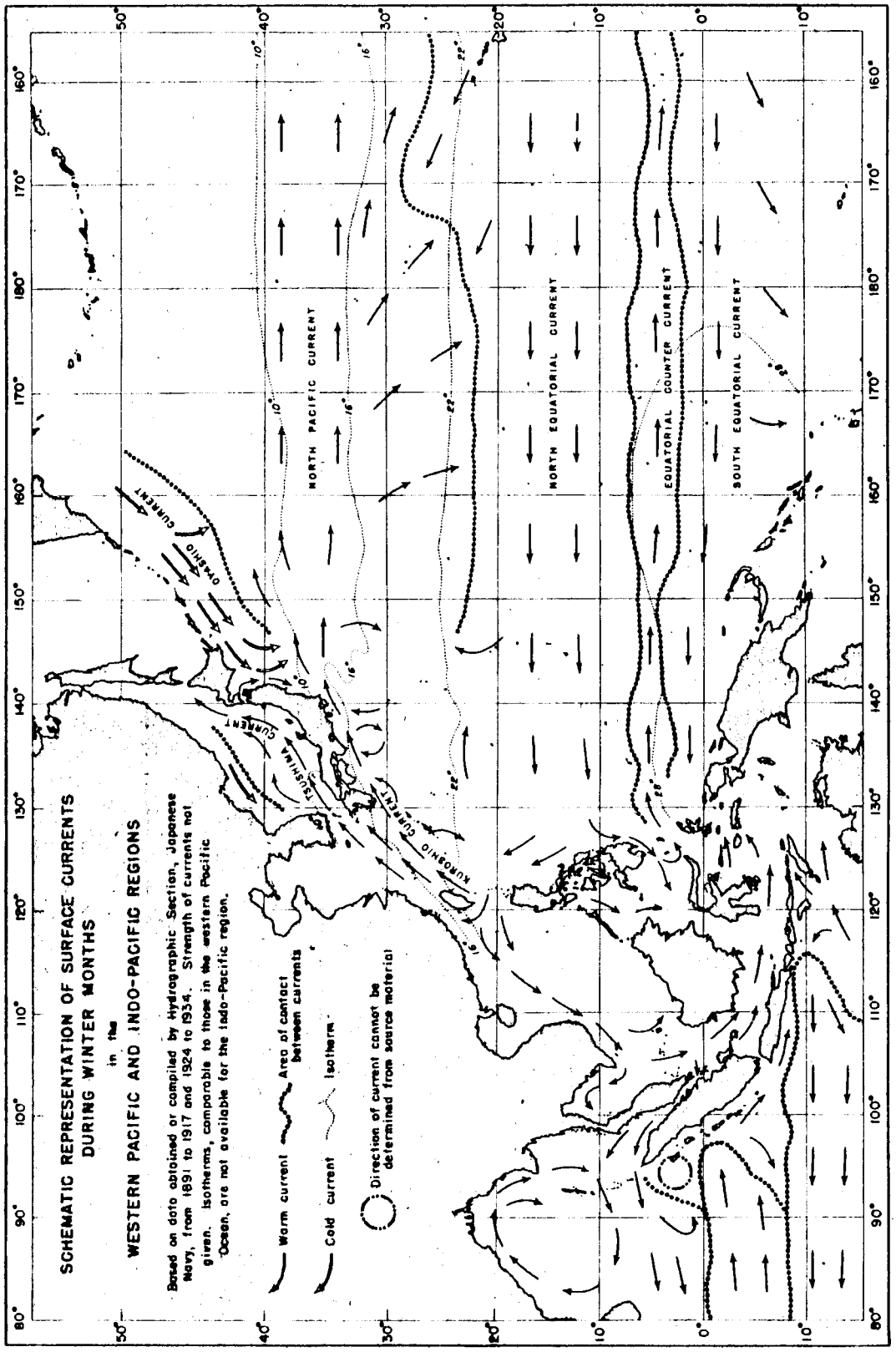


Figure 26.--Schematic representation of surface currents during winter months in the western Pacific and Indo-Pacific regions (Shapiro, 1948).

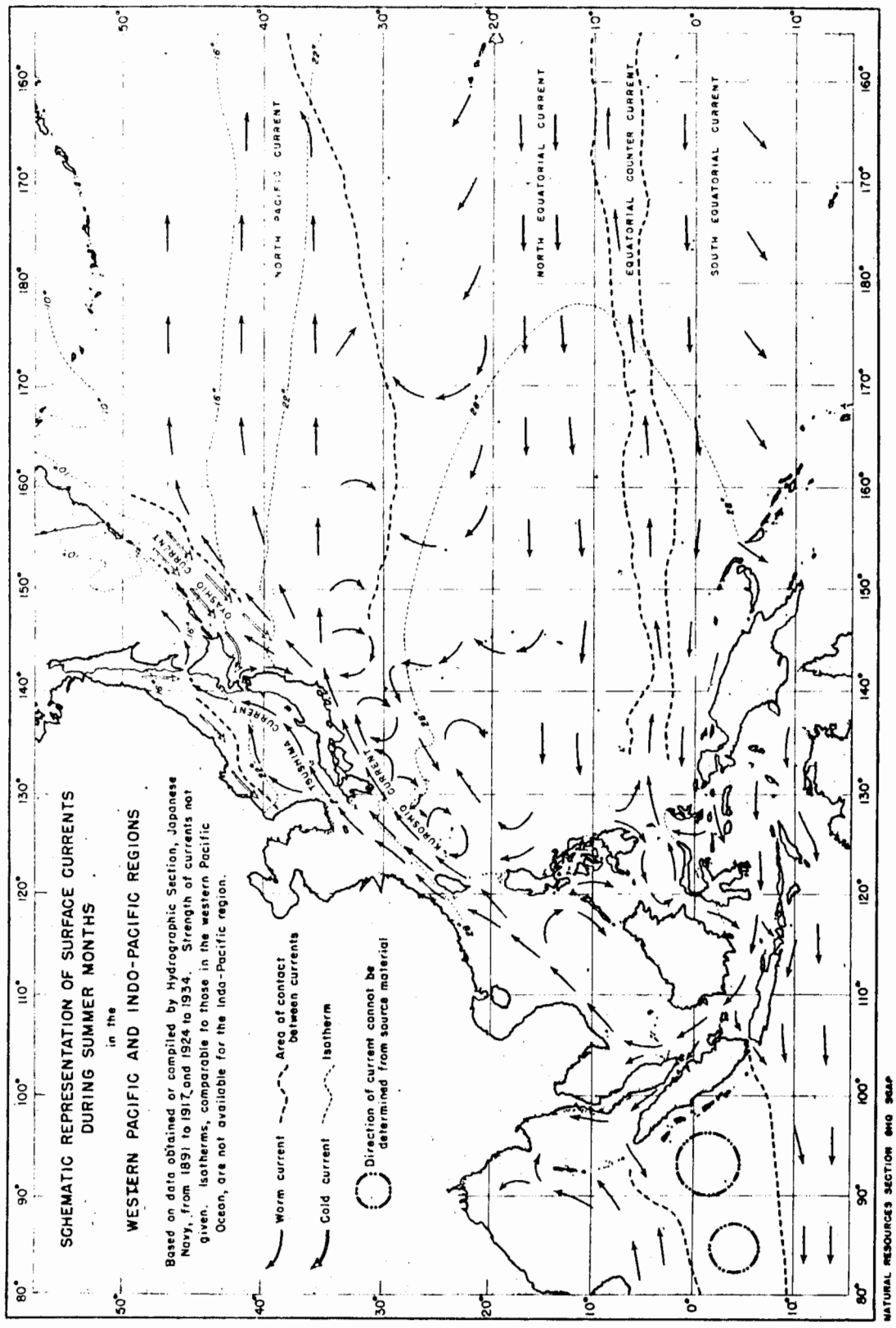


Figure 27.--Schematic representation of surface currents during summer months in the western Pacific and Indo-Pacific regions (Shapiro, 1948).

winds of east Asia also exert their influence; the strength of the Japan Current as well as the southeast-turning countercurrent near Palau vary with the seasonal monsoons.

To show greater detail in the waters around Micronesia, mean direction and force of the surface surrents in each 1° quadrangle, and the current rose, which presents a graphical picture of the frequency of direction and the average drifts within the directions in each 5° quadrangle, are presented, by month, in Figures 28a to 28ℓ (see Appendix 1 for explanation).

Because of the closeness of the Kuroshio, its countercurrent, and the subtropical currents to the currents which dominate the waters of Micronesia, we have included them in this discussion. A longitudinal oceanographic section, made from Japan to New Guinea along long. 137°E, was discussed by Masuzawa (1967). The oceanographic investigation, done in January 1967 aboard the RV Ryofu Maru, involved the Kuroshio, its countercurrent, weak currents in the subtropics, the North Equatorial Current, the Equatorial Countercurrent, and the Equatorial Undercurrent.

Figure 29 shows the track chart and stations of the CSK (Cooperative Study of the Kuroshio) cruise of the RV Ryofu Maru. Characteristic properties of zonal currents through a north-south section at long. 137°E are given in Table 14. The limits of the zonal currents were determined by the slope of the isobaric surfaces (Masuzawa, 1967). Three major zones were identified: The Kuroshio and its countercurrent between lat. 33°28' and 28°54'N, the nearly currentless zone between lat. 28°54' and 21°58'N, and the equatorial current system between lat. 21°58'N and 00°43'S.

The northernmost zone, which embraces the Kuroshio, is most intense although narrow. South of the eastward flow of the Kuroshio is a well-defined westward flow between lat. 31°18' and 28°54'N. This remarkable flow to the west probably is not a long continuous current independent of the Kuroshio but a clockwise eddy associated with the Kuroshio.

South of the Kuroshio countercurrent is a zone of weak or no current between lat. 28°54' and 21°58'N (Masuzawa, 1967). Here, weak eastward and westward currents appear alternately. Masuzawa found the most pronounced current in the upper 330 ft (100 m) to be an eastward flow at lat. 22° to 24°N and this current has been designated the "Subtropical Countercurrent" by some Japanese oceanographers.

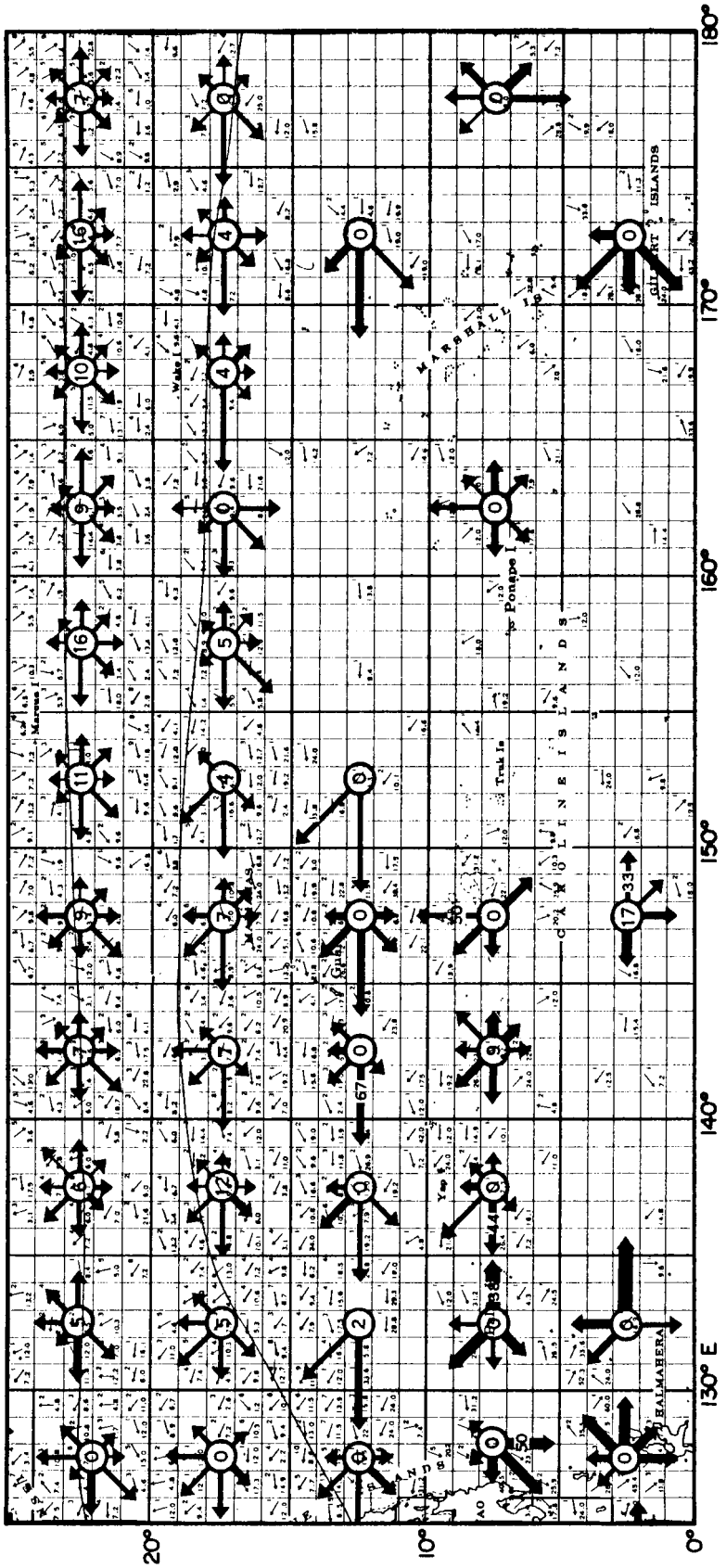


Figure 28a.--Surface currents in the northwestern Pacific Ocean in January (U.S. Navy Hydrographic Office, 1944).

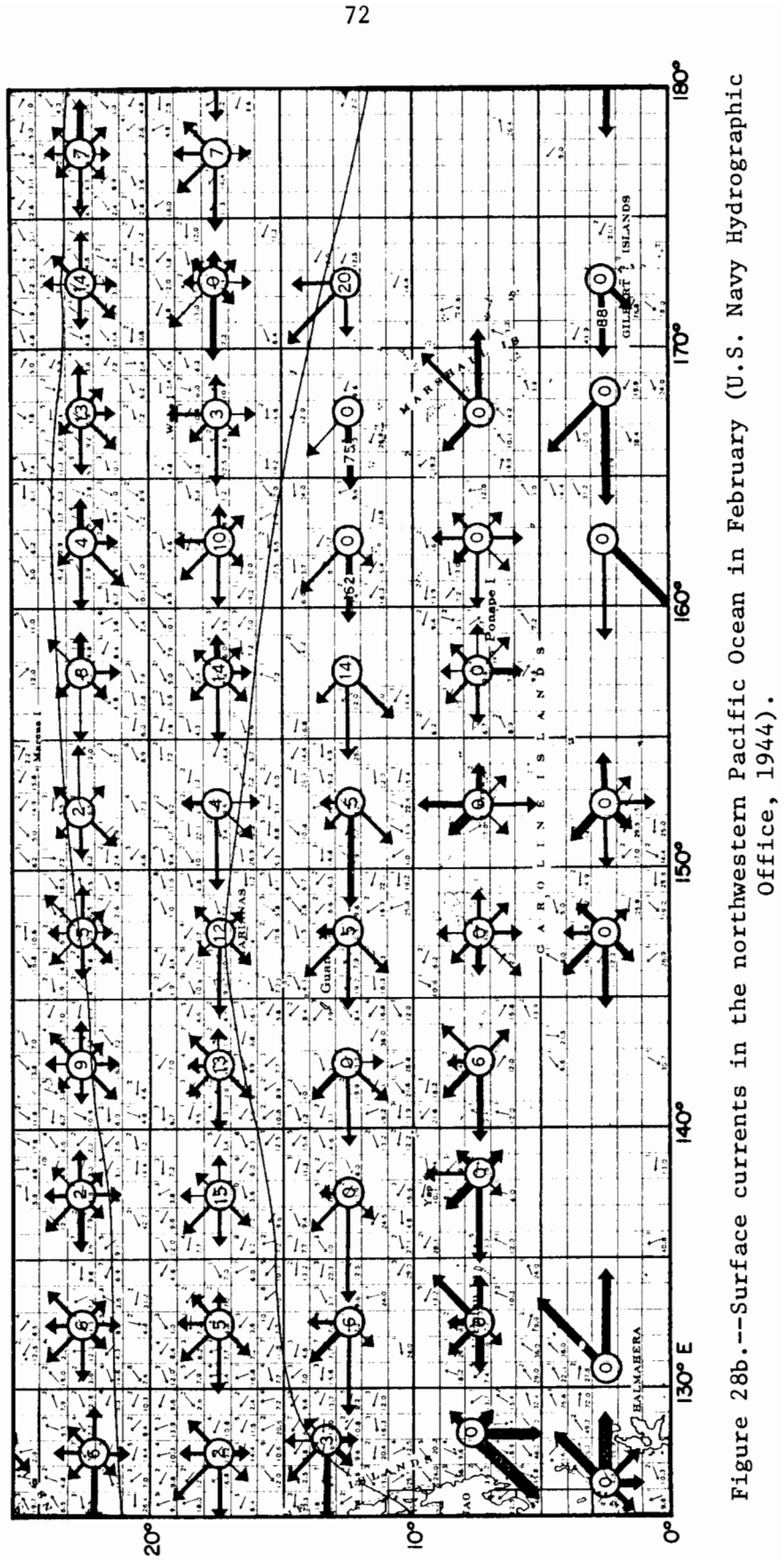


Figure 28b.--Surface currents in the northwestern Pacific Ocean in February (U.S. Navy Hydrographic Office, 1944).

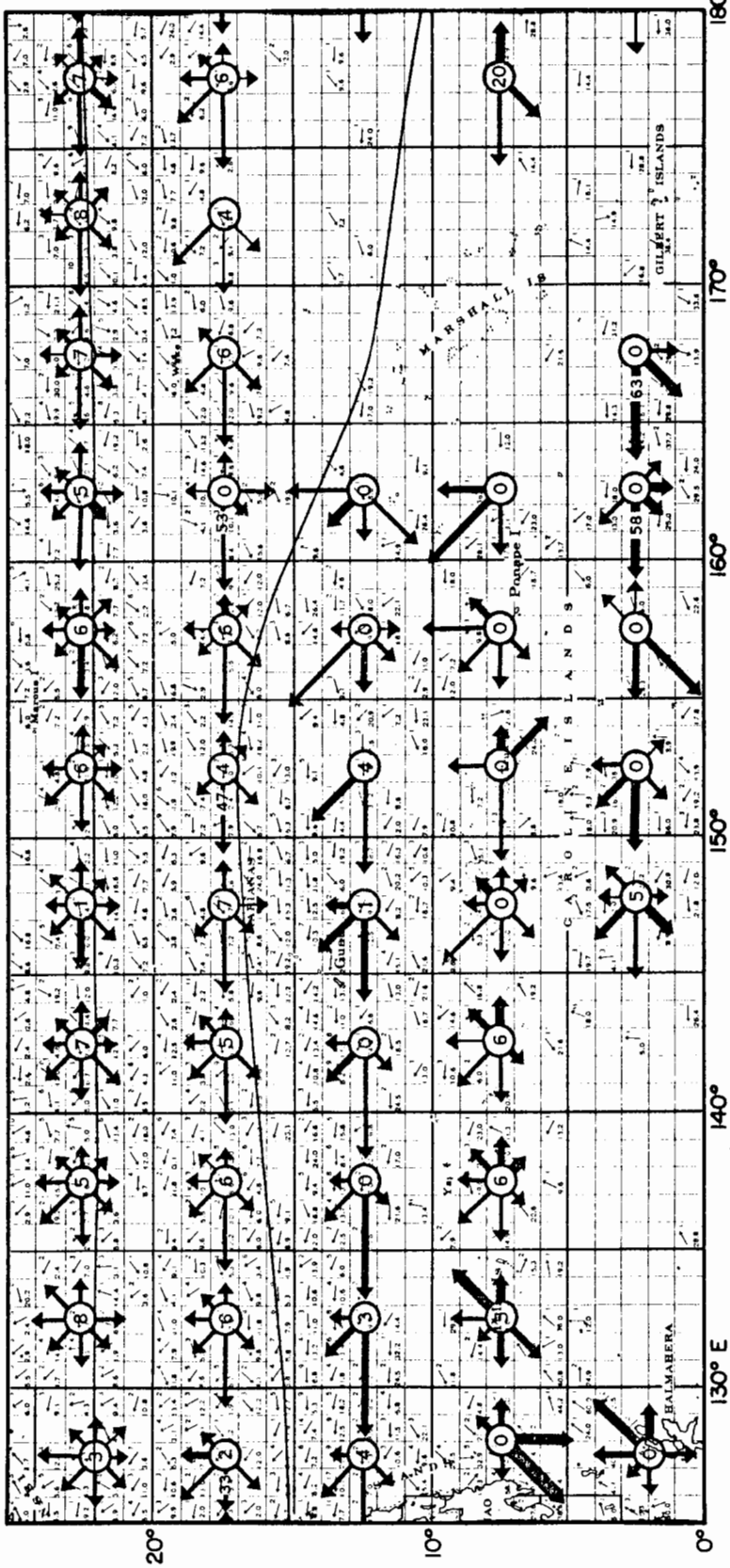


Figure 28c.--Surface currents in the northwestern Pacific Ocean in March (U.S. Navy Hydrographic Office, 1944).

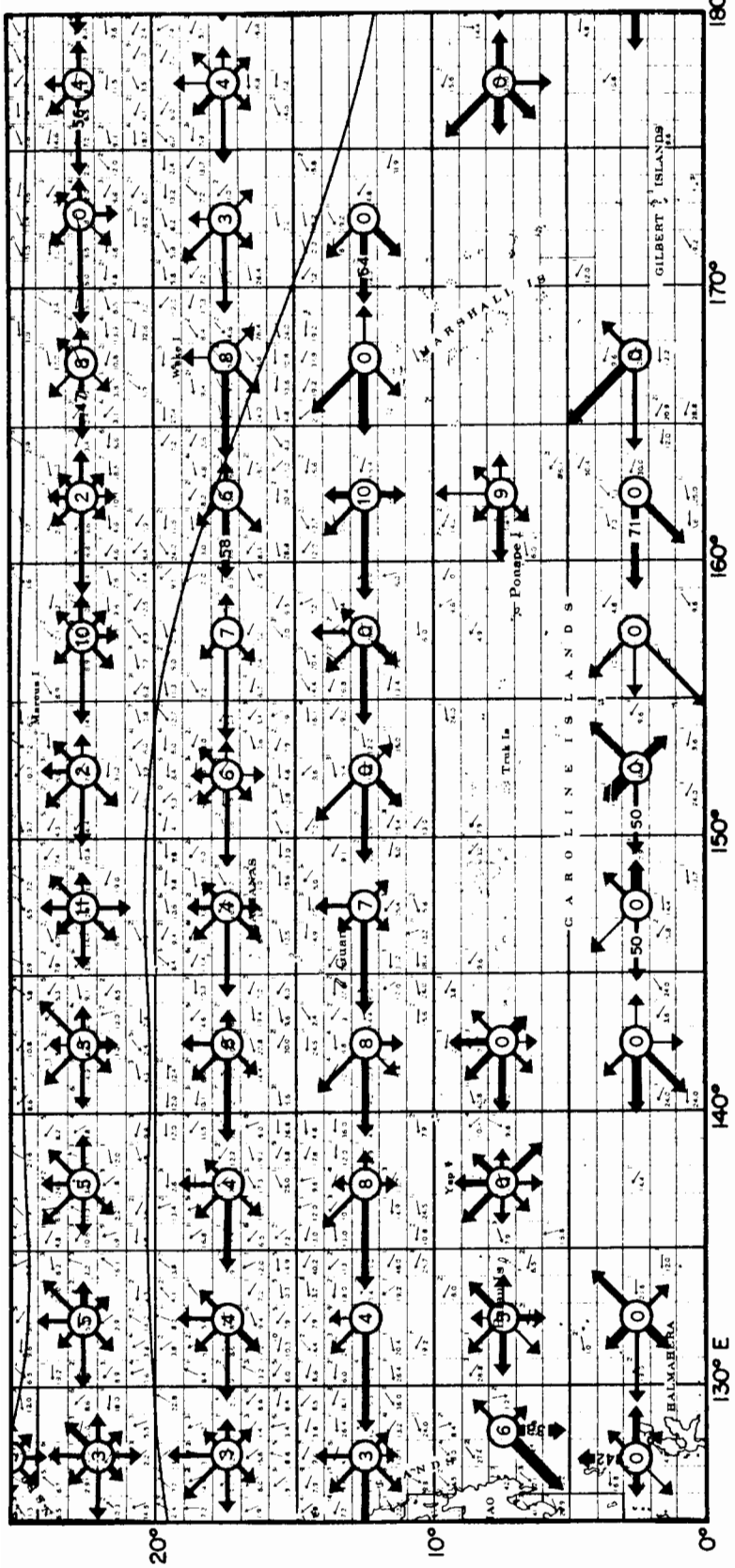


Figure 28d.--Surface currents in the northwestern Pacific Ocean in April (U.S. Navy Hydrographic Office, 1944).

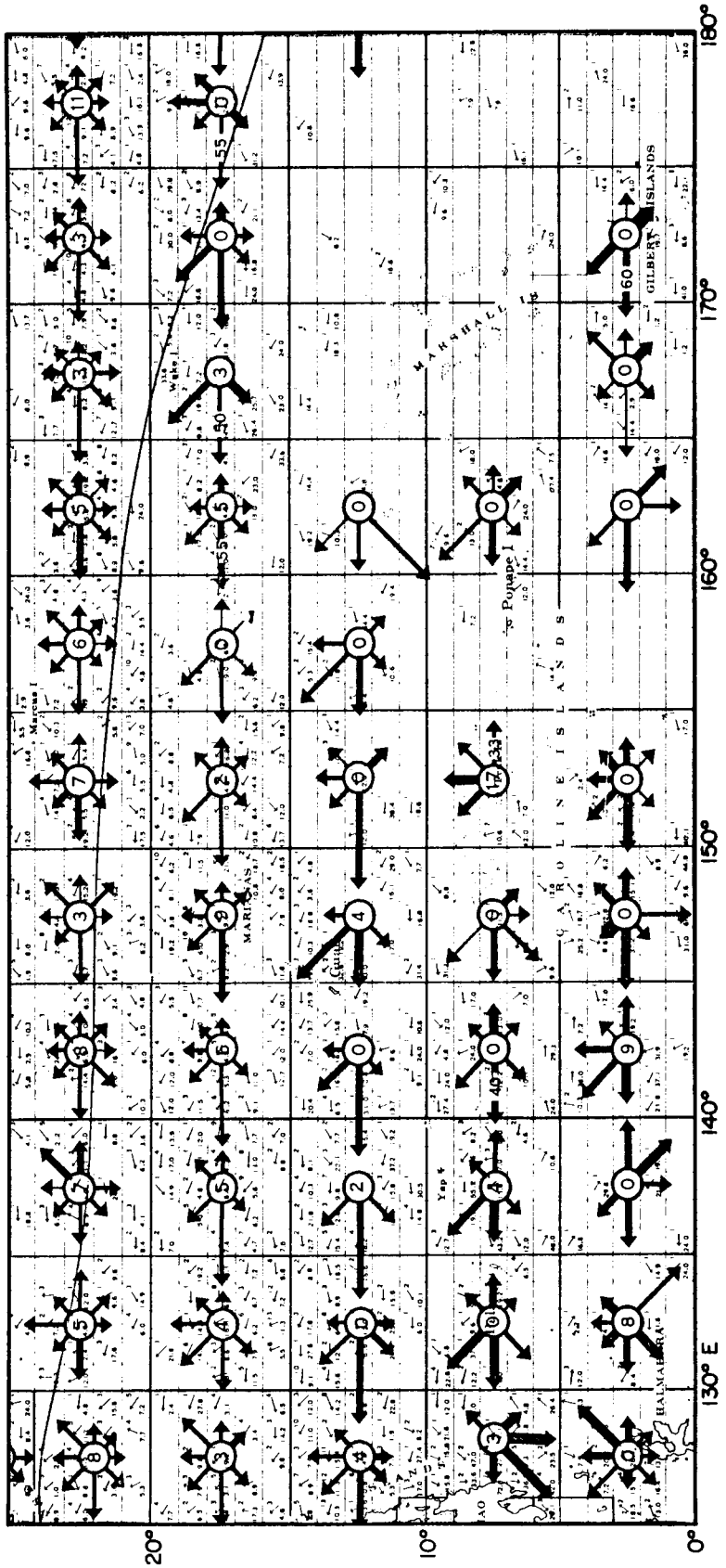


Figure 28e.--Surface currents in the northwestern Pacific Ocean in May (U.S. Navy Hydrographic Office, 1944).

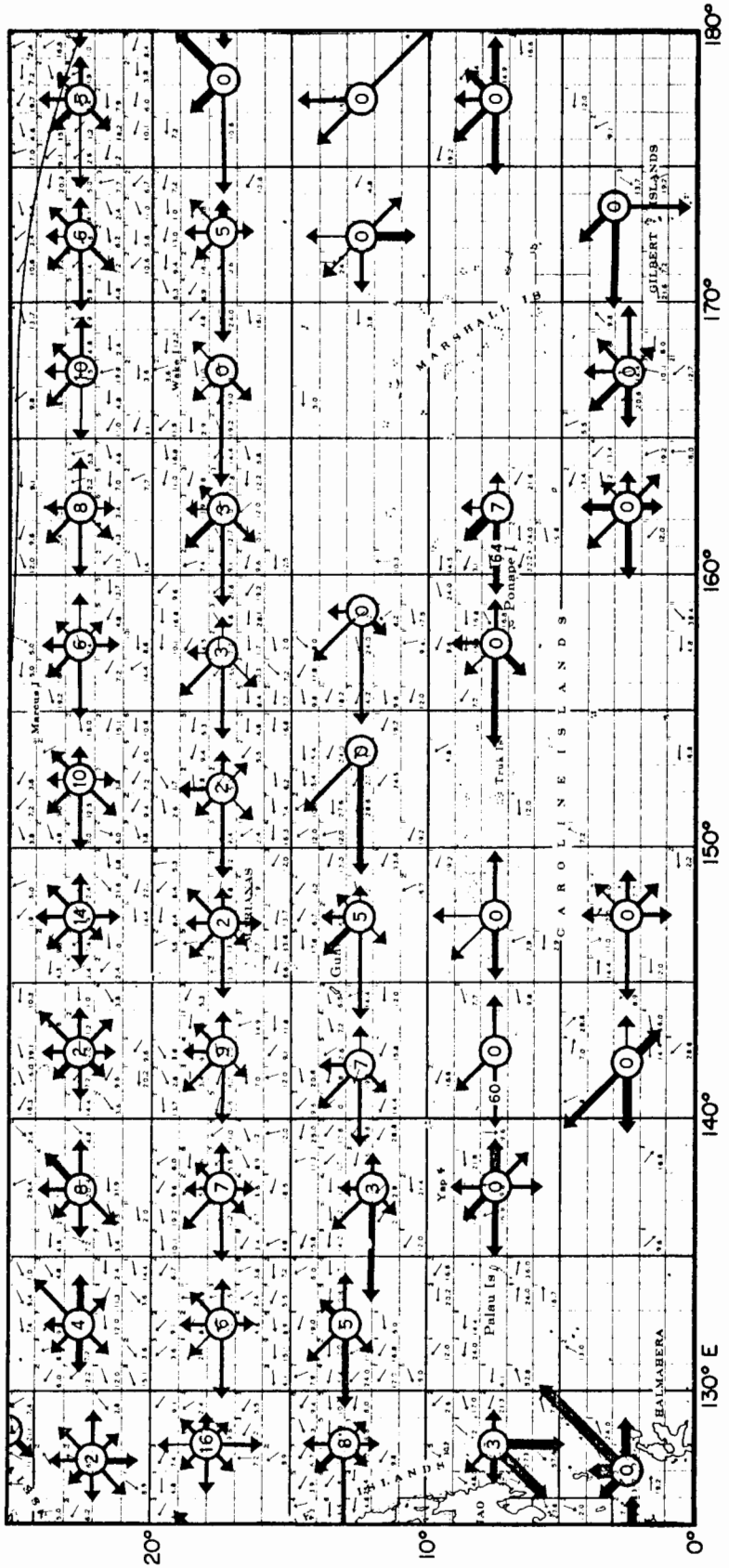


Figure 28f.--Surface currents in the northwestern Pacific Ocean in June (U.S. Navy Hydrographic Office, 1944).

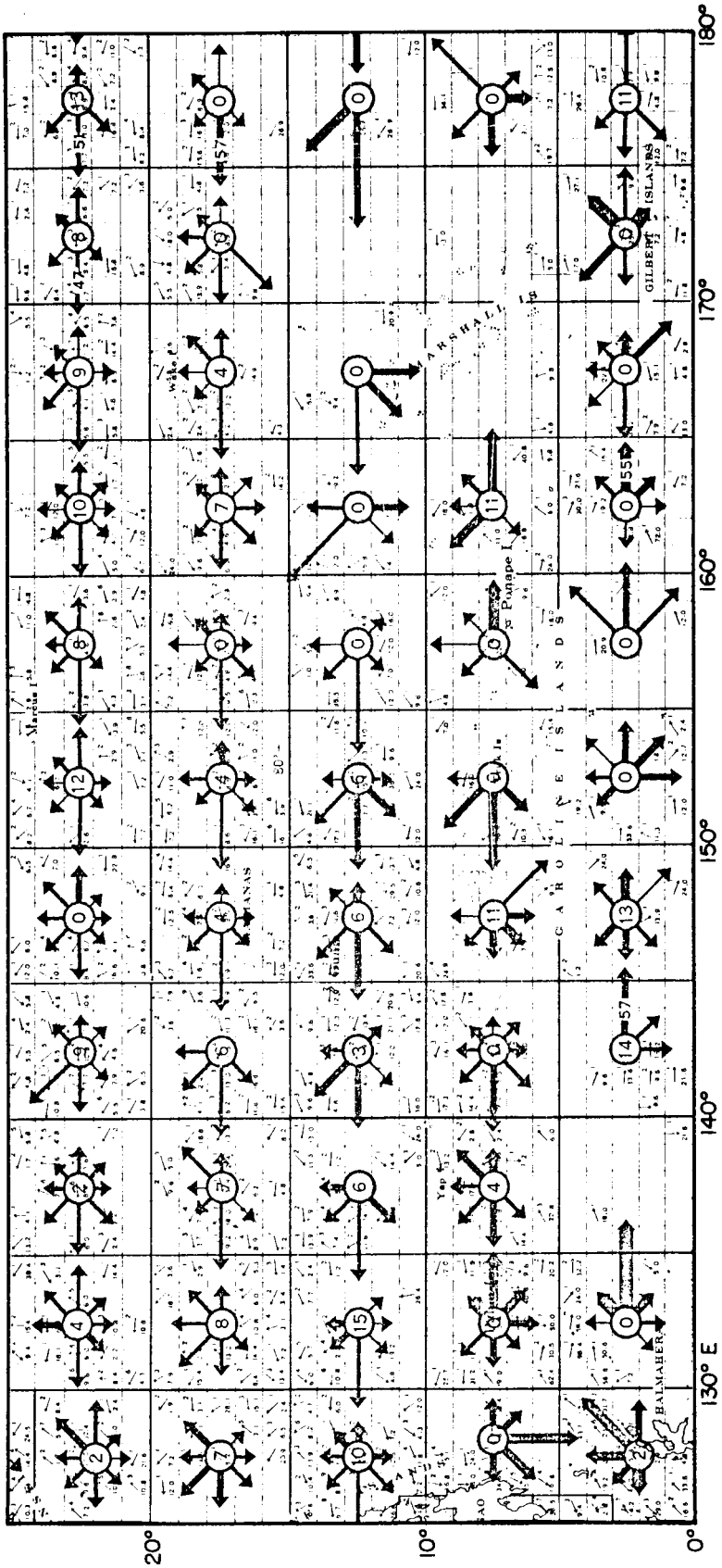


Figure 28g.--Surface currents in the northwestern Pacific Ocean in July (U.S. Navy Hydrographic Office, 1944).

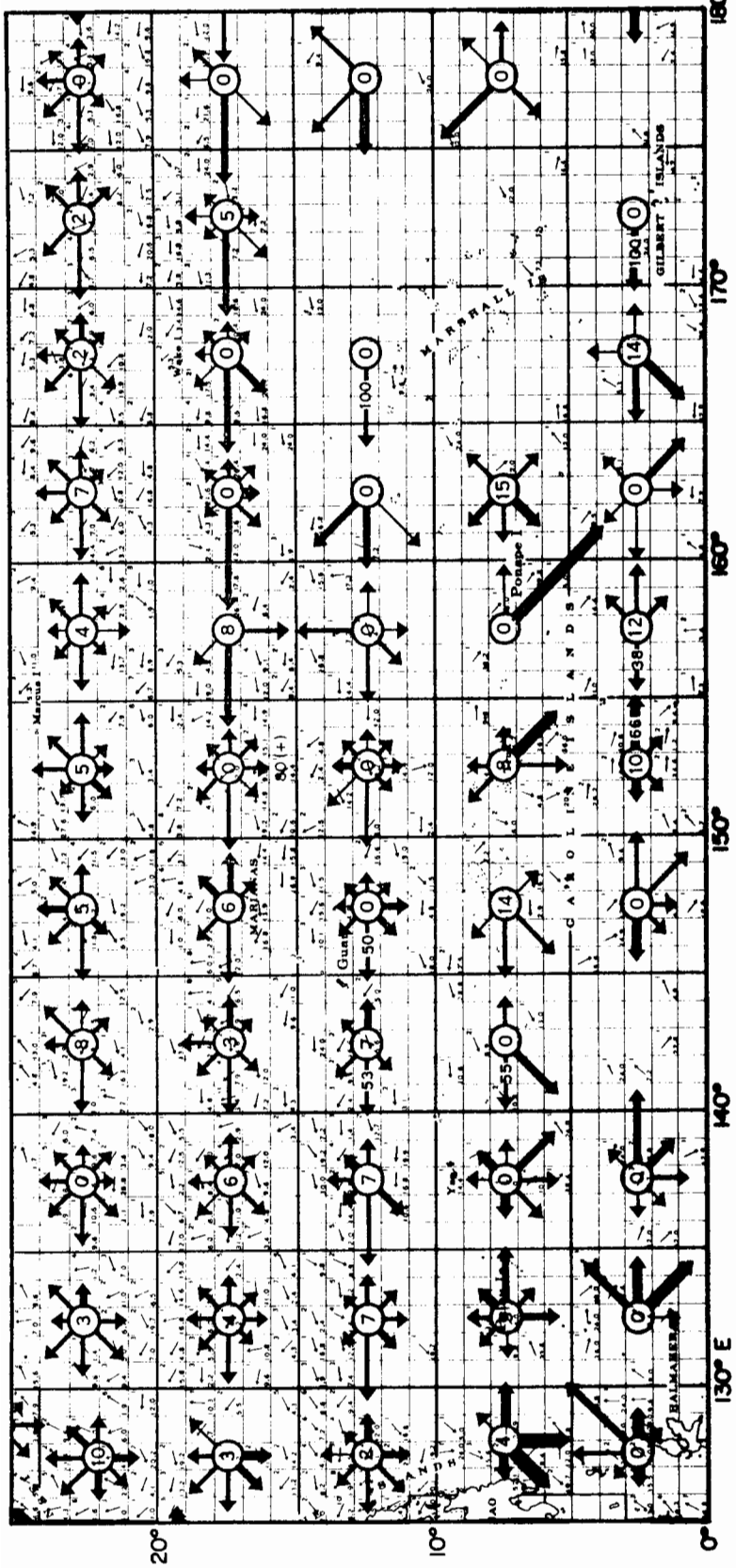


Figure 28h.--Surface currents in the northwestern Pacific Ocean in August (U.S. Navy Hydrographic Office, 1944).

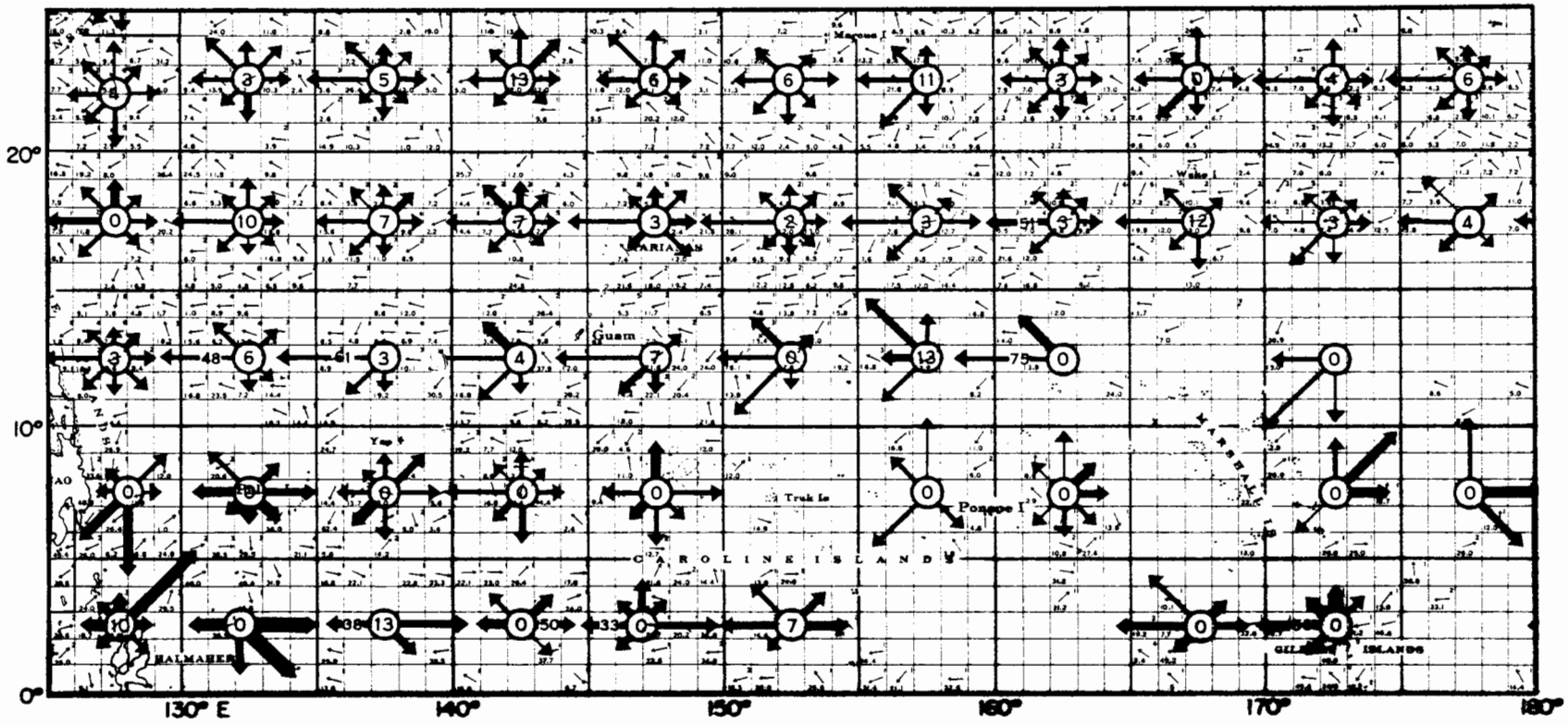


Figure 28i.--Surface currents in the northwestern Pacific Ocean in September (U.S. Navy Hydrographic Office, 1944).

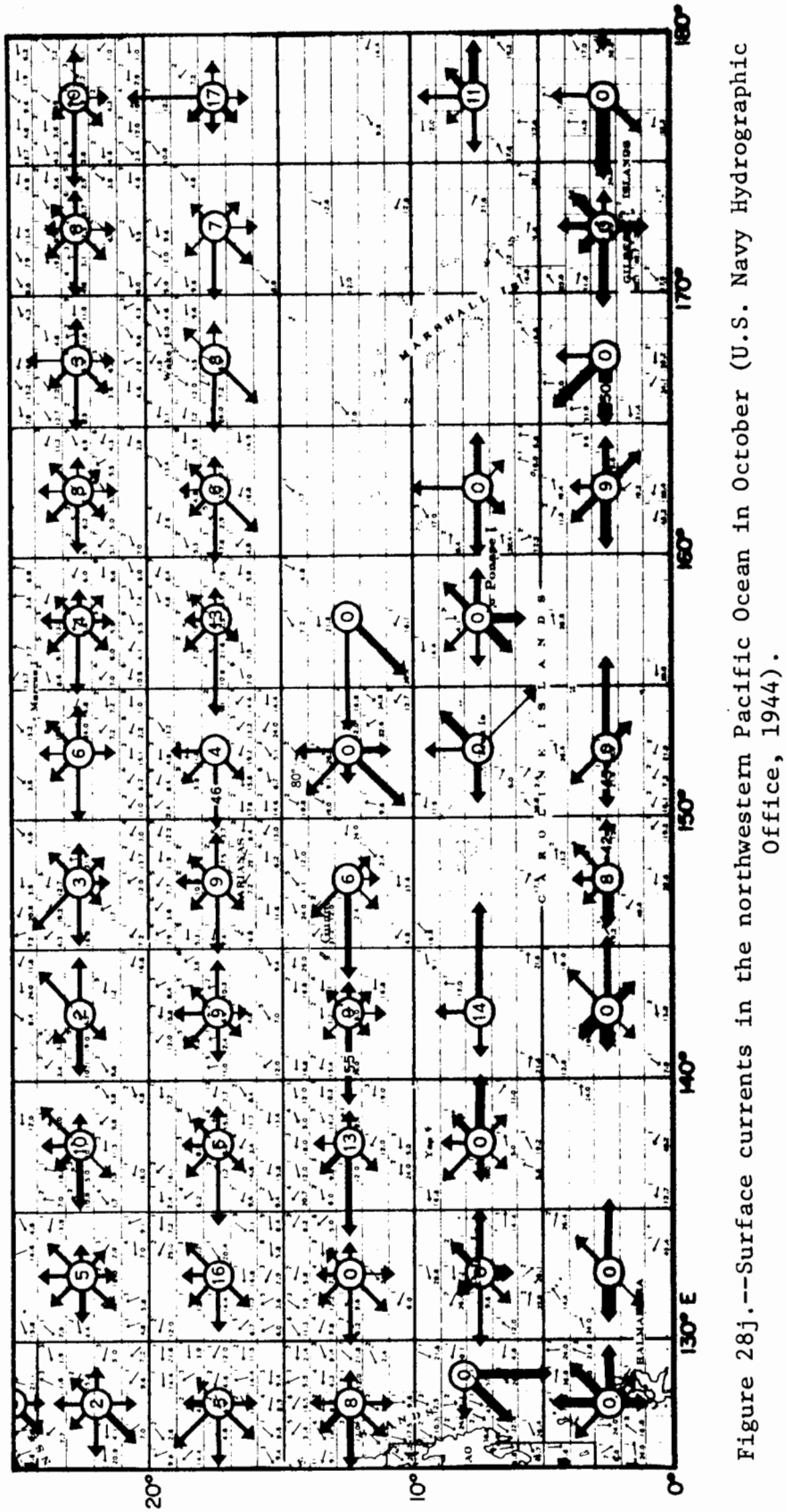


Figure 28j.--Surface currents in the northwestern Pacific Ocean in October (U.S. Navy Hydrographic Office, 1944).

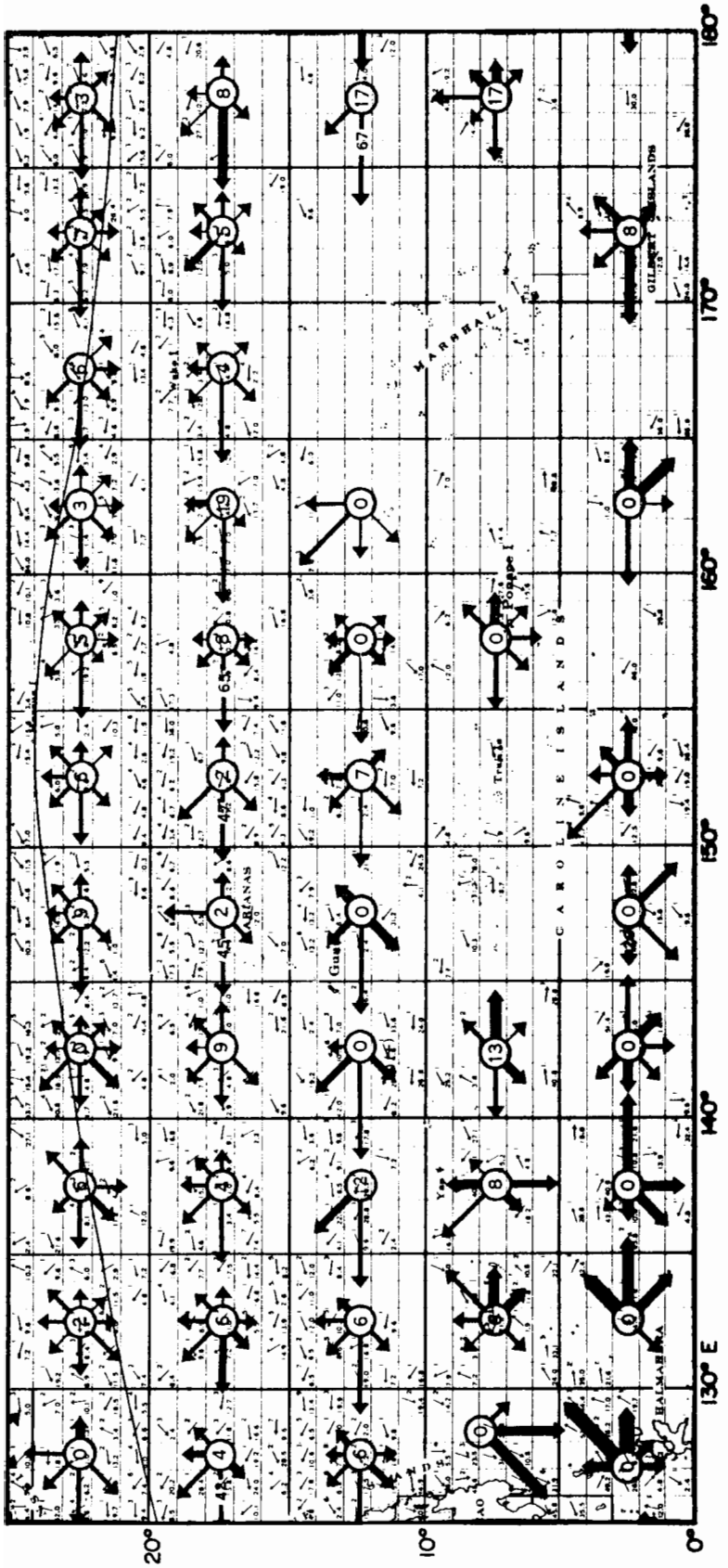


Figure 28k.--Surface currents in the northwestern Pacific Ocean in November (U.S. Navy Hydrographic Office, 1944).

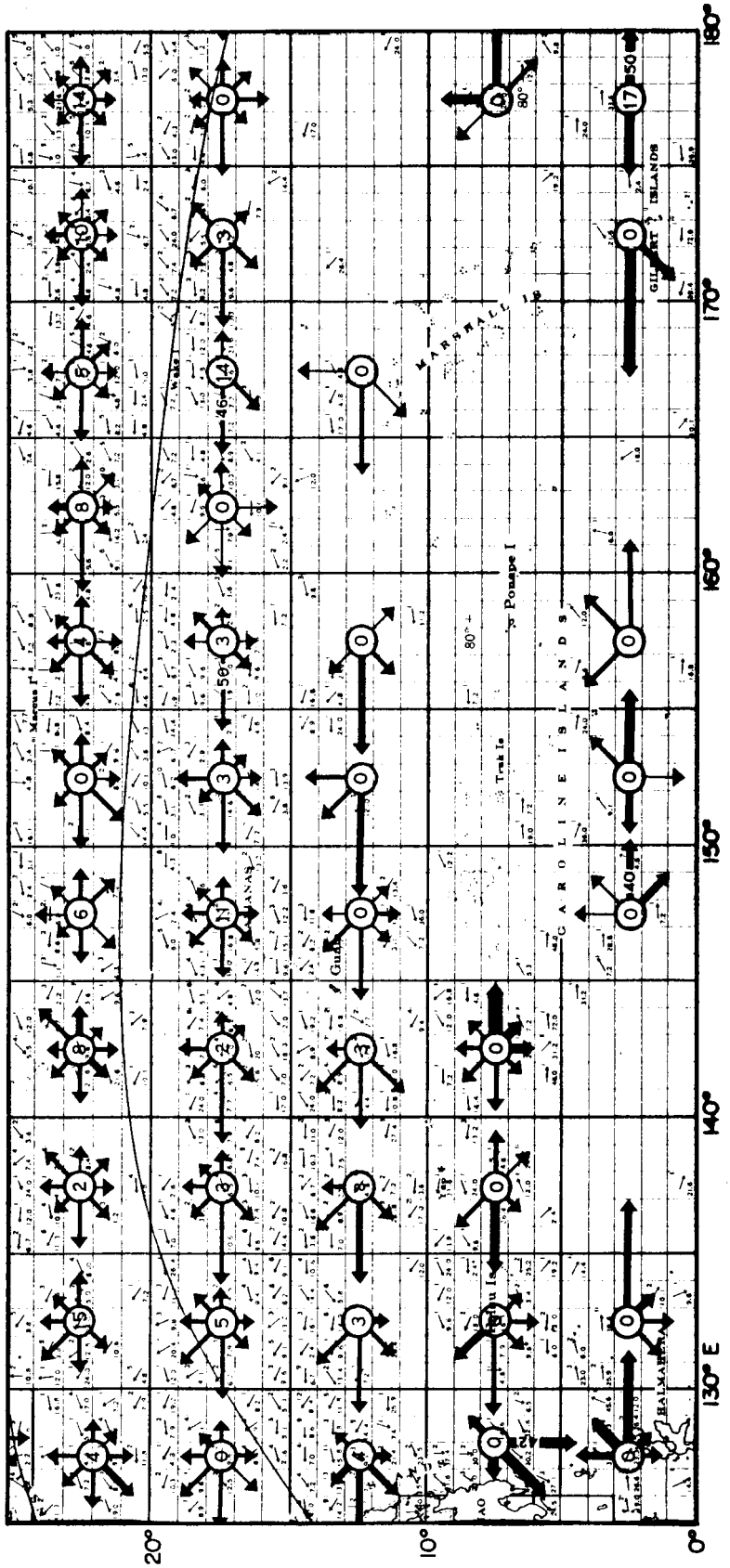


Figure 28.--Surface currents in the northwestern Pacific Ocean in December (U.S. Navy Hydrographic Office, 1944).

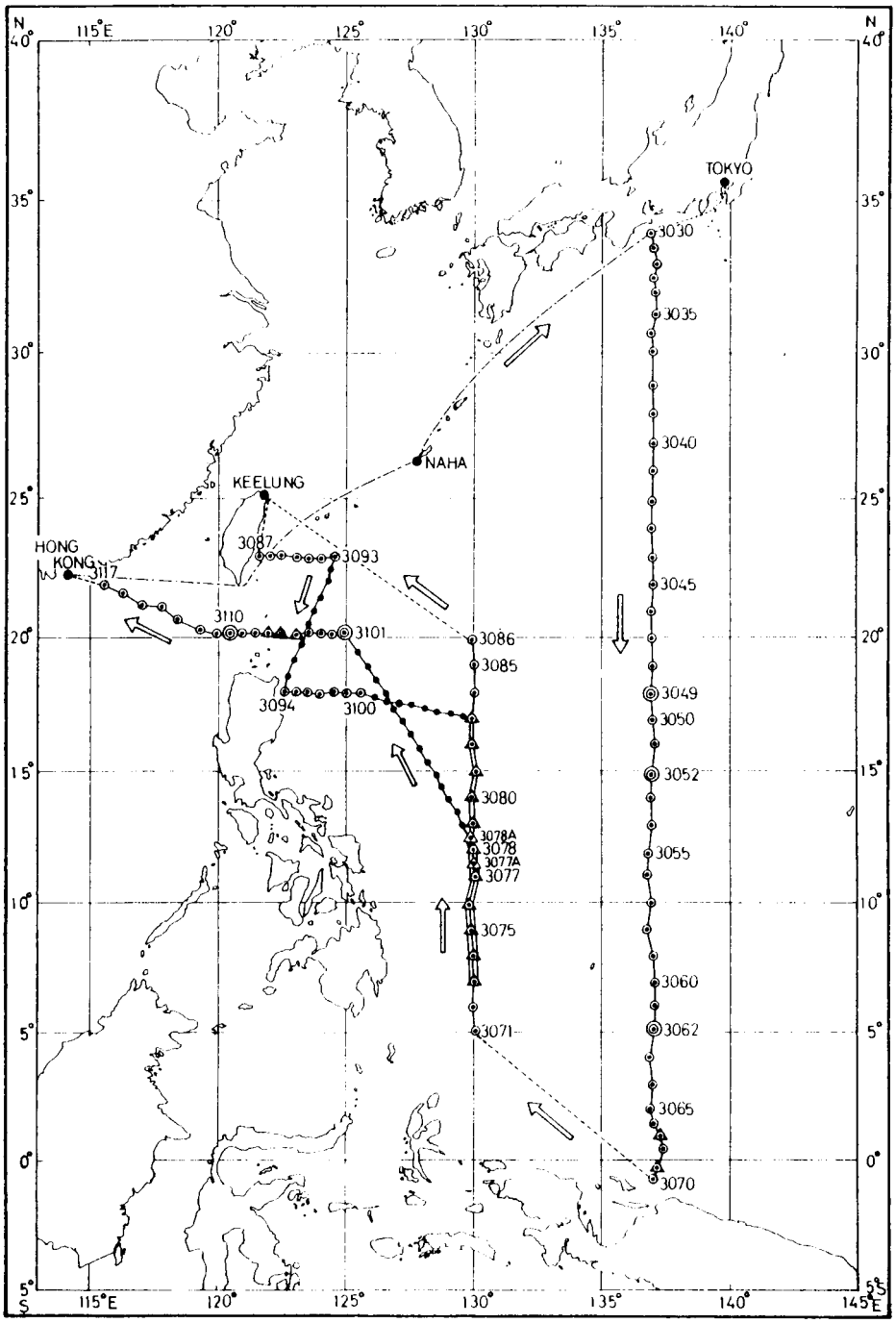


Figure 29.--Track chart of the CSK cruise of the RV Ryofu Maru, in January-March 1967 (Masuzawa, 1967).

Masuzawa (1967) recognized from the north-south sections that the North Equatorial Current could be split into two parts because of differences in the latitudes from which the slopes of the sea surface and isobaric surfaces began. The northern half was between lat. 21°58' and 14°54'N and the southern half between lat. 14°54' and 6°58'N.

South of the North Equatorial Current is the countercurrent, which is between lat. 6°58' and 2°04'N (Masuzawa, 1967). Centered in the surface layer at lat. 4°-5°N, it is not always clearly separated from the Equatorial Undercurrent, whose core lies 650-980 ft (200-300 m) deep near the equator. In the western Pacific, the Equatorial Undercurrent is not isolated from the countercurrent; in the central and eastern equatorial Pacific, it is.

One of the most important features of the current system in the Marshall Islands area is the existence of large-scale horizontal eddies between lat. 4° and 10°N, corresponding to the northern boundary of the countercurrent (Mao and Yoshida, 1955). These eddies have an approximate radius of several hundred kilometers. No eddies are found along the southern boundary of the countercurrent.

Mao and Yoshida (1955) proposed that these eddies are similar in nature to those found in the outer area of the Gulf Stream. When the countercurrent flows in the opposite direction to the surrounding currents, eddies are expected to be generated by cutoff from the meandering current system, that is, at the boundary zone between two different current systems. Another possibility is that the eddies are related to turbulence in this boundary zone. In such a zone, the current shear is very large and considerable horizontal mixing can occur. Under this condition, external disturbances, such as those caused by bottom topography, islands, or meteorological conditions, can produce eddies. Mao and Yoshida (1955) consider the effects of islands to be significant judging from the location of eddies.

The barrier effect of islands, interpreted another way, provides still another explanation for the formation of eddies. In the Marshalls, the Ratak and Ralik Chains are assumed to be barriers. Figures 30 and 31 depict how it is possible to produce eddies even where there is no significant turbulence or meandering.

Takahashi (1959) showed the existence and described the character of a "contra solem" vortex, which may be considered the western boundary vortex between the North Equatorial Current and the Equatorial Countercurrent. Located east of Mindanao Island in the Philippines, the vortex extends over an area 400 mi (741 km) in a north-south and 1,000 mi (1,853 km) in an east-west direction (Figures 32 and 33). The vortex is characterized by horizontal minimum temperature and salinity. Intermediate water, with a salinity minimum at

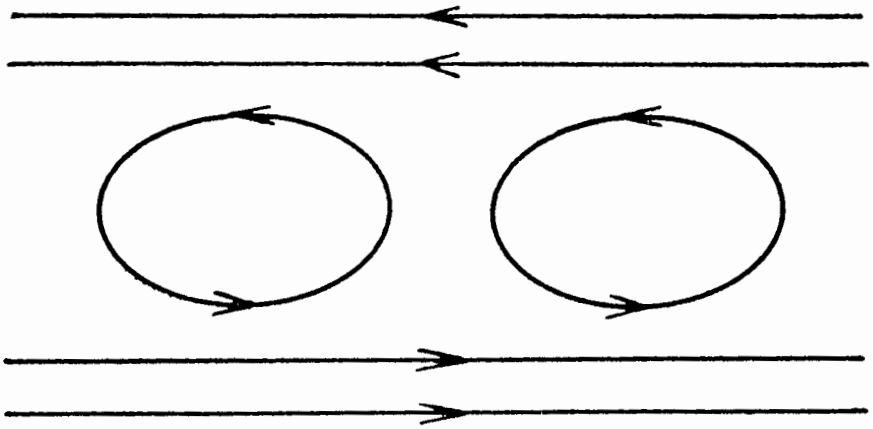


Figure 30.--A schematic representation of horizontal eddies produced in the boundary shear zone (Mao and Yoshida, 1955).

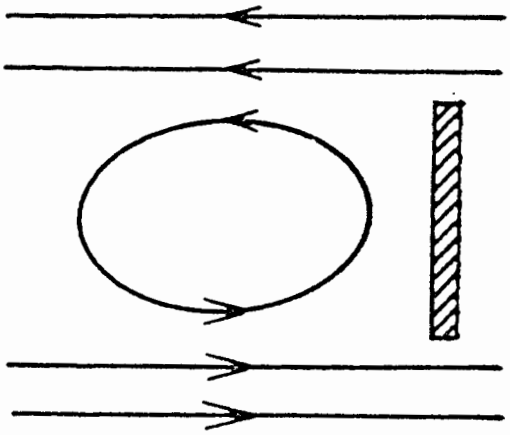


Figure 31.--A schematic representation of a horizontal eddy caused by a barrier (Mao and Yoshida, 1955).

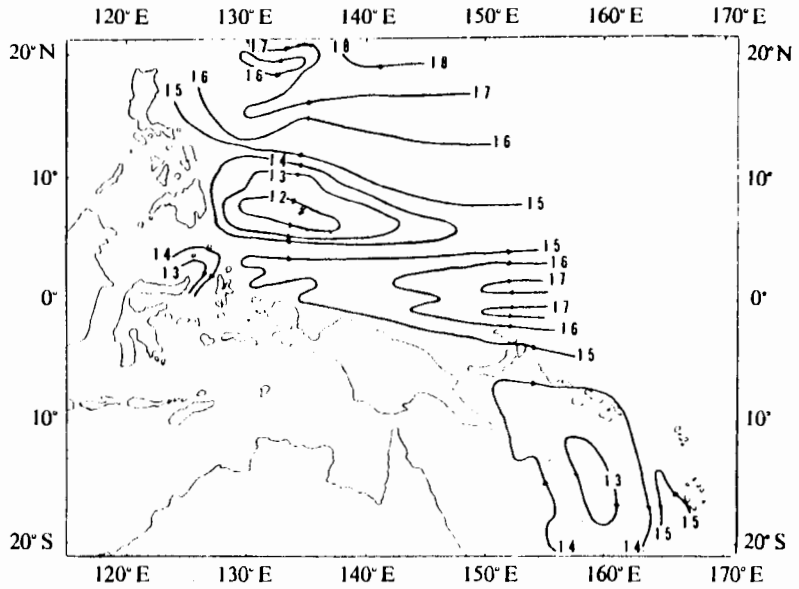


Figure 32.--Dynamic topography of the sea surface referred to the 500 decibar surface. Approximate current directions indicated by arrows (Takahashi, 1959).

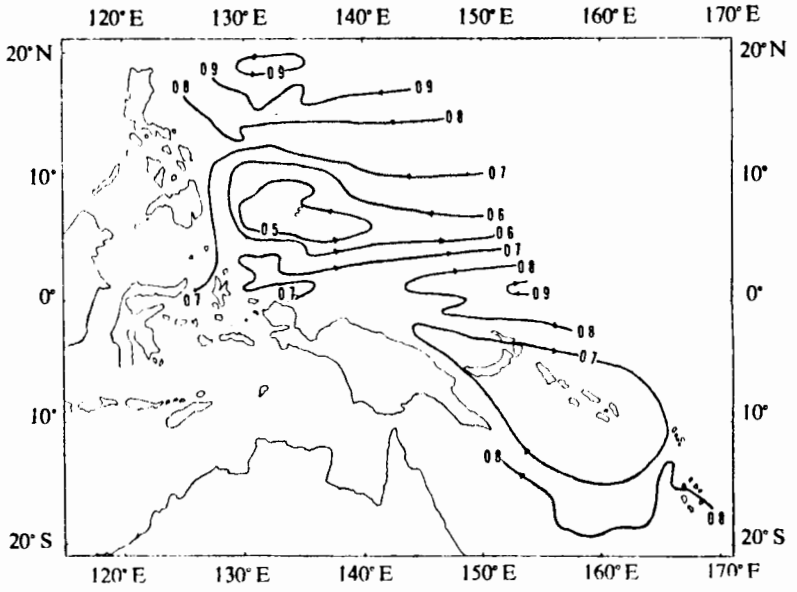


Figure 33.--Dynamic topography of 150 decibar surface referred to the 500 decibar surface. Approximate current directions indicated by arrows (Takahashi, 1959).

about 1,640 ft (500 m) almost vanishes in the vortex because of upwelling and mixing within this area. The maximum current velocity of about 3 knots occurs in the eastward flowing water on the southern part of the vortex. Another small vortex seems to exist around lat. 19°N within the North Equatorial Current.

THERMOCLINE DEPTH

There is evidence that suggests that temperature limits not only the horizontal distribution of tunas but their vertical distribution as well. Studying the rates of success with tuna purse seines in the eastern tropical Pacific tuna fishery, Green (1967) found that the success rate was clearly related to the depth of the thermocline and the average vertical temperature gradient within the thermocline. The success rate was 63.9% when the temperature gradient was large and the thermocline shallow; conversely, the combination of small gradient and deep thermocline gave a success rate of only 39.9%. Therefore, information on depth and temperature gradients of the thermocline may be useful in identifying areas where purse seining for tunas may be more successful.

On the cruise of MV Anela to the central and western Pacific to conduct exploratory pole-and-line fishing trials, Uchida and Sumida (1973) collected not only fishing but also environmental data. They found that while fishing around Majuro and Arno atolls in February, the thermocline was distinct and occurred between 200 and 330 ft (60 and 102 m). But by April very noticeable changes had occurred in the subsurface layer. The thermocline was shallower, with one trace showing it at 130 ft (40 m) and the other at 260 ft (80 m). And whereas the subsurface temperatures at 660 ft (200 m) were higher than 11°C in February, those observed in April were lower.

Figure 34 shows the approximate depth of the thermocline by means of contours drawn at depth intervals of 160 ft (50 m) (Sverdrup, Johnson, and Fleming, 1946). Of significance is the shallowness of the thermocline in the eastern Pacific, where a sharp temperature decrease is evident at depths of usually less than 160 ft (50 m). Toward the west the depth of the thermocline increases and in the western Pacific the minimum depth may vary between 490 and 660 ft (150 and 220 m).

Figure 35 shows the north-south variation in the thermocline at long. 137°E. Masuzawa (1967) stated that the main thermocline, centered at 50°-54°F (10°-12°C) north of lat. 15°N, slopes sharply downward from the northern edge of the Kuroshio to the southern edge, where the mixed layer is nearly isothermal and thickest over the

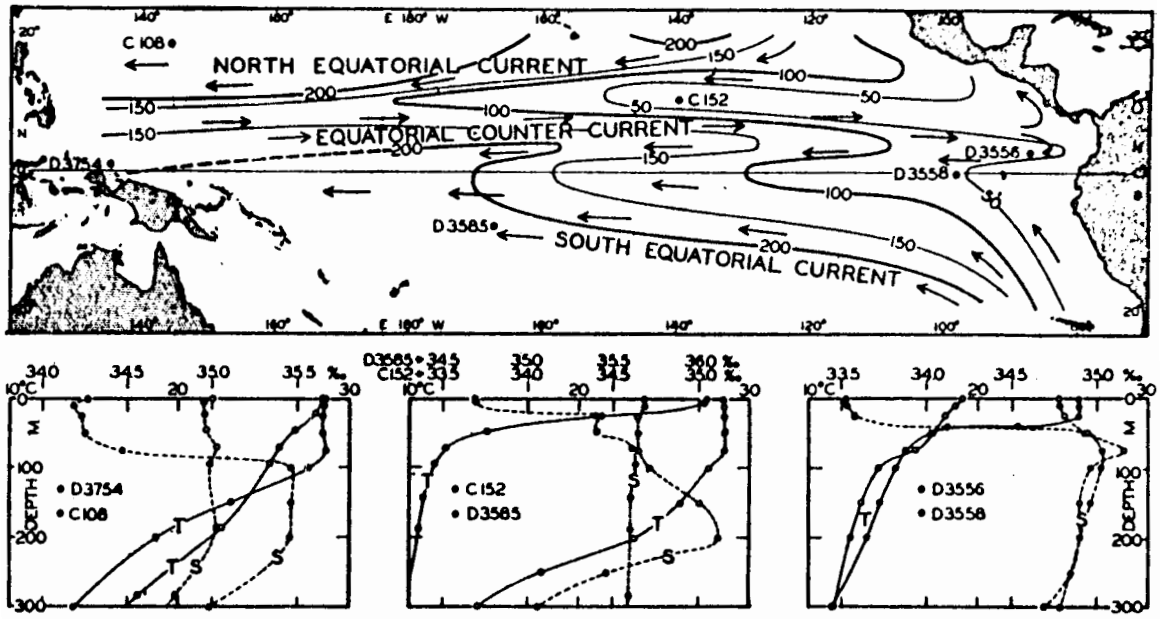
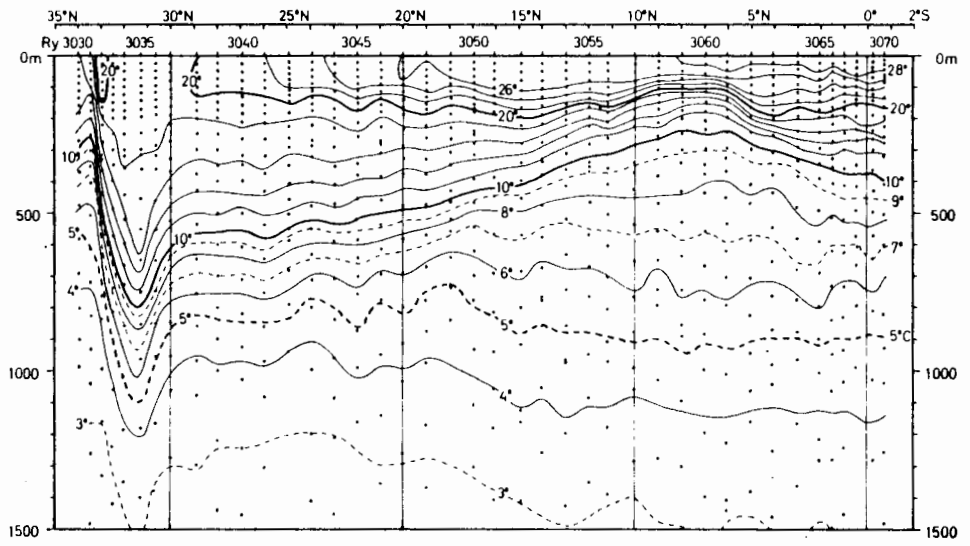
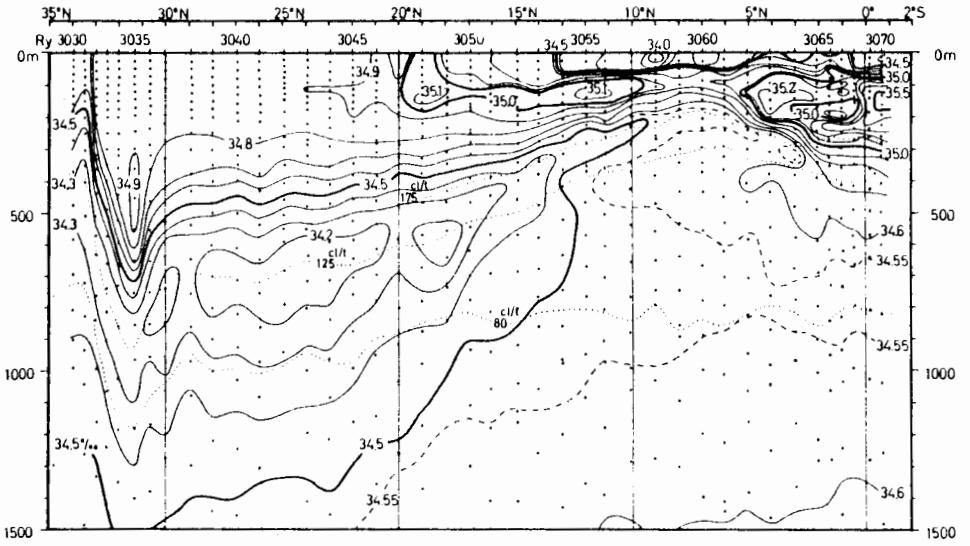


Figure 34.--Upper: Topography of the discontinuity surface in the equatorial region of the Pacific and corresponding currents. Lower: Vertical temperature and salinity curves at six stations, the locations of which are shown in the upper figure. Data are from Carnegie (C) and Dana (D) (Sverdrup, Johnson, and Fleming, 1946).

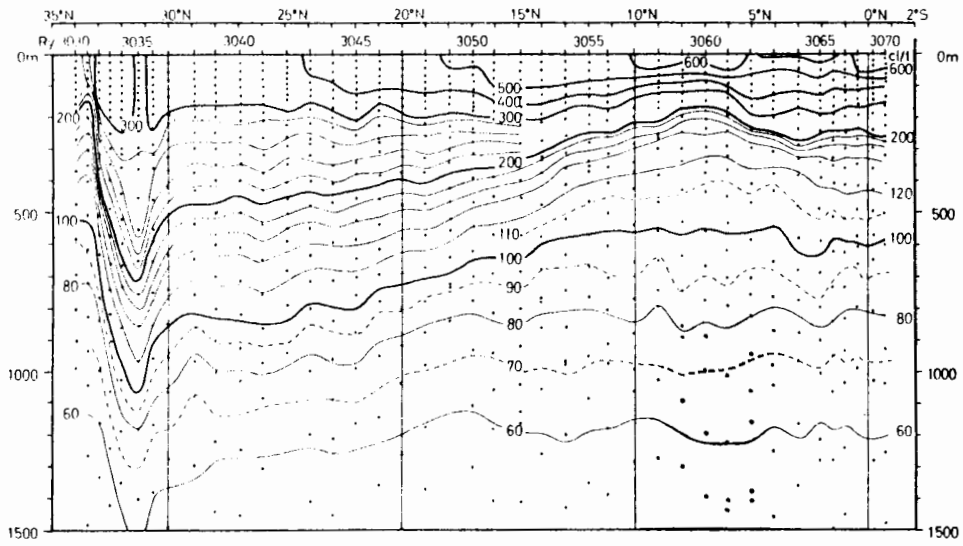


(a)

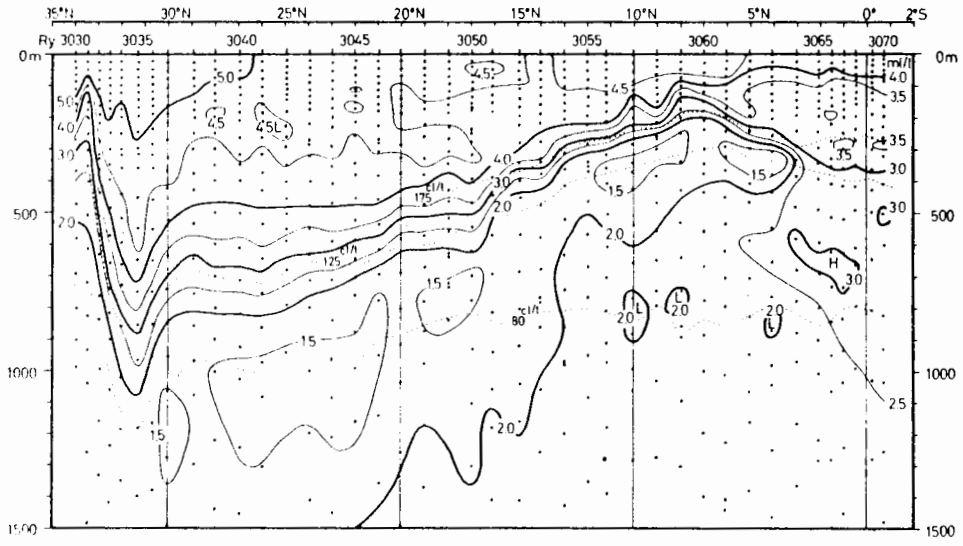


(b)

Figure 35.--Vertical sections of temperature (a), salinity (b), thermosteric anomaly (c), and oxygen content (d) at long. 137°E in January 1967 (Masuzawa, 1967).



(c)



(d)

Figure 35.--Continued.

section. Southward from lat. 30° to 15°N, the thermocline shallows gradually. At about lat. 15°N, the center of the thermocline is switched from 52°F (11°C) to about 68°F (20°C). The thermocline is shallowest and the vertical temperature gradient largest at the boundary between the North Equatorial Current and the countercurrent.

The temperature profile for the Marshall Islands area is shown in Figure 36. It can be readily seen that there are three parts: The topmost isothermal layer, the thermocline layer, and the layer of weak gradient. Mao and Yoshida (1955) found that in this region, the isothermal layer generally lies between 165 and 330 ft (50 and 100 m) with an average thickness of about 245 ft (75 m). The isothermal layer is somewhat thicker in winter than in summer. And there is a latitude dependence of the isothermal layer in this area; near the equator, it has a thickness of about 330 ft (100 m) or more. The shallowest depth occurs at about lat. 10°-12°N in the summer and at about lat. 8°-10°N in the winter.

The thermocline layer, indicated by the large gradient in the temperature profile in Figure 36 and by the crowding of isotherms in Figure 37, usually lies at 655 ft (200 m) for the area as a whole, varying between 245 and 985 ft (75 and 300 m) (Mao and Yoshida, 1955). The position of the shallowest thermocline appears roughly between lat. 5°-9°N, which corresponds fairly well with the northern boundary of the countercurrent. Mao and Yoshida have also indicated that for the Marshalls area, the substitution of the 28°C isotherm for the thermocline is satisfactory for lat. 10°-12°N or lower. For latitudes higher than 12°N, the thermocline is less distinct but the position of the 26°C isotherm appears to be a good approximation.

SALINITY AND OXYGEN

Figures 38a to 38d show the quarterly mean salinity at 10 m in the western Pacific Ocean. The outstanding feature of the horizontal distribution of salinity in the western equatorial Pacific is the separation of the northern and southern high-salinity regions by one of low salinity, usually located between lat. 0° and 10°N.

According to Cannon (1966), the low-salinty water which intervenes between the northern and southern tropical waters is also tropical water. He indicated that water with salinity less than 34°/$_{oo}$ can be found in the eastern Pacific and that this water could be transported westward. Another part of the low-salinity tropical water apparently comes through the Molucca Passage from the east Indian Sea.

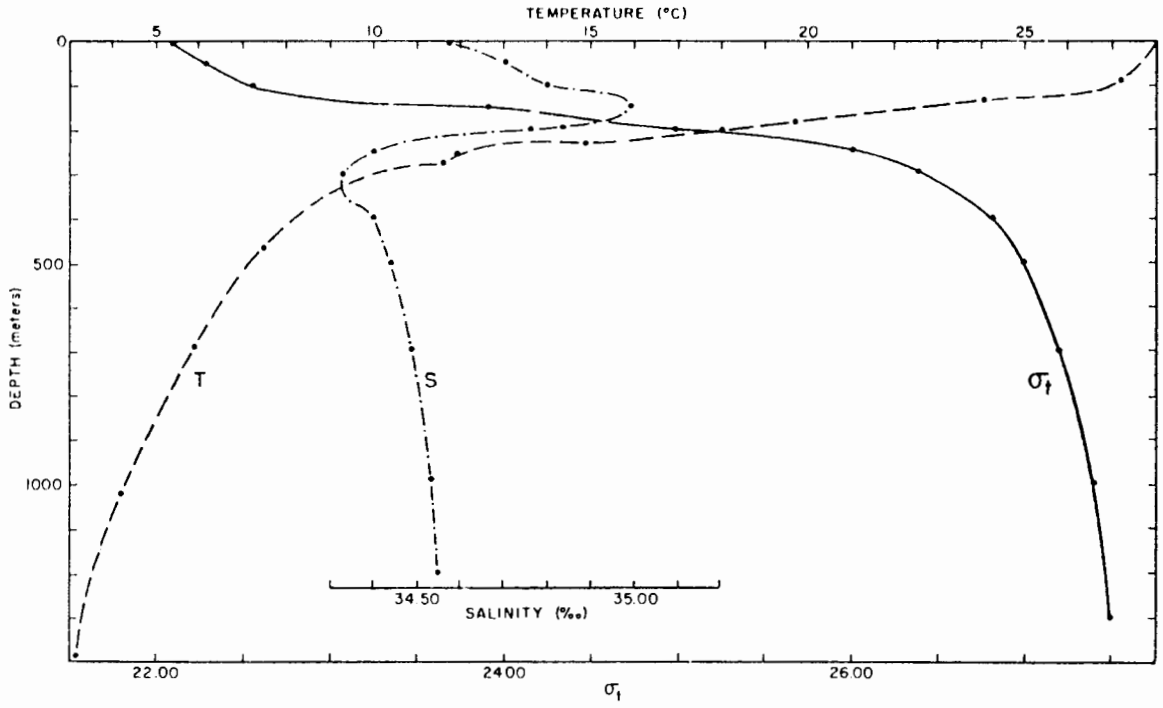


Figure 36.--Vertical distribution of temperature, salinity, and σ_t values at station B-39 (lat. 12°00'N, long. 168°01'E) from Crossroads data, July 12, 1946 (Mao and Yoshida, 1955).

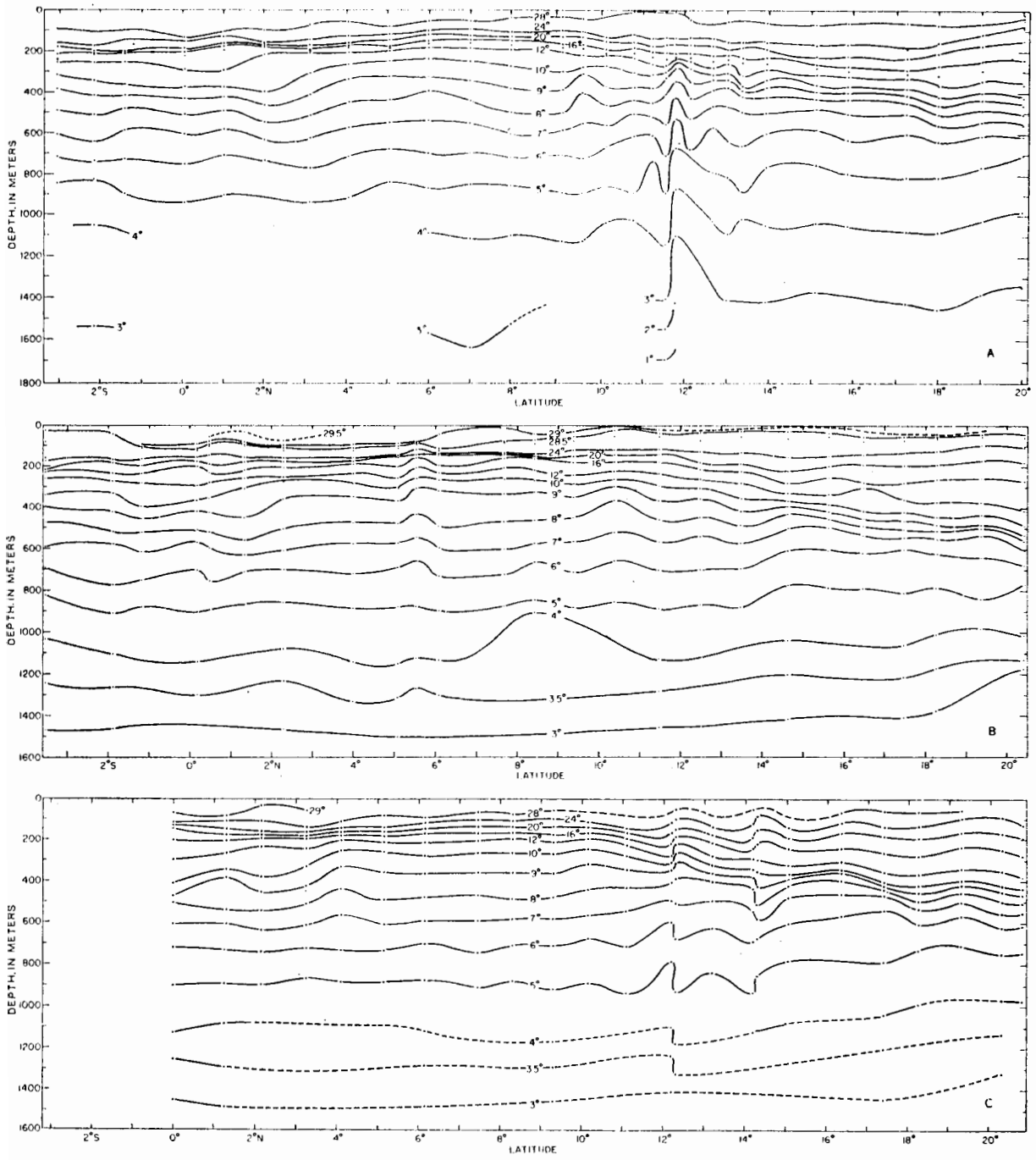


Figure 37.--Vertical distribution of temperature. A. From Crossroads data, March to August 1946. B. From Japanese data, 1933-41, summer season. C. From Japanese data, 1933-41, winter season (Mao and Yoshida, 1955).

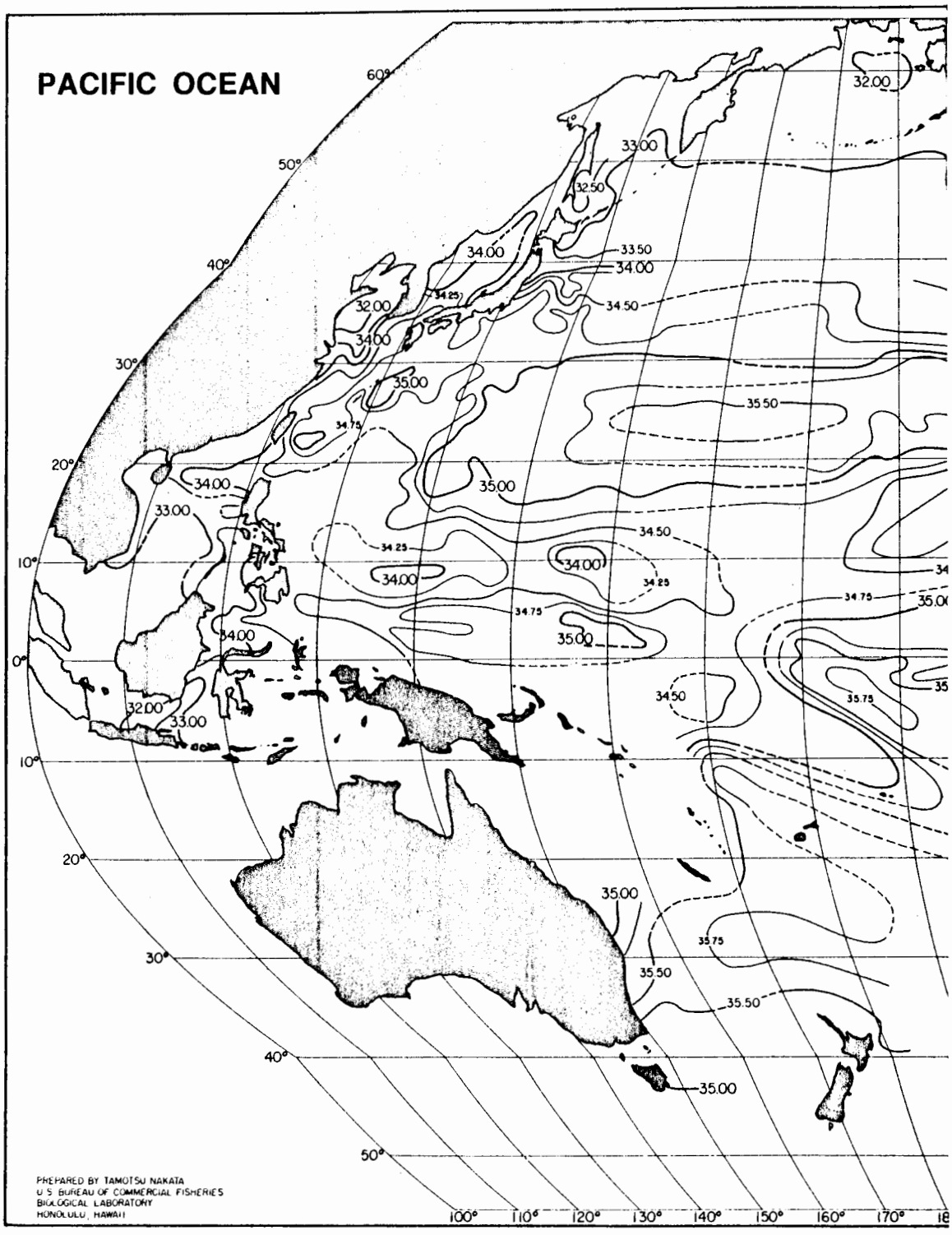


Figure 38a.--Salinity (°/$_{oo}$) at 10 m, first quarter (Barkley, 1968).

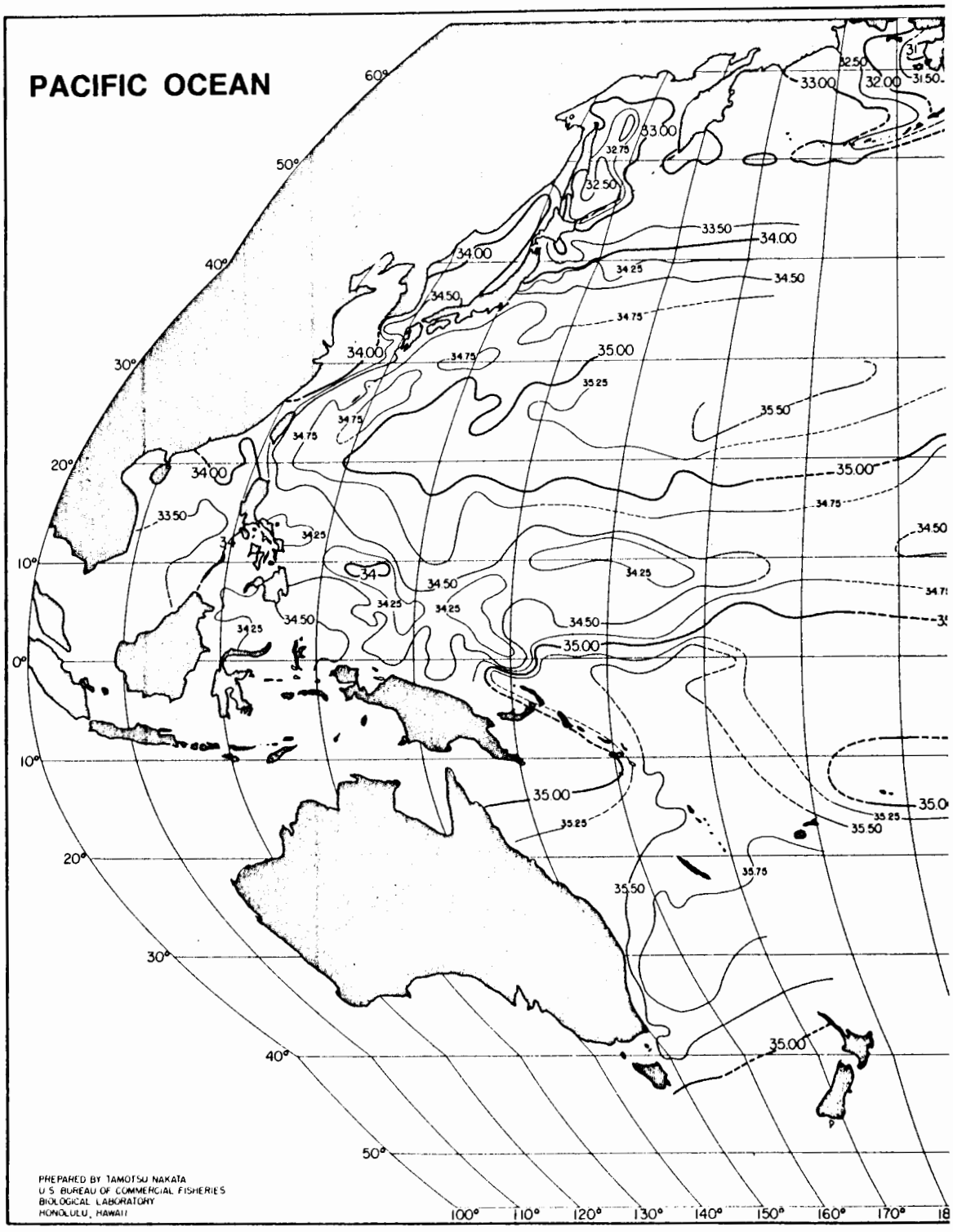


Figure 38b.--Salinity (°/₀₀) at 10 m, second quarter (Barkley, 1968).

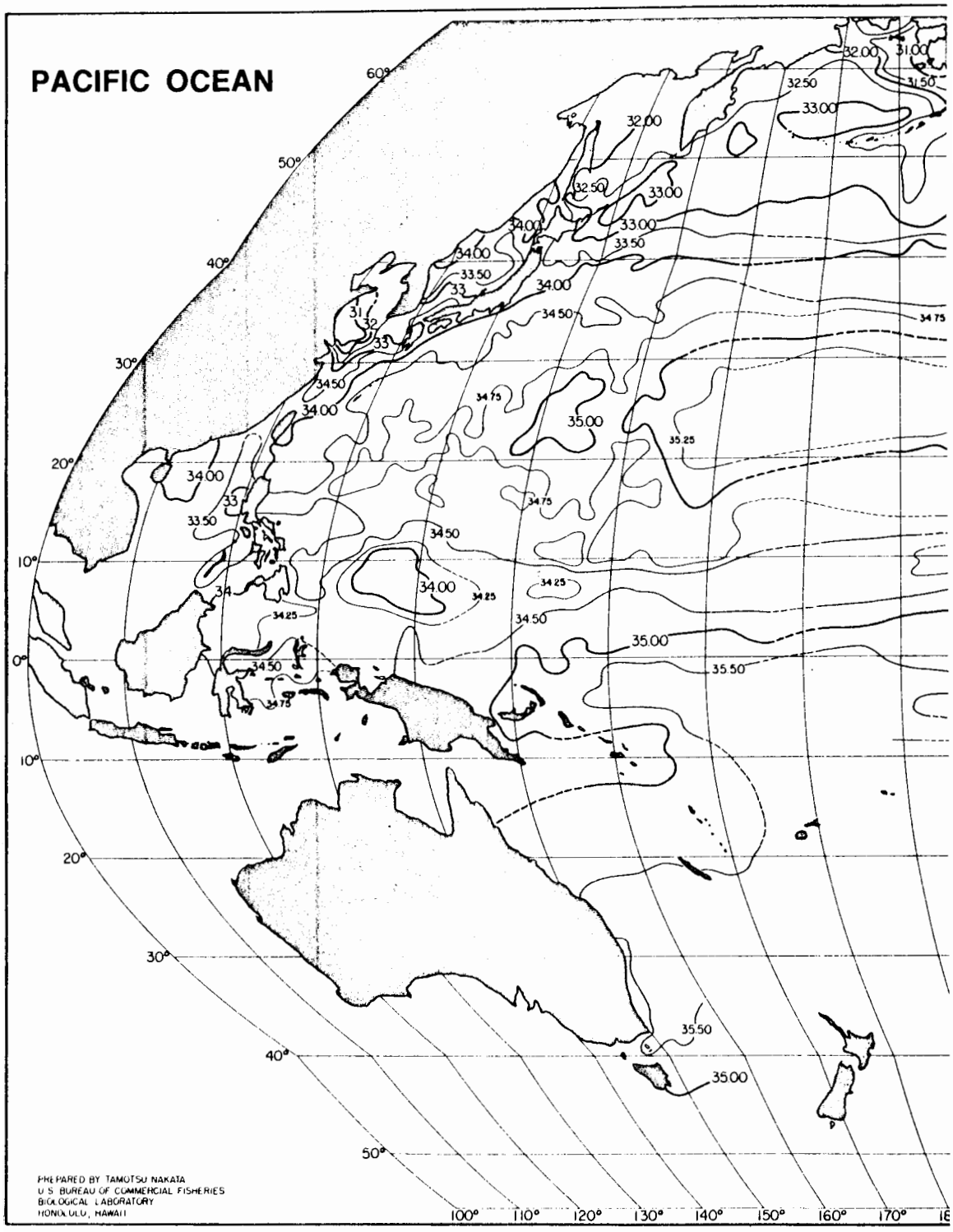


Figure 38c.--Salinity (°/$_{oo}$) at 10 m, third quarter (Barkley, 1968).

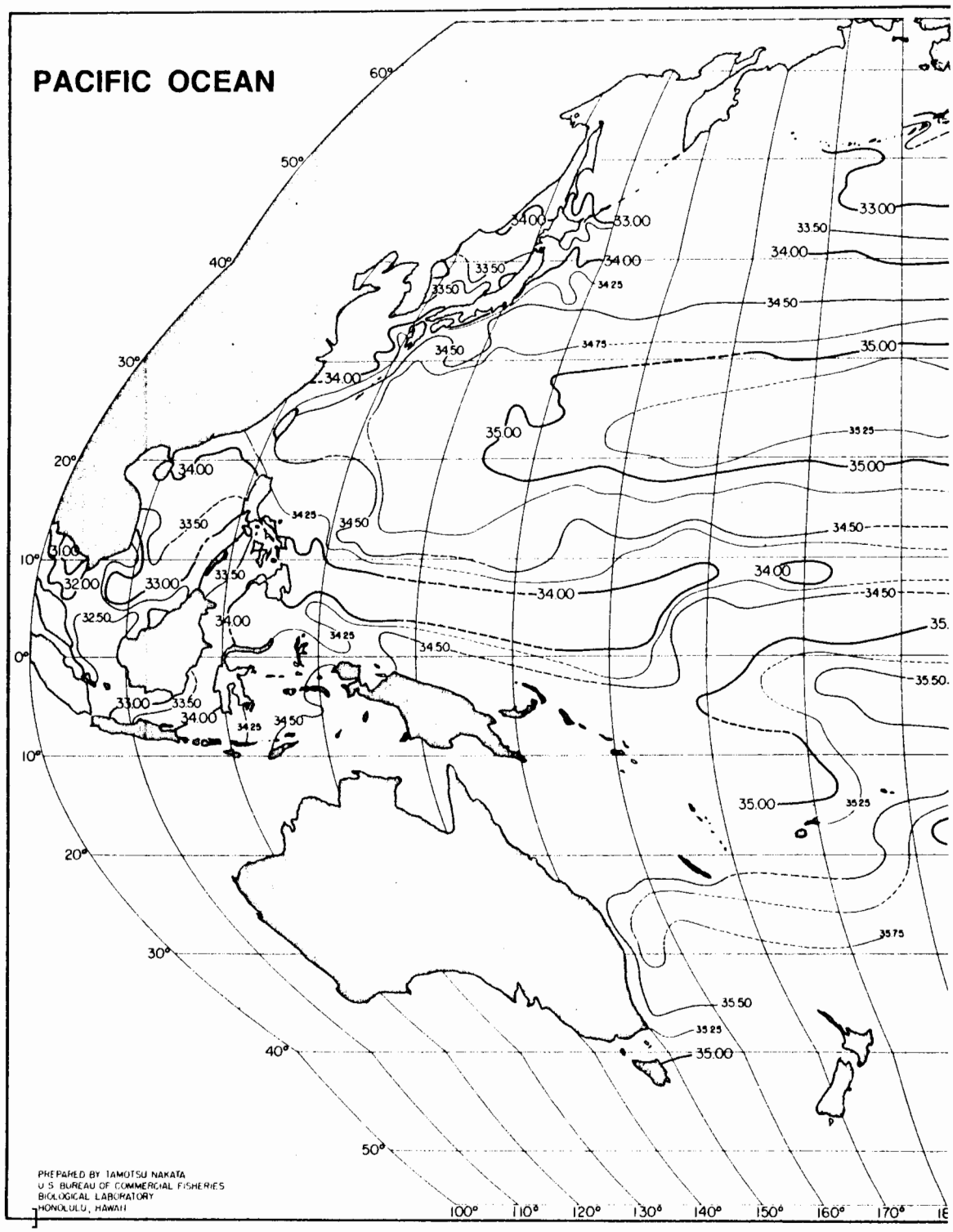


Figure 38d.--Salinity (°/₀₀) at 10 m, fourth quarter (Barkley, 1968).

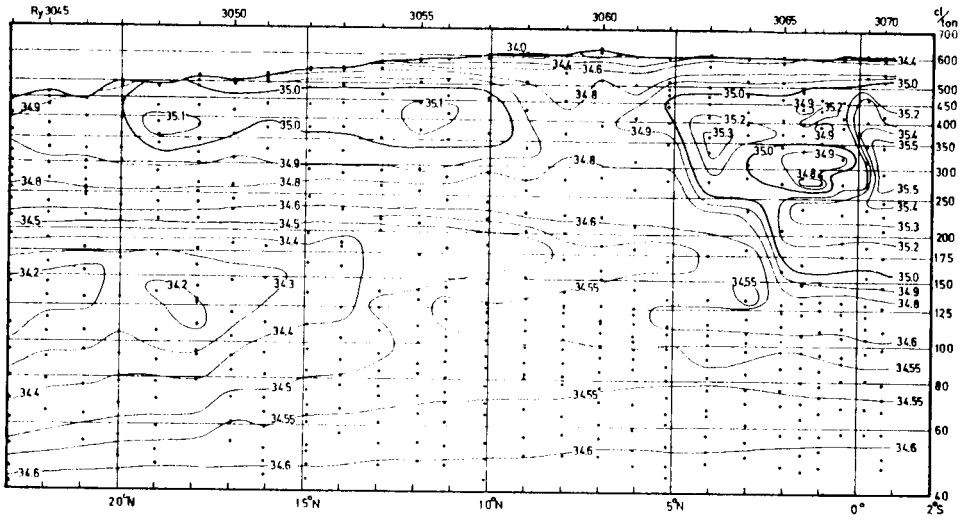
In the Western Carolines along long. 137°E, Masuzawa (1967) found that the North Pacific tropical water with salinity exceeding 35°/₀₀ lies in the upper part of the thermocline between lat. 10° and 20°N and is in contact with the sea surface near lat. 19°N (Figure 39). Saline water originating in the South Pacific is also detected in the Western Carolines and extends as far north as lat. 6°N near the northern boundary of the countercurrent. The North Pacific major salinity minimum can be traced from the coast of Japan as far south as lat. 15°N.

In the Marshalls, Mao and Yoshida (1955) found that the most outstanding feature of the horizontal distribution of salinity is the presence of a low-salinity band of low temperature at about lat. 5°-10°N or about where the large eddies exist (Figure 40). Waters of high salinity push toward this band of low salinity from both sides. The gradient on the southern side suggests that the strongest influx of high-salinity water comes from the southern hemisphere.

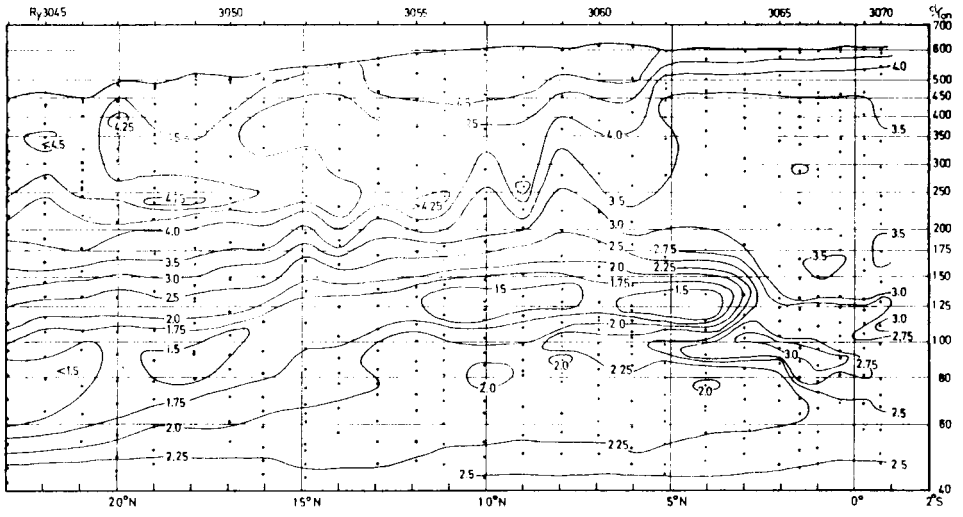
Mao and Yoshida suggested that the band of low-salinity water results from high precipitation, absence of saline tropical water from the north and south at these latitudes, ascent of the northern intermediate water mass with decreasing latitude, and upwelling associated with currents and eddies. They assumed that upwelling, which originates at some intermediate depth, brings cool and fresh water into the upper levels. The ascending northern and southern intermediate water masses may further strengthen this upwelling.

In the Marshall Islands area, the salinity profile, shown in Figure 36, has a topmost layer, the upper layer (characterized by salinity maximum), the intermediate layer (characterized by salinity minimum), and the deeper layer (characterized by weak salinity gradient). Figure 41 shows the vertical salinity distribution characterized by high- and low-salinity tongues of water coming into the area from both north and south (Mao and Yoshida, 1955). The two tongues of high-salinity water correspond to tropical water (salinity maximum) whereas the two tongues of low-salinity waters represent intermediate water (salinity minimum) (Cannon, 1966).

The saline tropical water originates in the tropics where evaporation is usually high (Mao and Yoshida, 1955). This water is warm and, therefore, its density relatively low. The depth of the salinity maximum corresponds to the central axis of the two saline tropical waters at a depth of about 490 ft (150 m). Comparison shows that the southern tongue is the more saline, reaching 35.60°/₀₀ to 36.80°/₀₀ whereas the salinity in the northern tongue rarely exceeds 35.50°/₀₀.



(a)



(b)

Figure 39.--Meridional sections of salinity (a) and oxygen content (b) against thermosteric anomaly in logarithmic scale in the equatorial current system at long. 137°E in January 1967 (Masuzawa, 1967).

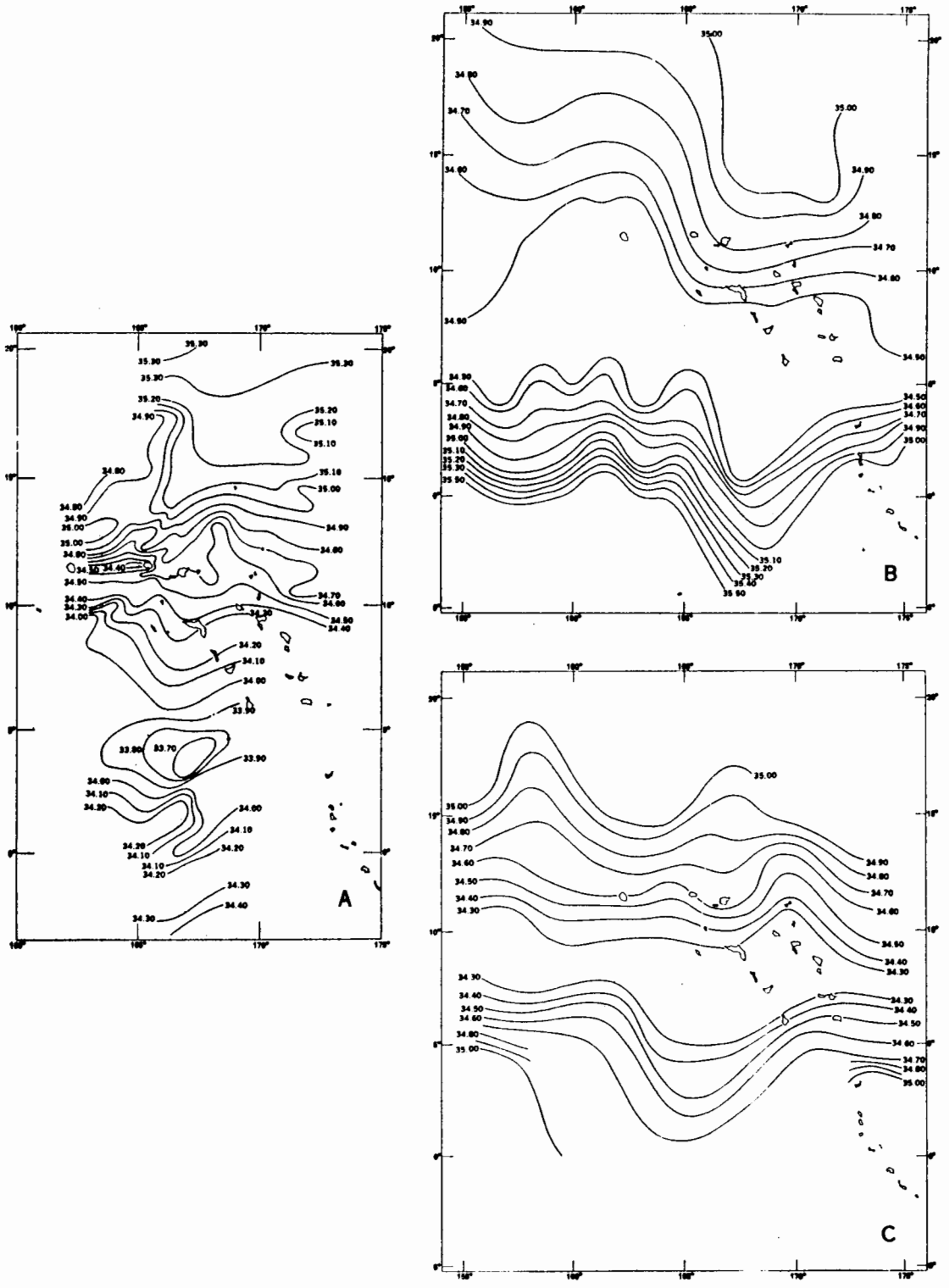


Figure 40.--Horizontal distribution of salinity at surface. A. From Crossroads data, March to August 1946. B. From Japanese data, 1933-41, summer season. C. From Japanese data, 1933-41, winter season (Mao and Yoshida, 1955).

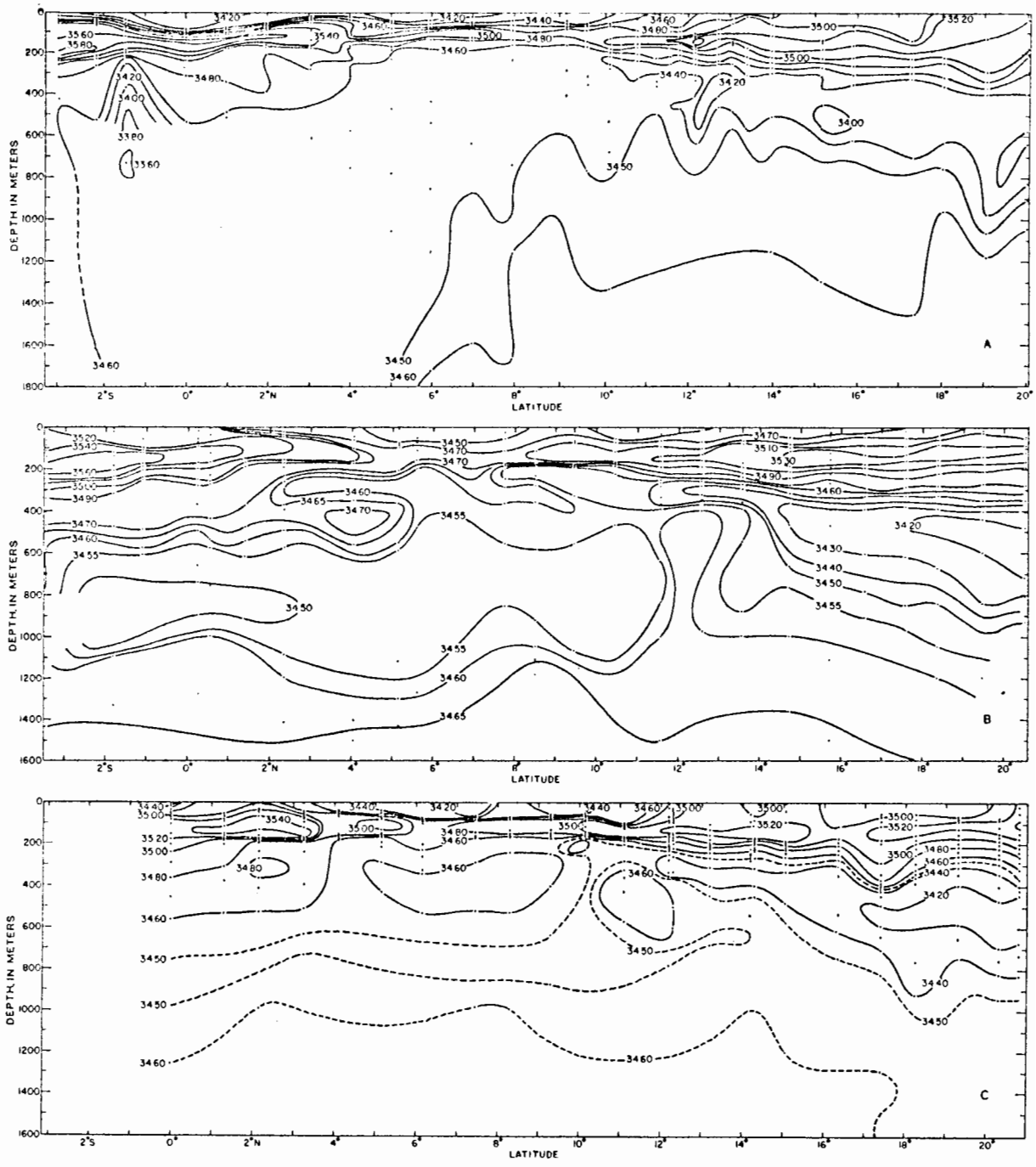


Figure 41.--Vertical distribution of salinity. A. From Crossroads data, March to August 1946. B. From Japanese data, 1933-41, summer season. C. From Japanese data, 1933-41, winter season (Mao and Yoshida, 1955).

In contrast to tropical waters, intermediate waters have low temperature and low salinity, properties which were acquired at the north and south subpolar areas where the air temperature is low and the precipitation high (Mao and Yoshida, 1955). Although of low salinity, intermediate water is dense because of its low temperature. Near the equator, the salinity minimum of about 34.50°/$_{oo}$ may be as deep as 2,625 to 3,280 ft (800 to 1,000 m). Of interest is the inclination of the northern intermediate water, which lies at 1,640-1,970 ft (500-600 m) at lat. 20°N but rises almost linearly to 490-655 ft (150-200 m) at lat. 8°-10°N. The ascent of the northern intermediate water with decreasing latitude is probably the result of warming of this water mass through mixing with the surrounding water masses.

The vertical and horizontal distributions of oxygen in waters around Micronesia are depicted in Figures 39 and 42. In the Western Carolines, Masuzawa (1967) found that there is an outstanding oxygen minimum of less than 1.5 ml/liter below the thermocline extending from the coast of Japan southward to lat. 3°N (Figure 39). The core of the minimum changes depth in the vicinity of lat. 15°N. In the Marshalls, Mao and Yoshida (1955) found that the main feature of oxygen distribution is the division of the vertical distribution of oxygen into an oxygen-saturated layer at or near the surface, an oxygen-minimum layer at the intermediate depth, and an oxygen-rich layer at greater depth (Figure 43). A subsurface layer of oxygen supersaturation was also detected in the data, and Mao and Yoshida believed that this feature was probably the result of either the intrusion of the northern tropical water mass or high production of oxygen by plants, or both.

PLANKTON

Zooplankton volume in the Pacific Ocean is distributed in the same manner as PO_4-P (Reid, 1962). In general, the volumes are high in the eastern boundary currents, low in central water, relatively high along the equator and in two zones north and south of the equator corresponding to the equatorial divergence (Figure 44).

The distribution of plankton in the western Pacific also has been analyzed and discussed by Vinogradov (1968). Figure 45 shows the stations from which quantitative samples of plankton were collected in the Indian Ocean and western Pacific. Quantitatively, Vinogradov found that the tropical region of the ocean is much poorer in surface plankton than subpolar waters.

In central water, the planktonic biomass from the surface to 328 ft (100 m) is usually less than 25 mg/m^3 or roughly 10-20 times less than in subpolar regions. In the equatorial currents, Vinogradov estimated that the planktonic biomass reaches 50-100 mg/m^3.

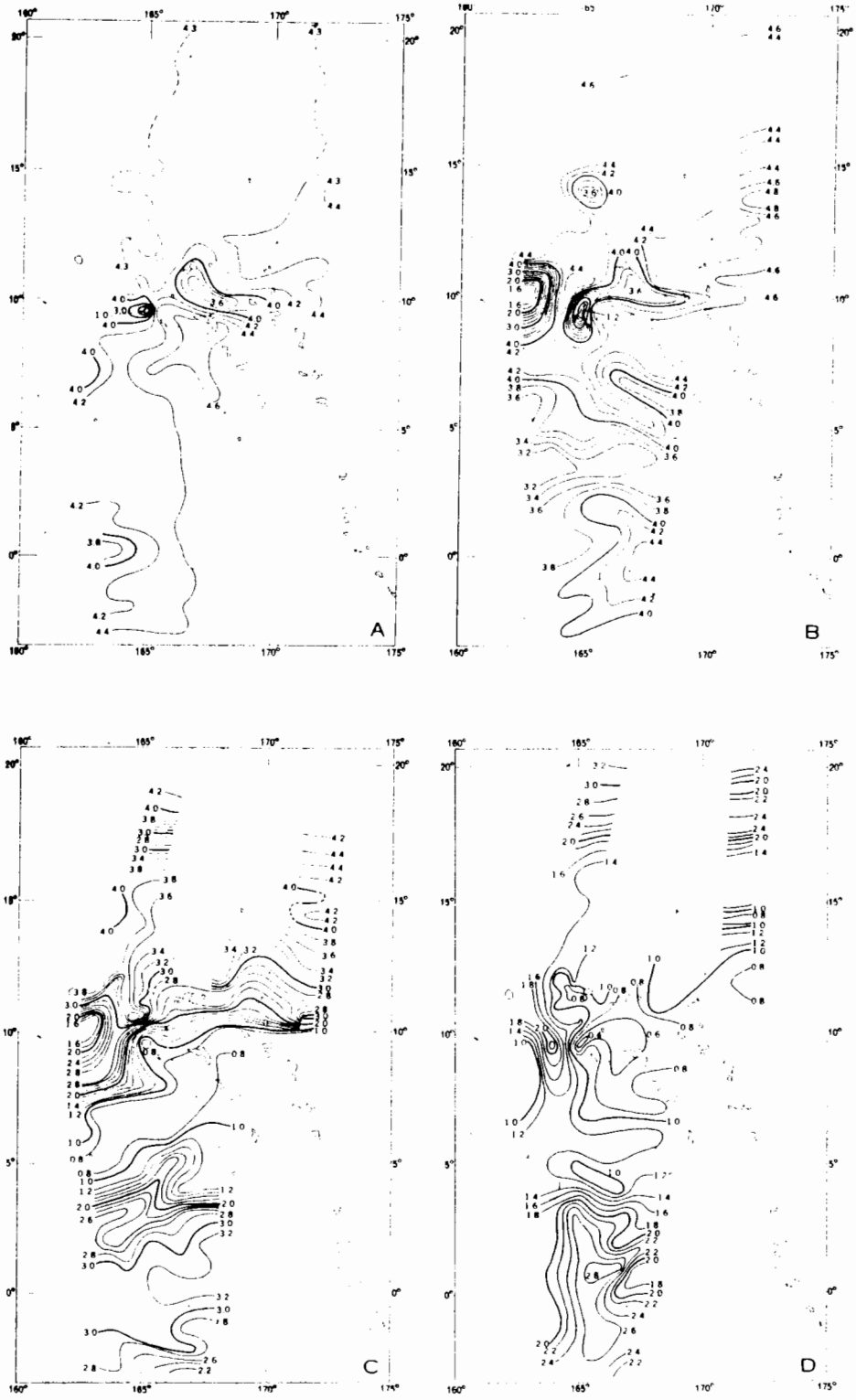


Figure 42.--Horizontal distribution of oxygen concentration (ml/liter), from Crossroads data, March to August 1946. A. At surface. B. At 100 m. C. At 250 m. D. At 500 m. (Mao and Yoshida, 1955).

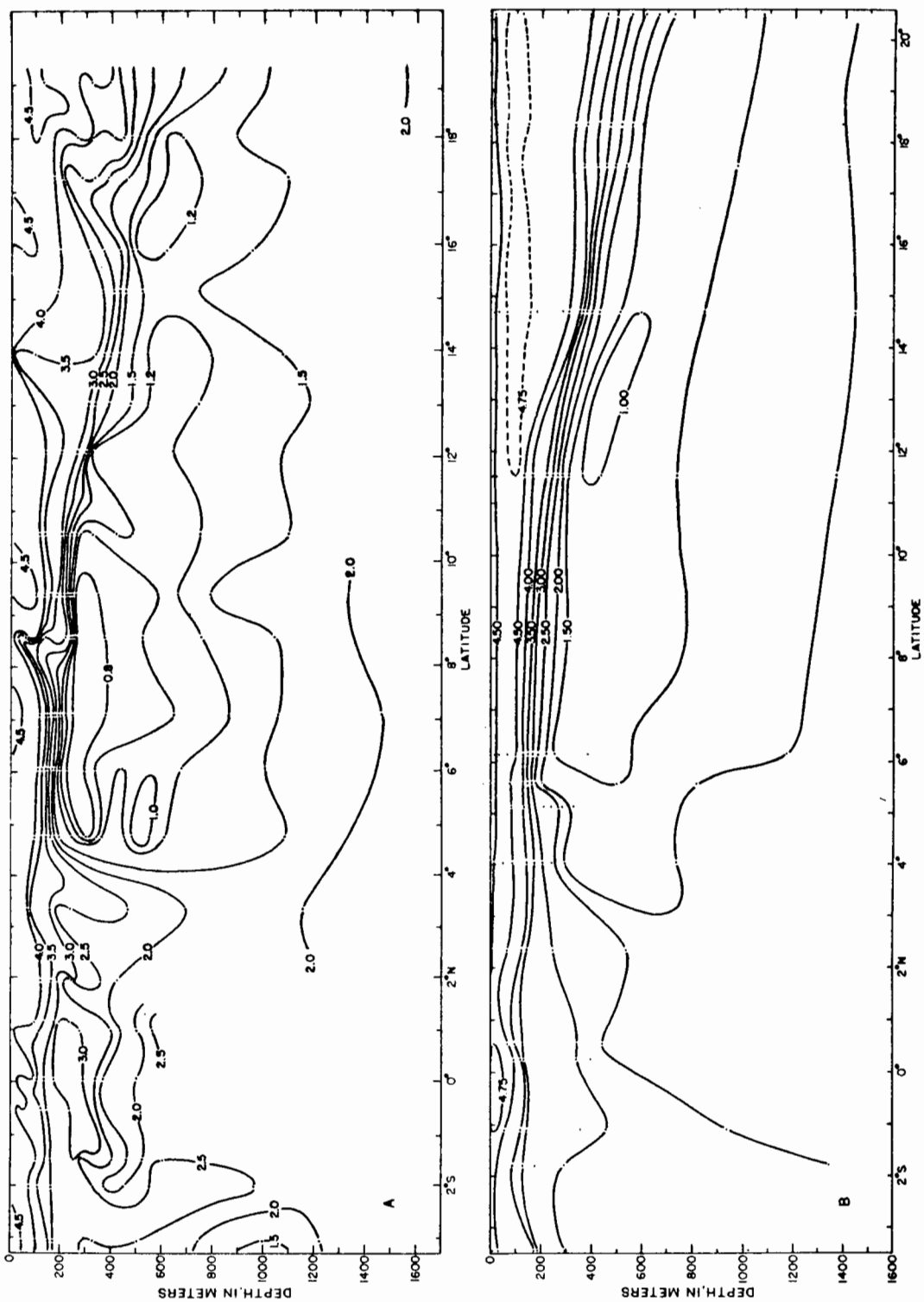


Figure 43.--Vertical distribution of oxygen concentration (ml/liter). A. From Crossroads data, March to August 1946. B. From Japanese data, 1933-41, summer season (Map and Yoshida, 1955).

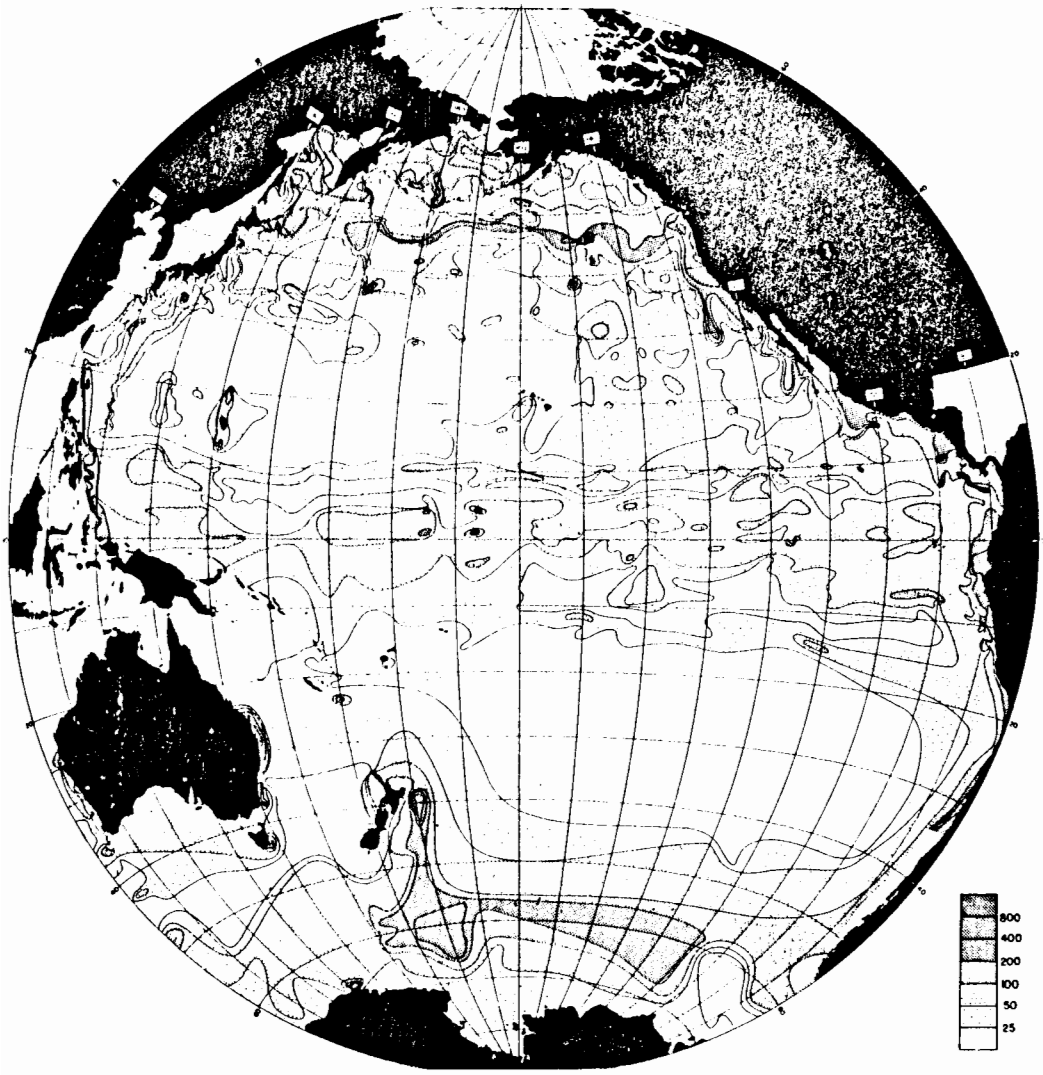


Figure 44.--Distribution of zooplankton volume (parts per 10^9 by volume) in approximately the upper 150 m of the Pacific Ocean, shaded by values (Reid, 1962).

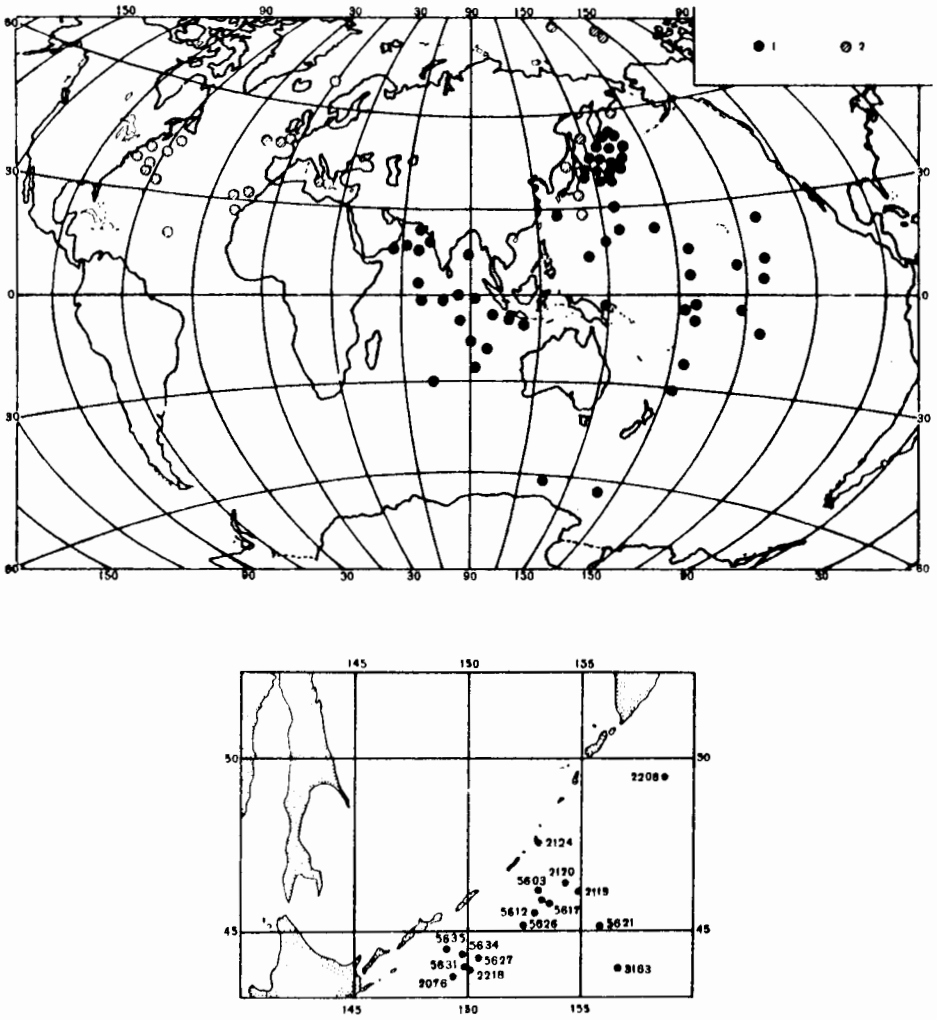


Figure 45.--Stations at which quantitative samples of plankton were taken from the different layers from the surface to a depth of more than 2,000 m. Stations of the Vityaz and Ob (1); stations of other vessels (2) (Vinogradov, 1968).

Four stations were occupied by the Vityaz within or near Micronesia. At a station to the east of the Marianas located in western central water at lat. 19°49'N and long. 154°02'E, the biomass was 18 mg/m^3 at 0-1,640 ft (0-500 m) (Vinogradov, 1968). Further east at the same latitude and roughly 8° north of the Marshalls or about long. 172°E, Vinogradov found the plankton-poorest area of the tropical part of the northern hemisphere with only 9.0 mg/m^3 at 0-1,640 ft (0-500 m). Water of the northern periphery of the North Equatorial Current in the vicinity of Guam at lat. 11°-14°N and long. 142°-147°E was also very poor in surface plankton with biomass of only about 8-11 mg/m^3 at 0-1,640 ft (0-500 m).

FISHERIES DEVELOPMENT

The harvesting of the tuna resources in Micronesian waters has a long and varied history. It is of interest, therefore, to discuss some of the developments that took place prior to World War II in the Trust Territory (then the Japanese Mandated Islands) and then review the important developments in the postwar era.

PRE-WORLD WAR II PERIOD

The development of the fisheries potential of Micronesia goes back to the Japanese regime that followed the Spanish and German administrations. After World War I, Japan took possession of the islands under the Treaty of Versailles and was given the mandate to administer all the former German possessions north of the equator. Japanese Civil Administration of the former mandated islands began on 1 April 1922. In 1935, Japan withdrew from the League of Nations and promptly annexed the islands.

Japan was keenly aware of the developmental potential of the fishery resources of the mandated islands. The decade 1921-30 was one of general inquiry into the potential of the marine resources of the numerous islands and atolls. Fishery research and exploratory fishing in 1925-29 showed that many islands possessed tremendous possibilities of becoming bases for large commercial fishing operations (South Seas Government-General Fisheries Experiment Station, 1937b). That the Japanese accurately appraised the tuna fishing potential of the mandated islands is attested to by the rise in the offshore landings of skipjack and other tunas by Japanese vessels (Figure 46).

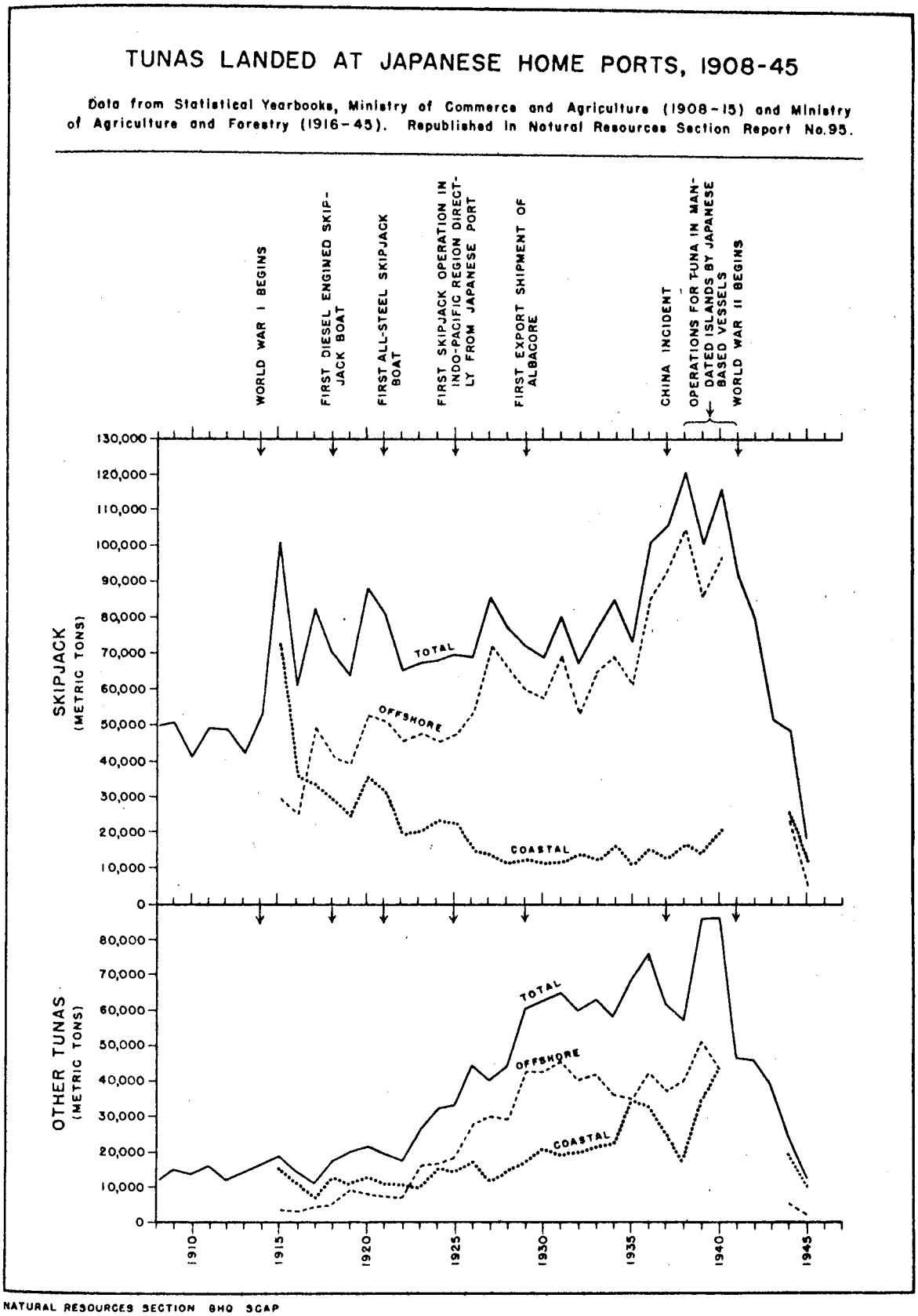


Figure 46.--Tunas landed at Japanese home ports, 1908-45 (Shapiro, 1948).

The Pole-and-Line Skipjack Tuna Fishery

The Japanese skipjack tuna fishery in the former mandated islands developed only after a lengthy period of persistent effort (Cleaver and Shimada, 1950). Even with government subsidies, the fishermen's early efforts failed. But gradually, suitable methods of catching and handling bait evolved.

Because of the scarcity of suitable live bait in many of the island outposts, the Japanese fishermen resorted to using as live bait a wide variety of reef fishes belonging to several families in addition to the anchovies and herringlike fishes (Cleaver and Shimada, 1950). Table 15 lists fishes that were used as live bait in waters of the mandated islands. According to Cleaver and Shimada, "fool bait," Spratelloides delicatulus, was preferred at Saipan and Tinian, but young carangids; filefish, Monacanthus sp.; atherinids; and Caesio sp. were also caught near the reefs and used. Ikebe and Matsumoto (1938), who published a detailed account of their bait investigation in Saipan waters, concluded that in September-November there were no suitable live bait for skipjack tuna fishing. In June-August, large schools of "tarekuchi," Stolephorus heterolobus, and "akamuro," Caesio chrysozonus, were seen but their occurrence was very irregular. The best bait in Palau was the anchovy, S. heterolobus, but during periods of bait shortage, numerous other small fishes were also used (South Seas Government-General Fisheries Experiment Station, 1937b). Ikebe and Matsumoto (1937) reported finding an abundant supply of "tarekuchi" in Yap Bay. At Ponape, fishermen used juvenile Priacanthus sp. and Decapterus sp. (South Seas Government-General Fisheries Experiment Station, 1937a), whereas at Truk, both juvenile Priacanthus and anchovy, Anchoviella purpurea were the best bait.

In fishing for bait, lights were particularly effective in Palau when used with a lift net (Cleaver and Shimada, 1950). At Tinian, a variation of the lift net was used. The fishing vessel anchored near a cliff and the crew, after setting the net, swam along the cliff, rounded up a school of "fool bait," and herded it into the net. To capture reef fish for bait, the Okinawan drive-in net (oikomi-ami) was used. The net, consisting of a large pocket flanked by wings of netting, was set in an open space between the reefs. The crew swam in a large semicircle and herded the various species of reef fishes into the net opening.

The Japanese initially attempted pole-and-line fishing for skipjack tuna near Saipan, but bait was inadequate and the results were poor. Further exploration revealed, however, that the Palau Islands had a large, reliable supply of bait and the Japanese devoted much attention to developing this area (South Seas Government-General Fisheries Experiment Station, 1937b; Smith, 1947). Favorable reports

Table 15.--Some baitfishes used by the Japanese skipjack tuna fishery (Cleaver and Shimada, 1950).

JAPAN AND RYUKYU ISLANDS			
Scientific Name	Common Names	Scientific Name	Common Names
Amia notata	kuroboshi-tenjikudai, ufumi	Harengula zunasi	sappa
Amia truncata	ufumi	Lutjanus vaigiensis	mochinogwa, okifusfuki
Atherina bleekeri	tōgoro-iwashi	Pomacentrus anabatoids	hichigwa, hikigwa
Atherina tsurugae	soharara, gin-isō-iwashi	Pseudupeneus sp.	himeji
Beryx decadactylus	gasagasa, nanyō-kinmedai	Sardinella mizun	mizun
Caesio cadrulaureus	sanesra, shimamuro-gurukun	Sardinia immaculata	hoshinashi-iwashi, shiira
Caesio digramma	gurukun	Sardinia melanosticta	ma-iwashi
Caranx djeddaba	gatsun	Scomber japonicus	ōsabanoko, saba
Engraulis japonicus	katakuchi-iwashi, ezgurō-iwashi, tarekuchi-iwashi		
SOUTH SEAS			
Amia sp.	akadoro	Harengula molluciensis	ma-iwashi, nanyō-ma-iwashi
Apogon sp.	akadoro	Labracoglossa argentivantris	takaba
Archamia bleekeri	atohiki-tenjikudai	Mullus sp.	ojisan
Atherina sp.	kokera, tobi-iwashi, tōgoro-iwashi	Sardinella leiogaster	mangurōbu-iwashi
Atherina valenciennesii	nanyō-tōgoro-iwashi	Scomber kanagurta	saba
Caesio chrysozonus	akamuro, gurukun, sanesra, umeiro	Sphyraena obtusata	kamasu
Caranx leptolepis	aji	Spratelloides delicatulus	ao-iwashi, baka, nanyō-kibinago, shiira
Caranx malibaricus	shima-aji	Trachurops crumenophthalma	ma-aji
Caranx sp.	aji, gatsun	Trachurus japonicus	ma-aji
Chilodipterus sp.	akadoro	Upeneus sp.	ojisan
Dascyllus trimaculatus	montsuki	Upeneus tragula	yomehimeji
Decapterus russelli	akamuro	Upenoides sp.	ojisan
Decapterus sp.	muro, shima-muro	Stolephorus heterolobus	nanyō-katakuchi-iwashi, tarekuchi
Gazza equulaeformis	hiiragi	Stolephorus japonicus	bakasako, kibiko-iwashi, sururu

1/The bait species listed herein were not limited in use exclusively to the area for which listed. They were used by the fishery wherever available in quantity.

Note: The data was obtained from: Prog. Rept. Okinawa Pref. Fish. Exp. St. for 1937; Marukawa, H., South Sea Fisheries 5 (5), 1939; and Dr. Y. Hiyama, Tokyo University, Tokyo, Japan.

Table 16.--Skipjack tuna stick (katsuobushi) production in Japan, Formosa, and the mandated islands, 1922-40, in metric tons (Shapiro, 1948).

Year	Japan	Formosa	Mandated Islands
1922	10,296.5	618.2	0.1
1923	10,600.1	823.1	ND
1924	9,619.3	589.2	1.1
1925	9,956.9	606.5	1.6
1926	9,654.0	556.1	9.9
1927	9,007.5	460.9	4.7
1928	9,514.2	583.0	18.9
1929	9,553.0	611.6	104.3
1930	7,405.2	363.9	279.1
1931	10,613.6	294.7	842.2
1932	8,900.3	142.3	972.9
1933	9,649.7	223.6	1,305.3
1934	11,561.4	338.2	1,695.4
1935	9,831.4	179.0	2,097.4
1936	12,758.0	220.9	2,422.9
1937	9,055.8	185.1	5,812.7
1938	7,767.8	43.6	2,501.2
1939	9,789.9	74.4	3,229.6
1940	10,022.0	ND	2,975.2

a/ Dried weight. This is 17-18 percent of original fresh weight.

ND: No data available

SOURCE: Data compiled from Statistical Yearbooks of Agriculture and Forestry, published by Ministry of Agriculture and Forestry, and Yamamoto, 1942.

regarding the abundance of skipjack tuna schools and the ease of fishing in calm tropical waters throughout the year reached Japan and induced various Japanese fishing companies to establish bases in the mandated islands (Shapiro, 1948). The Japanese Government not only sent Japanese fishermen to these far-flung bases but also provided subsidies to Okinawan fishermen to induce them to migrate to the mandated islands (South Seas Government-General Fisheries Experiment Station, 1937b).

From about 1930, the Japanese established shore-based operations consisting of fleets of small pole-and-line fishing vessels (Smith, 1947). Fishing operations, originally centered around Saipan in the Marianas and at Palau and Truk in the Carolines, were extended to Yap, Ponape, and Kusaie, also in the Carolines, and to Jaluit in the Marshalls (Figure 47) (Ikebe and Matsumoto, 1937). The long distances of these fishing bases from the Japanese homeland precluded the transport of raw fish. As a result, all the skipjack tuna caught were processed for export in the form of dried skipjack tuna sticks called "katsuobushi" (Table 16).

The burgeoning pole-and-line fishery, however, was not without problems. Catches fluctuated widely. Inanami (1941, 1942) observed that in 1939 oceanographic conditions were abnormal over a wide expanse of ocean from the vicinity of Palau eastward to about long. 150°E in January-March. During this period, longline catches of yellowfin tuna declined, whereas the catches of bigeye tuna, Thunnus obesus, and albacore, T. alalunga, increased. The pole-and-line fishing fleet at Palau, Truk and Ponape also experienced poor fishing. The increase in catches of bigeye tuna and albacore meant low-water temperatures in the surface layers; the low-surface temperature also affected skipjack tuna distribution. By May, when oceanographic conditions returned to normal, Inanami found that skipjack tuna fishing improved at Palau, Truk, and Ponape. He concluded that the poor fishing resulting from adverse oceanographic conditions in the countercurrent at about long. 150°E was temporary and that good fishing returned when the conditions returned to normal.

The rapidity with which the skipjack tuna fishery expanded in the mandated islands from 1922 to 1940 is reflected in the catches given in Table 17. Maximum fishing intensity was reached in 1937 when the catch from the mandated islands reached 36,442 short tons (ST) (33,060 metric tons (MT)). The fleet in Palau landed 42% of the total catch whereas that based at Truk produced 38%. The large 1937 catch resulted from the operation of an unusually large number of fishing vessels (Table 18). The fleet was reduced in 1938 because of protests from Japanese producers and subsequent government restrictions on the number of vessels that could be operated in the mandated islands (Smith, 1947). Table 19 shows that by 1940 the fleet was reduced to 132 pole-and-line vessels operating in the mandated islands.

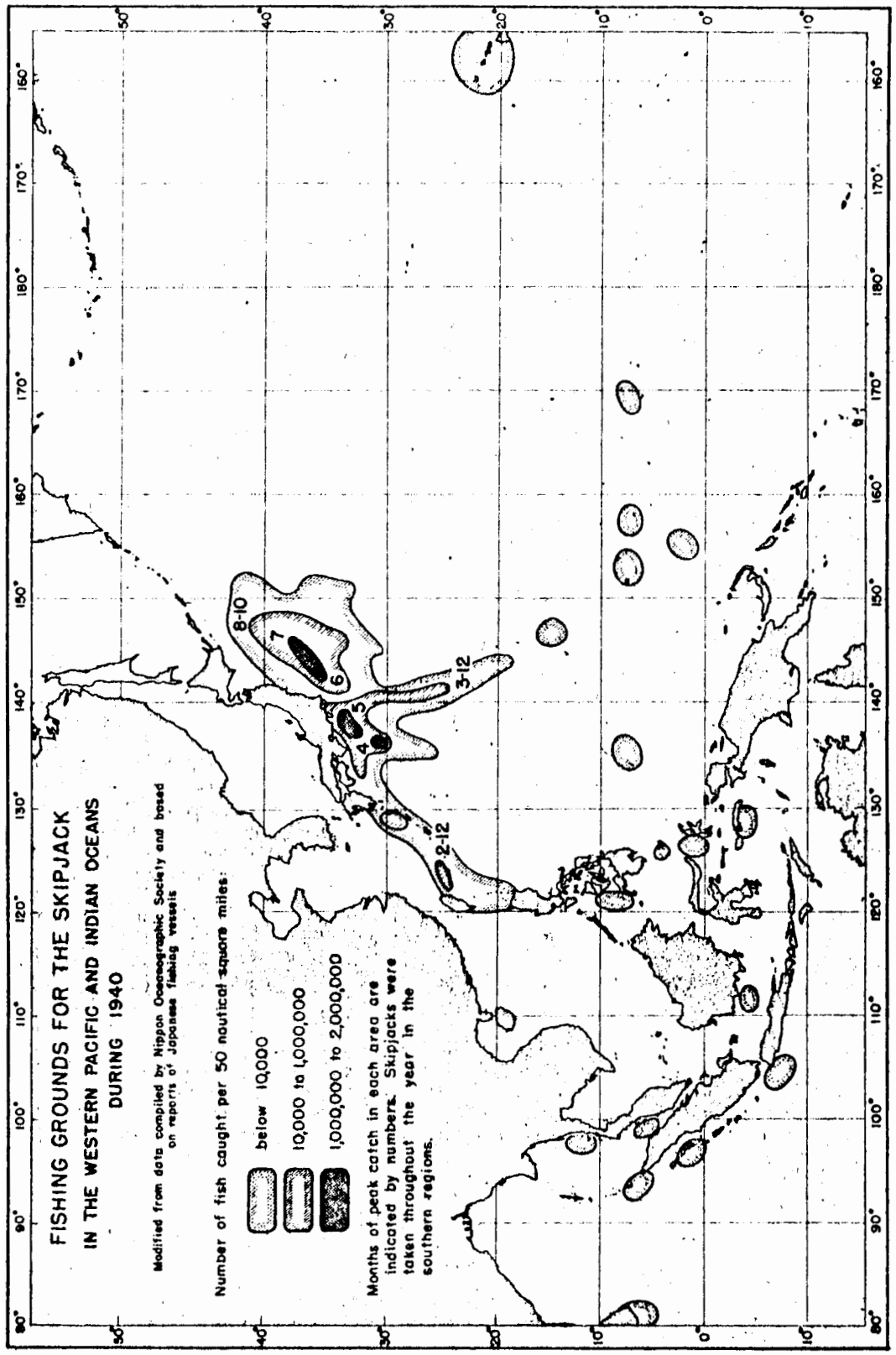


Figure 47.--Fishing grounds for the skipjack tuna in the western Pacific and Indian Oceans during 1940 (Shapiro, 1948).

Table 17.--Skipjack tuna catch landed in the former Japanese Mandated Islands, 1922-40, in metric tons (Shapiro, 1948).

Year	Saipan	Yap	Palau	Truk	Ponape	Jaluit	Total
1922	2.36	ND	ND	3.60	3.75	ND	9.71
1923	2.81	1.46	ND	3.04	ND	ND	7.31
1924	9.10	1.76	1.56	5.21	0.11	ND	17.74
1925	14.81	1.99	8.53	6.05	4.95	ND	36.33
1926	44.84	2.16	42.41	2.76	0.11	ND	92.28
1927	28.11	0.73	14.77	7.50	1.62	0.22	52.95
1928	26.49	1,13	131.45	4.50	0,15	ND	163,72
1929	24.69	0.89	228.90	214.50	0.53	ND	469.51
1930	258.00	0.90	157.06	913.39	6.36	ND	1,335.73
1931	564.26	0.44	548.12	1,097.13	525.24	51.26	2,816.45
1932	1,309.73	ND	1,592.33	810.26	544.18	614.76	4.861.26
1933	1,762.30	ND	2,144.46	1,883.36	926.95	172.43	6,889.40
1934	2,516.00	4.19	3,778.65	1,199.98	1,202.46	255.13	8,956.41
1935	1,785.98	ND	5,390.99	3,002.43	1,313,12	229.78	11,722.30
1936	1,696.01	ND	3,835.97	5,870.23	2,695.84	167.73	14,265.78
1937	2,697.30	ND	13,774.70	12,433.53	4,063.96	91.30	33,060.79
1938	2,392.03	149.28	3,420.21	5,294.78	1,495.58	6.71	12,758.59
1939	2,086.99	36.06	3,548.77	7,639.63	3,707.75	ND	17,019.20
1940	3,379.05	3.64	6,047.38	7,217.09	1,586.30	0.51	18,233.97

ND: No data available
SOURCE: Statistical Yearbook of South Sea Islands published by South Sea Government General.

Table 18.--Number of fishing vessels in the mandated islands, 1937 (Smith, 1947).

Port	Below 20 tons	Above 20 tons	Total	No. crew
Saipan	34	3	37	630
Yap	4	--	4	96
Palau	89	160	249	3,154
Truk	47	3	50	817
Ponape	18	1	19	586
Jaluit	1	--	1	21
Total	193	167	360	5,304

Table 19.--Tuna operations by vessels based in the southwest Pacific, 1940 (Shapiro, 1948).

Base	Type of Operation	Vessels Operated	Fishing Grounds	Amount of Catch	Disposition of Catch
Philippine Islands					
Zamboanga	Pole and line fishing; live bait fishing	20-ton boats - 2 50-ton boats - 2	Within 20 sea miles of port	462 MT (80% skipjack, 20% yellowfin tuna)	Mostly canned or frozen for shipment to U.S.A.
Davao	Pole and line fishing; live bait fishing; tuna long line	Skipjack boats - 5 Tuna long line boats - 6 (tonnage not available)	Within Davao Bay	Only value of catch given: Skipjack - 80,000 pesos Other tunas a/ - 70,000 pesos	Mostly distributed for local consumption
North Borneo					
Tawao	Pole and line fishing; live bait fishing	20-ton boats - 9	Within 20 sea miles of Bungu and Sheail	4,643 MT skipjack and yellowfin tuna (1939)	Local distribution; part of skipjack catch processed into fish stick and shipped to Japan
Celebes					
Boentin	Pole and line fishing; live bait fishing	20-ton boats - 10	Within 10 sea miles of Boentin and Ternate	900,000 fish (skipjack and yellowfin tuna); weight not given	Mostly processed into fish stick and shipped to Japan
Amboina	Pole and line fishing; live bait fishing	20-ton boats - 3	Within 10 sea miles of port	360,000 fish (skipjack and yellowfin tuna); weight not given	Local distribution
Mandated Islands	Pole and line fishing; tuna long line; live bait fishing		Within 30 sea miles of port		Skipjack mostly processed into fish stick and shipped to Japan
				(metric tons)	
Saipan		Skipjack boats b/-25 Tuna long line boats d/ - 2		Skipjack - 3,379.1 c/ Other tunas a/ - 84.5	
Yap		ND		Skipjack - 3.6 Other tunas - 15.8	
Palau		Skipjack boats -42 Tuna long line boats -14		Skipjack - 6,047.4 Other tunas - 686.6	
Truk		Skipjack boats -46 Tuna long line boats - 1		Skipjack - 7,217.1 Other tunas - 96.6	
Ponape		Skipjack boats -17 Tuna long line boats - 5		Skipjack - 1,586.3 Other tunas - 17.3	
Jaluit		Skipjadk boats - 2		Skipjack - 0.5 Other tunas - 8.0	

a/ Includes spearfishes
b/ Skipjack boats operated locally were less than 30 tons
c/ See Tables 17 and 19 for catch in other years
d/ Tuna long line boats operated locally were about 40 tons
ND: No data available
SOURCE: Data compiled by Japanese Tuna Fishermen's Association.

The Tuna Longline Fishery

A longline fishery for deep-swimming tunas was also developed in the mandated islands, but not on a scale as large as the skipjack tuna fishery (Shapiro, 1948). In 1931-34, several large Japanese fishing firms began to show increased interest in the deep-swimming tuna resource, and together with several research stations began surveys to determine the fishing grounds and the density of the population (Nakamura, 1951). The surveys covered the area from the mandated islands west through the Dutch East Indies and into the Indian Ocean. The results were encouraging, particularly for the development of longline fisheries for yellowfin tuna, and marlins, Makaira sp. (Ikebe, 1941). The fishing grounds for yellowfin tuna in 1940 are shown in Figure 48.

Lack of capital for the purchase of large, well-equipped fishing vessels and refrigeration equipment contributed to the lack of growth of the fishery and expansion of the fishing grounds (Smith, 1947). Experienced longline fishermen were also in short supply, thus keeping longline operations limited to a few vessels (Table 19) (Shapiro, 1948). By 1938, however, vessel operators in Japan became aware of the potential of the mandated islands fishing grounds for yellowfin tuna and billfishes and began to send large vessels of up to 60 net tons to fish that area. Catches of these large vessels on the fishing grounds around the mandated islands were good (Table 20), with catch per unit of effort higher than those in Japanese waters (lat. 30° to 40°N) and in Ryukyu and Bonin waters (lat. 24° to 30°N) (Tables 21 and 22). The principal species taken was yellowfin tuna followed by sizable quantities of albacore, swordfish, Xiphias gladius, and other billfishes, and small numbers of sharks. Figure 49 shows the fishing grounds for albacore in 1940 in the western Pacific.

Table 23 shows that tuna landings were highest in Palau, which was also the leading port of landing for skipjack tuna. And although fishing could be conducted throughout the year in the calm tropical waters, the catch rates were usually higher in summer during the southwest monsoon season (Table 24).

POST-WORLD WAR II DEVELOPMENTS

In the course of World War II, most of the infrastructure developed by the Japanese in the 1920's and 1930's was destroyed (Nathan Associates, 1966). A postwar survey of the fisheries resources of the former Japanese Mandated Islands was begun as part of the general economic survey undertaken by the Pacific Ocean Division of the United States Commercial Company, Reconstruction Finance Corporation (RFC), at the request of the Navy Department (Smith, 1947).

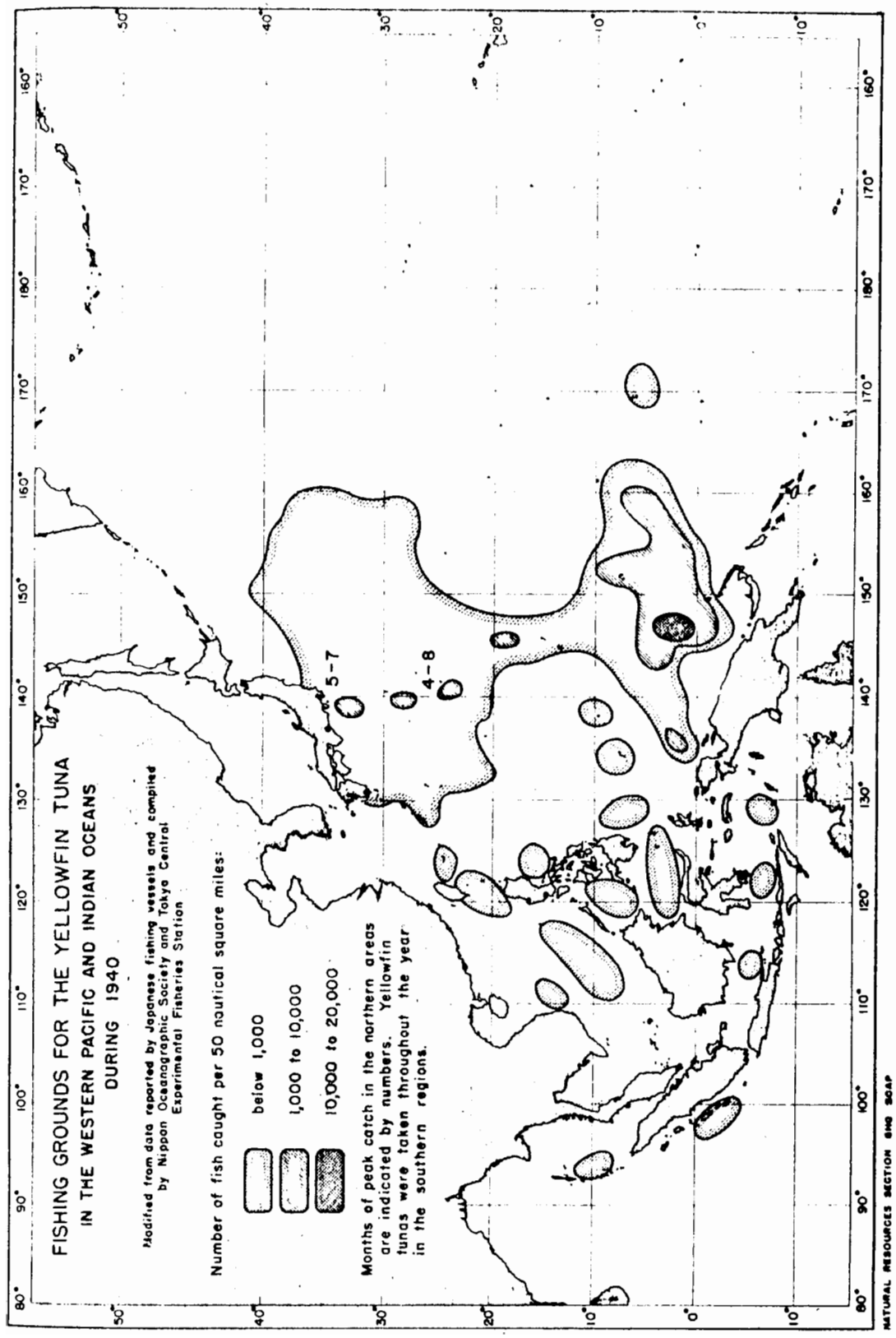


Figure 48.--Fishing grounds for the yellowfin tuna in the western Pacific and Indian Oceans during 1940 (Shapiro, 1948).

Table 20.--Tuna longline catch landed at Misaki Port, 1938-41 (Shapiro, 1948).

Year	Area of operation					
	Japanese waters (lat. 30°-40°N)		Ryukyu and Bonin area (lat. 24°-30°N)		Mandated islands (lat. 0°-24°N)	
	No. of voyages	Total catch (metric tons)	No. of voyages	Total catch (metric tons)	No. of voyages	Total catch (metric tons)
1938	478	4,542	476	7,963	185	5,319
1939	455	4,824	309	5,306	236	5,148
1940	412	5,312	212	2,571	239	8,470
1941	167	1,361	137	2,844	124	5,373

Source: Data compiled by Misaki Tuna Fishermen's Association.

Table 21.--Tuna longline catch in three major fishing areas by vessels operating from the port of Misaki during 1939 (Shapiro, 1948).

Area	No. of voyages	Average fishing days per voyage	Average tonnage per vessel	Total catch (metric tons)	Average catch per fishing day per ton of vessel
Japanese waters (lat. 30°-40°N)	412	15	45	5,312	0.0191
Ryukyu and Bonin area: (lat. 24°-30°N)	212	14	56	2,571	0.0155
Former mandated area: (lat. 0°-24°N)	239	13	113	8,470	0.0241

Table 22.--Composition of tuna catch obtained by longline operations in southwest Pacific and Indo-Pacific regions (Shapiro, 1948).

Area	Number of Hooks Used	Total Catch per 100 Hooks a/	Percent Composition of Tuna Catch				Avg Weight of Yellowfin Tuna (kilograms)
			Black Tuna	Yellowfin Tuna	Big-Eyed Tuna	Marlins	
East of Formosa: 20°-25°N and 120°-130°E	55,715	1.91	7.3	21.2	8.0	63.5	47.2
East of Philippine Islands to 130°E	10,234	6.35	0.0	96.4	2.3	41.3	33.0
Former Mandated Islands: 0°-12°N and 130°-170°E	220,626	5.23	0.0	79.2	9.3	11.5	33.0
South China Sea off Palawan	110,560	4.65	0.0	90.3	4.5	5.2	ND
Sulu Sea	4,600	3.96	0.0	ND	ND	11.1	47.1
Celebes Sea	157,156	4.37	0.0	ND	ND	16.3	44.0
North of New Guinea and Solomon Islands: from 130° to 160°E	21,792	4.21	0.0	71.8	7.1	21.1	37.0
Banda Sea: southeast and south of Celebes	81,779	8.40	0.0	89.5	3.3	7.2	48.5
Neighboring waters of Timor Island	48,756	9.19	0.0	88.6	3.8	7.6	48.0
Southern coast of Java	20,628	3.89	0.0	67.8	17.4	14.8	49.6
Southern coast of Sumatra	147,428	10.64	0.0	84.7	8.2	7.1	ND
Neighboring waters of Andaman and Nicobar Islands	15,568	6.23	0.0	89.4	4.4	6.2	40.0

a/ In Japanese waters the total tuna catch per 100 hooks averages between 3 and 4 fish.
ND: No data available
SOURCE: Data obtained by Japanese research and fishing vessels from 1930-40 and compiled by H. Nakamura of the Tokyo Central Fisheries Experimental Station.

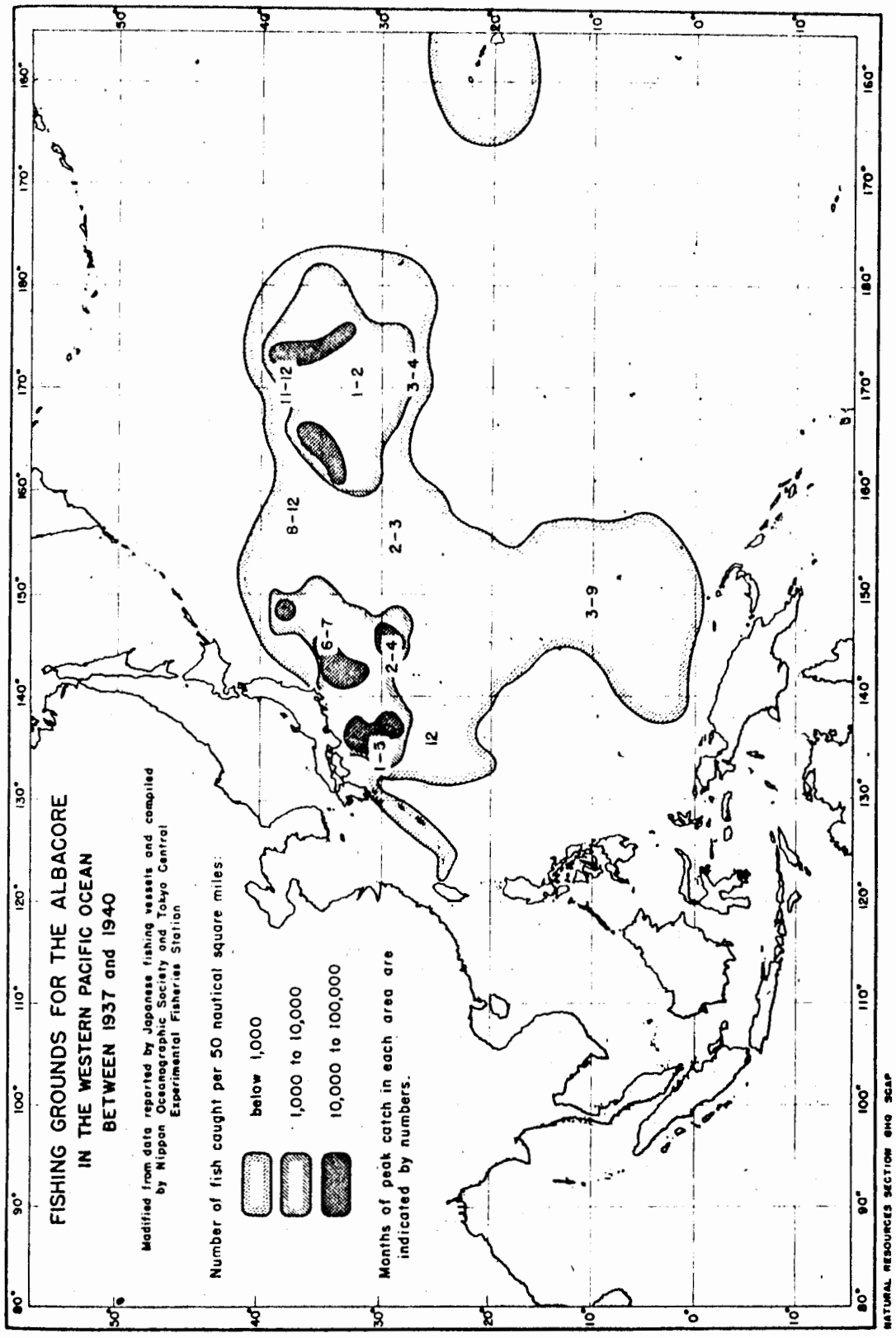


Figure 49.--Fishing grounds for the albacore in the western Pacific Ocean between 1937 and 1940 (Shapiro, 1948).

Table 23.--Tunas, excluding skipjack tuna, landed in the mandated islands, 1922-40, in metric tons (Shapiro, 1948).

Year	Saipan	Yap	Palau	Truk	Ponape	Jaluit	Total
1922	1.31	ND	ND	ND	2.36	2.40	6.07
1923	1.25	1.24	ND	ND	1.76	2.40	6.65
1924	1.53	1.54	6.75	ND	0.20	1.34	11.96
1925	1.40	1.48	5.31	ND	2.54	1.50	12.23
1926	2.31	0.75	46.80	0.34	4.50	0.83	55.53
1927	2.91	0.38	41.22	0.14	6.58	3.05	54.28
1928	1.26	1.05	152.33	ND	7.75	1.29	164.18
1929	0.56	0.76	167.94	0.40	1.62	0.22	172.00
1930	4.53	0.77	92.26	8.53	3.54	2.37	112.00
1931	16.73	0.46	156.61	29.43	4.83	3.85	211.91
1932	45.24	ND	137.62	5.18	34.69	135.72	361.45
1933	0.31	ND	242.23	55.39	41.42	25.87	365.22
1934	27.26	7.67	278.58	55.39	26.49	31.36	427.05
1935	42.32	0.93	301.18	98.50	23.50	13.91	480.09
1936	151.02	ND	213.26	179.02	29.96	14.85	587.11
1937	88.82	ND	189.78	342.18	56.37	3.96	681.17
1938	33.94	2.21	73.13	101.44	60.21	ND	270.93
1939	31.38	7.40	188.94	93.60	31.58	5.14	361.54
1940	84.51	15.82	686.57	46.62	17.31	7.97	858.80

a/ Includes spearfishes
ND: No data available
SOURCE: Statistical Yearbook of South Sea Islands, published by South Sea Government General.

Table 24.--Seasonal tuna catch by longline operations in southwest Pacific and Indo-Pacific regions (Shapiro, 1948).

Area	Southwest Monsoon Season (Summer)		Northeast Monsoon Season (Winter)	
	No of Hooks Used	Total Catch per 100 Hooks a/	No of Hooks Used	Total Catch per 100 Hooks a/
East of Formosa to 120°30'E	900	1.78	7,032	2.94
East of Philippine Islands to 130°E	7,840	7.98	2,394	0.67
Former Mandated Islands: 0°-12°N and 130°-170°E	115,099	5.40	105,527	4.18
South China Sea off Palawan	4,158	3.32	106,402	4.69
Celebes Sea	10,493	8.86	146,663	4.06
North of New Guinea and Solomon Islands: from 130° to 160°E	10,500	4.39	11,292	4.04
Banda Sea: southeast and south of Celebes	80,059	8.56	1,690	7.34
Neighboring waters of Timor Island	2,215	6.23	16,546	9.33
Southern coast of Sumatra	300	3.67	147,128	10.72

a/ Includes yellowfin tuna, big-eyed tuna, and marlins.
SOURCE: Data obtained by Japanese research and fishing vessels from 1930-40 and compiled by H. Nakamura of the Tokyo Central Fisheries Experimental Station.

Development of the Palau Skipjack Tuna Fishery

Attempts to revive the skipjack tuna fishery which thrived under the Japanese administration were first started in Saipan in 1946 (Smith, 1947). Two Japanese sampans, sunk at Saipan, were refloated, repaired, and subsequently operated by the U.S. military government. Manned by 26-28 fishermen who were paid only the regular daily wages established by the military government, the sampans caught and distributed the fish free to the native population. This operation, however, was short-lived. Inexperienced crews, inadequate fishing gear and maintenance facilities, and lack of dockside and refrigeration facilities all contributed to the abandonment of the project (Wilson, 1963).

In 1948, the Pacific Exploration Company, operating under contract with the RFC, dispatched two fishing vessels to prospect for tuna in the western Pacific (Smith and Schaefer, 1949). The MV Oregon, equipped for live-bait fishing, was sent to the Marianas and between 15 March and 19 April, fished for bait and scouted for tuna from Guam north to Farallon de Pajaros and back to Guam. Although much time was devoted to prospecting for bait along the beaches and cliffs of all the important islands in the Marianas, very little bait was found. Night-light fishing at Guam, Tinian, Alamegan, Pagan, Maug, and Rota was also tried and 3-5 lb (1.4-6.8 kg) of bait could sometimes be netted under the light but these amounts were hardly sufficient for a vessel the size of the Oregon.

Among the islands, Guam was the best baiting area (Smith and Schaefer, 1949). Night baiting produced 15-20 lb (6.8-9.1 kg) per night at Apra Harbor, Port Nerizo, and Talogogo Bay, whereas day baiting produced similar amounts at places along the cliffs on the leeward coast. The species taken were mixed. Half to three-fourths of the bait caught was round herring, Spratelloides sp., the rest being a small anchovy. Smith and Schaefer (1949) concluded that the supply of live bait, therefore, was uncertain and should be studied further.

Concerning skipjack tuna, Smith and Schaefer (1949) found that there are sufficient quantities of skipjack tuna in the waters around the Marianas to support a commercial fishery. But because of the limited quantities of bait in the Marianas, small boats of limited cruising range were recommended. In 5-6 days of scouting, the Oregon sighted 35 bird flocks and 8 fish schools, 3 of which were identified as skipjack tuna and 1 as yellowfin tuna.

Exploration of the Eastern Carolines and the Marshalls was conducted by MV Alaska. Fitted out as a tuna purse-seiner, Alaska had no need for bait but made cursory examination of beaches throughout the Eastern Carolines and the Marshalls. The results indicated that bait was not abundant. Schools of flat herring, Macrura sp.,

3-5 in (7.6-12.7 cm) long, were seen at Ailinglaplap in the Marshalls and at Truk in the Carolines. Marshall islanders also reported that the Japanese found large amounts of bait at Jaluit in the Marshalls. Reports also indicated that the Japanese found bait at Losap and Satawan, south of Truk.

Because few fish were seen during Alaska's cruise, no attempts were made to set the net. Only six schools were sighted; two in the Marshalls, and four in the Carolines.

Smith and Schaefer (1949) interviewed natives for information and found that January-March were poor tuna-fishing months and that May-August were the best. They concluded that Alaska's exploratory cruise was made at the wrong time of the year. Furthermore, they believed that it might be possible to develop a tuna fishery in the Eastern Carolines and Marshalls, but that it should be limited to late spring and early summer.

In the Western Carolines, Oregon visited Ulithi, Yap, Palau, Pulo Anna, Sonsoral, Tobi, and Helen Reef (Smith and Schaefer, 1949). Bait scouting at Ulithi revealed only a few schools of fish about an inch long. Yap had no bait at all. At Palau, however, bait was plentiful. Schools containing from a few to several hundred scoops were found along much of the rugged shoreline of the many limestone islands. The bait was primarily silverside, Atherinidae, but also caught were flat herring and small round herring. The most important species used by the Japanese was a small translucent anchovy; however, this species was not found by the crew of the Oregon.

Scouting for tuna in Palau waters, Oregon sighted 23 fish schools and about 20 bird flocks (Smith and Schaefer, 1949). Of the 14 schools identified to species, 7 were skipjack tuna, 5 were bigeye tuna, 1 was mixed skipjack-bigeye tunas, and 1 was black skipjack, Euthynnus lineatus. Smith and Schaefer (1949) concluded that a skipjack tuna fishery could be developed in Palau, but they recommend a relatively small vessel for fishing operation because it would have the advantage of moving close to the baiting grounds. A large tuna clipper might be necessary only if fishing was carried on outside the Palaus.

Despite the promising outlook for a commercial fishery for skipjack tuna in Palau, the Trust Territory Government, working with a limited budget, believed that fisheries development should be kept at a level sufficient only to provide food for the Micronesian people. But it became increasingly apparent that the Trust Territory needed to develop its marine resources and the government saw that fishing, traditionally an economic activity of the people of Micronesia, was an important source of jobs and money income.

Preparations for reviving commercial fishing in Palau were started in the mid-1950's and by 1962, a complete dockside fishery station with ice plant, sharp freezer, and storage reefer was in operation (Wilson, 1963).

In 1963, the Trust Territory Government and Van Camp Sea Food Company completed arrangements to begin commercial skipjack tuna fishing in Palau (Rothschild, 1966b). The company constructed a 1,500-ton freezer-storage plant at Malakal Harbor, purchased pole-and-line fishing vessels from Japan and Okinawa, and manned the vessels with skilled Okinawan fishermen and Micronesian trainees. According to terms of the agreement, the trained Micronesians will eventually replace the Okinawans in the fishery. Actual fishing began in the summer of 1964, at which time six skipjack tuna fishing vessels were in operation. Details of the Palau skipjack tuna fishery may be obtained from Wilson (1965) and Uchida (1970).

The pole-and-line fishing vessels in Palau are typical of those used for surface school fishing throughout the western Pacific. They are characterized by a long, high bowsprit with fishing racks extending from the tip of the bowsprit along both sides of the vessel and completely around the stern.

In 1974, there were 11 vessels in the fleet. The vessels ranged in length from 58 to 65 ft (17.7 to 19.8 m) and varied in gross tonnage from 32 to 49 tons. Three of the 11 vessels, operated by Micronesian crews, had 90 hp engines and a maximum speed of 6.5 knots. The remaining vessels, operated by Korean and Okinawan crews, had from 210 to 320 hp engines and cruising speeds of 8 knots. Usually, these vessels carried 18-20 fishermen.

Wilson (1966) reported on the building of a sampan at the Palau Boatbuilding and Drydocking Association. According to Wilson, this vessel, named Emeraech, was almost identical in design with the Hawaiian skipjack tuna sampans, which are noted for seaworthiness, stability, and speed but not carrying capacity. Owned and operated by the Trust Territory Government, Emeraech was about 75 ft (23 m) long, had six baitwells arranged on the afterdeck in two parallel rows of three, and carried about 50 buckets of bait. Characteristic of the Emeraech (and Hawaiian sampans) was the large, clear afterdeck, unlike the Japanese- and Okinawan-designed vessels which have all baitwells, fishholds, and iceholds on the well deck forward of the bridge. The Emeraech also had a sponson or fishing platform, about 4 ft (1.2 m) wide, raised about 2 ft (0.6 m) above deck and extending around both sides of the afterdeck and across the stern. Emeraech had a maximum speed of 11 knots and carried from 10 to 14 crew members.

Development of a pole-and-line fishery depends to a large extent on the abundance of live bait. In the 1920's, the Japanese found bait plentiful everywhere inside the reefs at Palau (South Seas Government-General Fisheries Experiment Station, 1937b). And the Oregon also confirmed the abundance of baitfish along much of the rugged shoreline of the many limestone islands between Peleliu and Koror (Smith and Schaefer, 1949).

In his report, "The bait resources of the Palau Islands" (unpublished),[1] Wilson concluded that the small round herring, locally called "kuaol," Spratelloides delicatulus, was the most important and abundant bait species in Palau during a survey made in November 1956. But Smith and Schaefer (1949) learned that a small, translucent anchovy was the "number-one bait" of the Japanese, with the silverside a close second.

Samples of baitfish collected routinely in the 1960's at Palau by technicians of the Honolulu Laboratory of the National Marine Fisheries Service (formerly Bureau of Commercial Fisheries) indicate that the "number-one bait" is the anchovy, Stolephorus heterolobus, call "katakuchi" by the Okinawan fishermen (Uchida, 1970). Other species present in the bait samples have been identified as silverside, locally called "teber," Allanetta woodwardi, Sardinella sp., and small round herring or "kuaol," S. delicatulus. The present fleet in Palau relies primarily on fishing at night for anchovy, which accounts for about 90% of the bait catch.

The baiting ground in the Palaus, shown in Figure 50, is the limestone islands area, extending from the western entrance to Malakal Harbor southward to the western boat passage by Gamudoko Island (Uchida, 1970). Figure 51 shows the main baiting area in detail. The vessels fish for bait by night light, usually catching sufficient bait by 0400-0500. They depart for the fishing grounds by daybreak and return to port in the evening to unload the day's catch, resupply, and return once again to the baiting ground. In 1964-72, the bait catch varied between 10,888 buckets in 1964 and 111,103 buckets in 1969 and averaged 68,844 buckets (Muller, MS)[2] (Table 25). Baiting intensity during those years also fluctuated widely, from 270 to 2,860 boat nights. The catch per boat night was 40.3 buckets in 1964, fluctuated irregularly between 44.7 and 49.7 buckets in 1965-68, rose sharply to 69.9 buckets in 1969 then declined precipitiously to only 17.0 buckets in 1971. The 1972 catch rate showed a recovery to 45.9 bucket/boat night.

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[1]Wilson, P. T. [1957] The bait resources of the Palau Islands. Hawaiian Tuna Packers, Ltd., Honolulu, on file at Southwest Fisheries Center, National Marine Fisheries Service, NOAA, Honolulu, HI 96812, 21 p. (Mimeogr.)

[2]Muller, R. G. Some aspects of the population biology of Stolephorus heterolobus from Palau. Draft report distributed for information in connection with Tuna Baitfish Workshop, 4-6 June 1974, Honolulu, HI 96812.

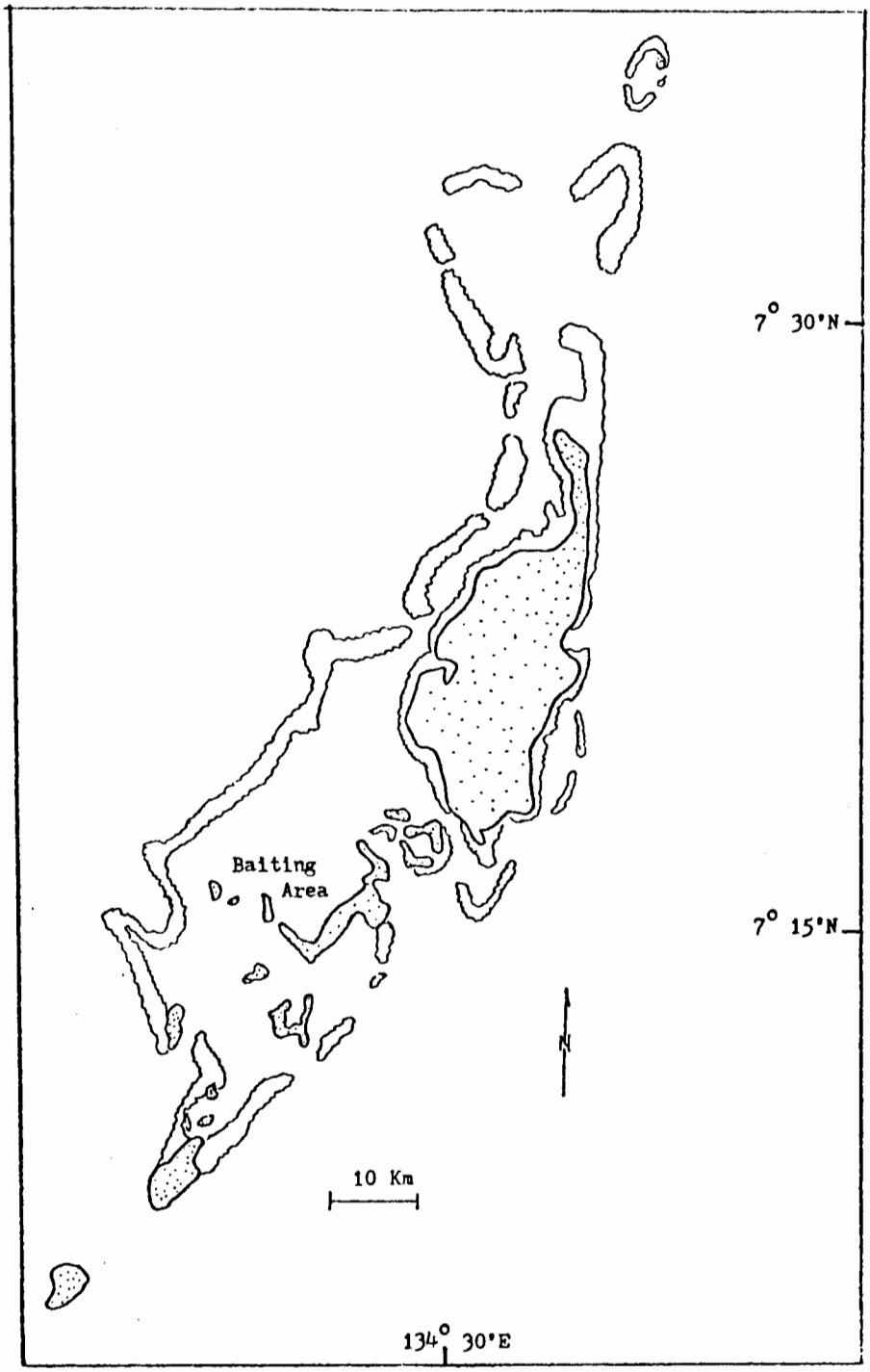


Figure 50.--Baiting area in the Palau Islands (Muller, see text footnote 2).

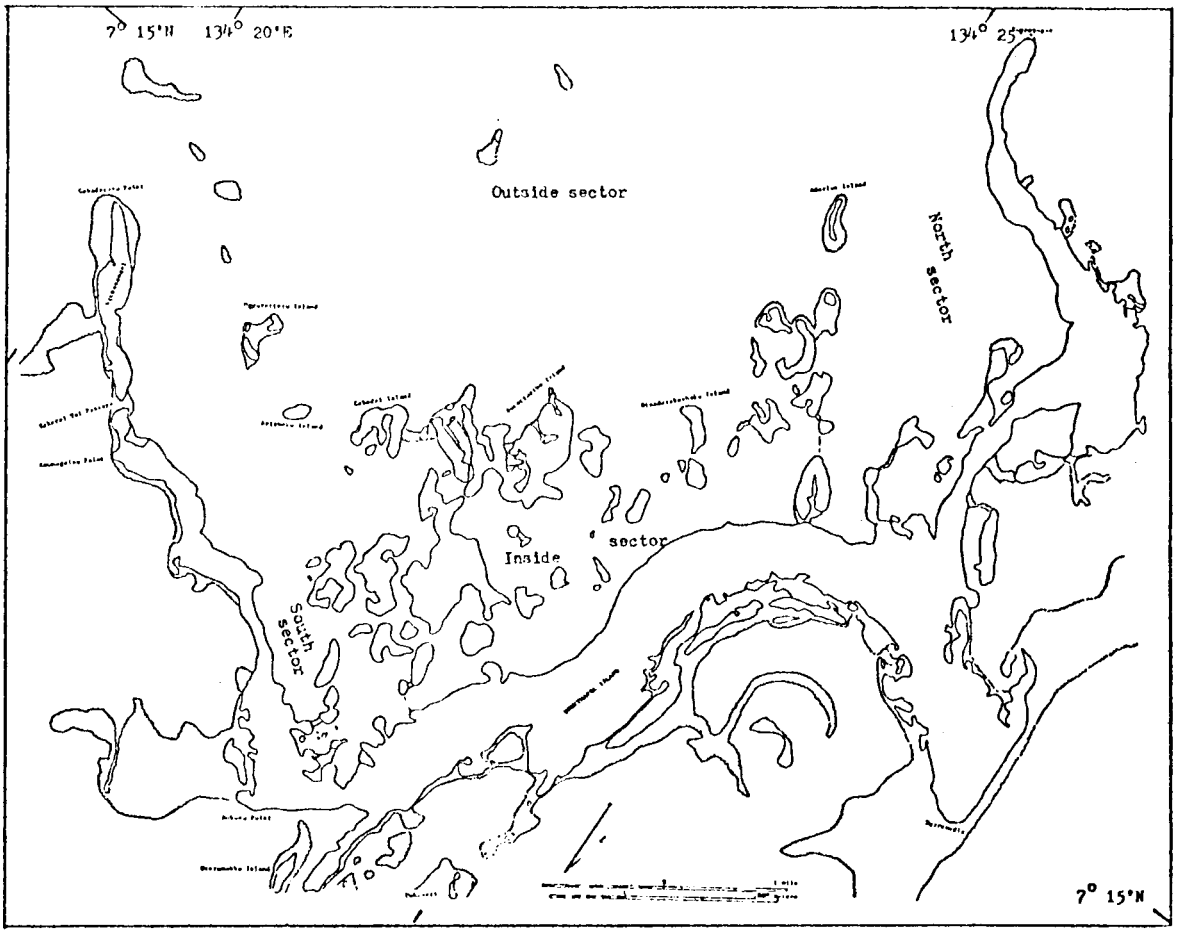
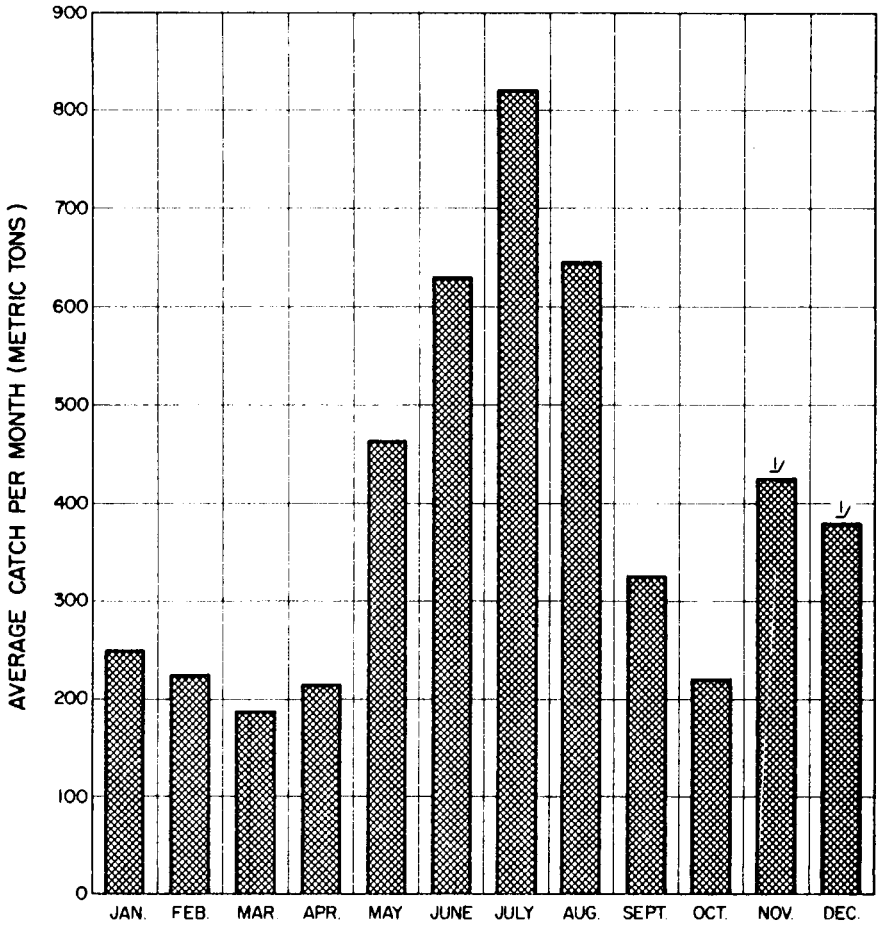


Figure 51.--Detailed map of the main baiting area in the Palau Islands (Muller, see text footnote 2).

Table 25.--Annual total catch, effort, and catch per effort statistics for the Palauan bait fishery (Muller, see text footnote 2).

Year	Catch buckets	Boat nights	Catch/boat night
1964	10,888	270	40.3
1965	53,358	1,073	49.7
1966	62,780	1,406	44.7
1967	73,620	1,616	45.6
1968	82,082	1,784	46.0
1969	111,103	1,590	69.9
1970	96,462	1,565	61.6
1971	48,674	2,860	17.0
1972	80,630	1,755	45.9



1/ Based on data for 1966-70.

Figure 52.--Average monthly catch of skipjack tuna in the Palau fishery 1966-71 (Uchida, in press).

In Palau, year-round fishing for skipjack tuna is possible, although the catches fluctuate widely from month to month. Monthly catches, averaged for the years 1966-71 and shown in Figure 52, peak twice during the year. A major peak appears in July and a minor one in November. The average monthly catch varied from a low of 203 ST (184 MT) in March to 905 ST (821 MT) in July (Congress of Micronesia, 1972). The pre-World War II Japanese fishery also experienced the summer and winter peaks in abundance (Uchida, 1970). The poor fishing in February was associated with generally lower water temperatures at this time of the year due to heavy rains (South Seas Government-General Fisheries Experiment Station, 1937b).

Annually, the catches from the Palau skipjack tuna fishery varied between 3,243 and 9,304 ST (2,942 and 8,441 MT) in 1966-70 (data for 1971 incomplete), and averaged 5,773 ST (5,237 MT) (Table 26). Catches made in Palau in 1966-71 compare favorably with those made by the Japanese in 1922-40 (Table 17).

Japanese Southern Water Pole-and-Line Fishery

The most dramatic increase in fishing effort and catches of skipjack tuna from Trust Territory waters since the end of World War II has been made by the Japanese pole-and-line fishing fleet. The development of Japan's southern water (refers to waters south of lat. 24°N) fishery stems from the realization that the skipjack tuna resource in Japan's coastal waters was nearing the limit of exploitation (Tohoku Regional Fisheries Research Laboratory, undated a). A second prime consideration for expansion southward was that the large available skipjack tuna resource in the southern waters could be exploited during the off-season for skipjack tuna in Japanese coastal waters.

Figure 53 depicts the geographical location of skipjack tuna fisheries and fishing areas in the Pacific in the early 1960's. All the fishing at that time was confined to areas relatively close to the coastlines of Central and South America and Japan and near island groups in the central and western Pacific. From about 1962, Japanese vessels operating out of ports in several prefectures (Kagoshima, Mie, Shizuoka, Ibaraki, and Miyagi) and carrying live anchovies, Engraulis japonica, obtained from bait stations in southern Japan, began to move into southern waters along the Bonin and Mariana archipelagoes (Tohoku Regional Fisheries Research Laboratory, undated b).

The principal fishing grounds in the southern water fishery are divided into the Bonin-Mariana region, which is usually fished in July-October, and the Caroline Islands region fished from November through March (Iwasaki, 1970). The expansion of the fishing grounds, shown in Figure 54, continued over the years so that by 1971 some vessels were fishing in equatorial waters between Truk and the Marshalls and south of the equator in waters from lat. 1°-5°S between long. 147°

Table 26.--Number of boats fishing, catches of skipjack tuna, and catch per boat, by month, in the Palau skipjack tuna fishery, 1966-71 (Congress of Micronesia, 1972).

Month	1966			1967			1968		
	Boats	Catch	Catch per boat	Boats	Catch	Catch per boat	Boats	Catch	Catch per boat
	No.	MT	MT	No.	MT	MT	No.	MT	MT
January	—	101.414	--	5	361.103	72.2	10	341.896	34.2
February	--	220.402	—	4	107.918	26.9	9	477.397	53.0
March	—	133.402	--	4	101.678	25.4	8	443.479	55.4
April	--	108.210	--	4	120.516	30.1	6	375.414	62.5
May	--	161.820	--	4	130.399	32.6	6	733.787	122.3
June	--	185.283	--	10	258.949	25.9	11	771.853	70.1
July	--	524.830	--	10	384.659	38.4	11	996.055	90.5
August	--	326.672	—	9	430.843	47.9	9	769.427	85.4
September	—	477.440	--	10	210.327	21.0	9	177.879	19.7
October	8	320.839	40.1	10	205.587	20.6	5	37.497	7.5
November	8	250.227	31.2	10	580.735	58.1	6	84.864	14.1
December	8	130.871	16.3	9	510.787	56.7	4	2.868	0.7
Total	--	2,941.600	--	--	3,403.501	—	—	5,212.416	--
Average	—	245.134	--	7.4	283.625	38.2	7.8	434.368	55.5
		1969			1970			1971	
January	8	72.107	9.0	7	389.421	55.7	6	242.875	40.4
February	9	141.385	15.8	7	274.983	39.2	6	102.734	17.1
March	8	35.330	4.4	6	192.730	32.1	8	199.799	24.9
April	5	58.195	11.6	7	422.949	60.4	7	190.919	27.2
May	5	259.846	51.9	9	1,021.297	113.5	8	466.544	58.3
June	4	623.630	155.9	9	1,642.223	182.4	8	282.685	35.3
July	8	678.585	84.8	9	2,343.803	260.4	12	72.200	6.0
August	9	1,282.252	142.4	9	1,055.522	117.3	12	78.200	6.6
September	9	809.540	89.9	2	95.873	47.9	12	197.877	16.5
October	9	593.678	65.9	5	149.753	29.5	6	31.895	5.3
November	7	702.714	100.4	5	512.560	102.5	—[1]	--	--
December	7	929.011	132.7	6	340.172	56.7	—[1]	--	--
Total	—	6,186.183	--	--	8,441.286	--	--	1,716.832	--
Average	7.3	515.515	70.3	6.75	703.441	104.2	8.5	171.683	20.2

[1]Data unavailable at time of publication.

Figure 53.--Location of skipjack tuna fisheries in the Pacific Ocean in 1960.

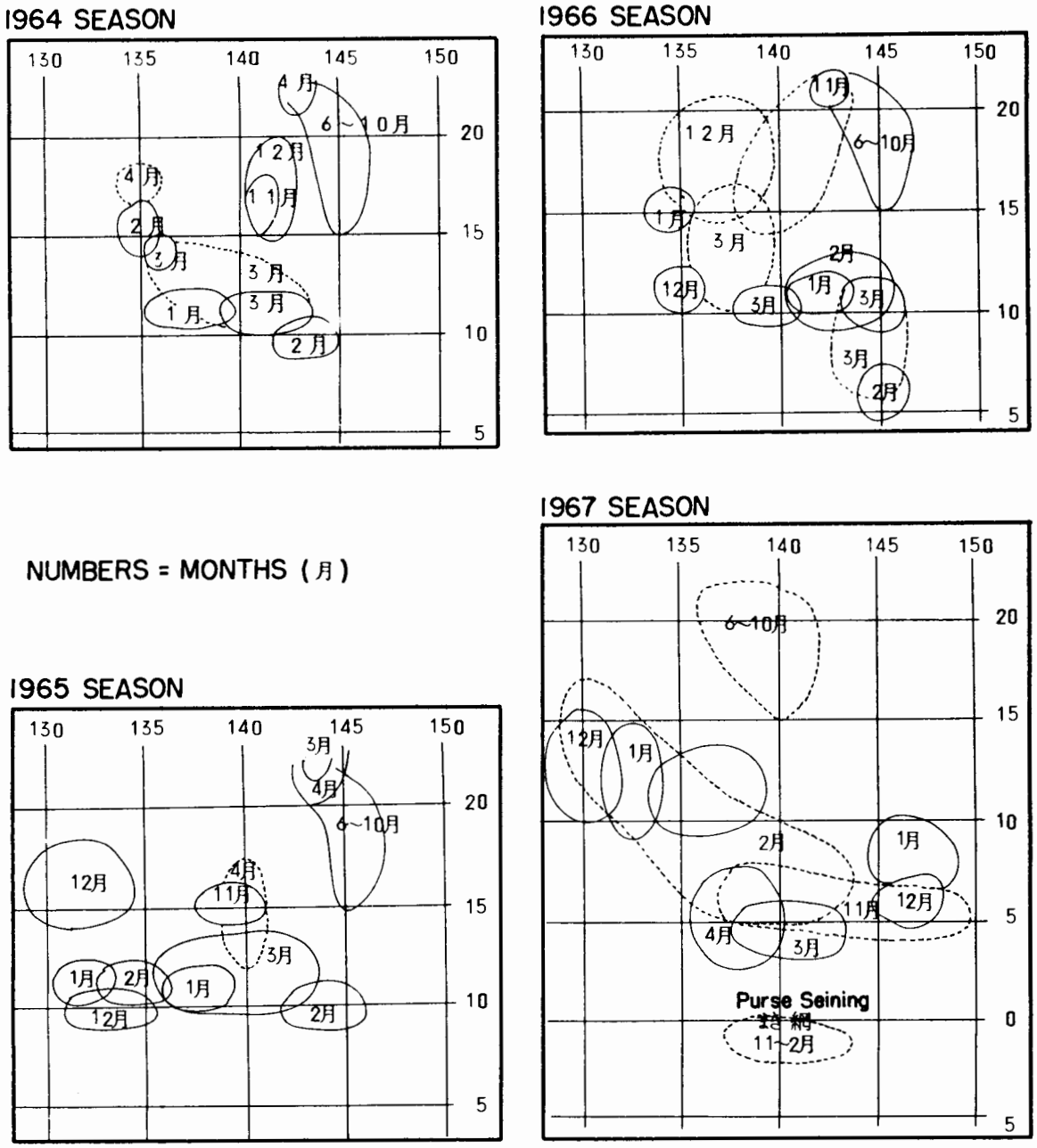
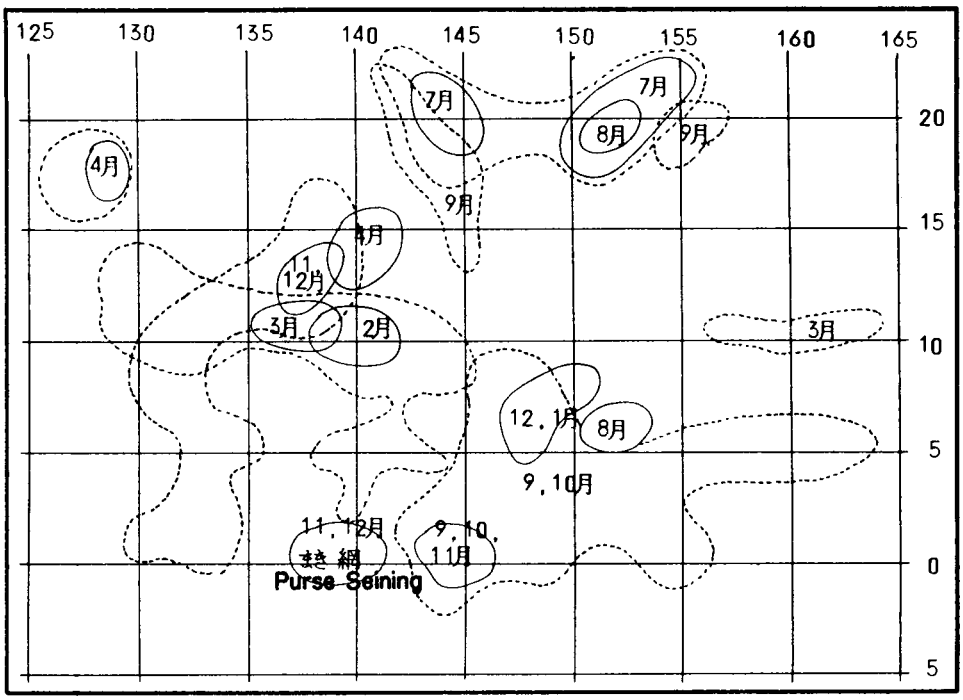


Figure 54.--The monthly movements of the skipjack tuna fishing grounds in southern waters. Areas of intense fishing effort encircled by solid line; area of moderate effort shown by broken line (Tohoku Regional Fisheries Research Laboratory, undated d). Note: Numerals denote months of year.

1968 SEASON



1969 SEASON

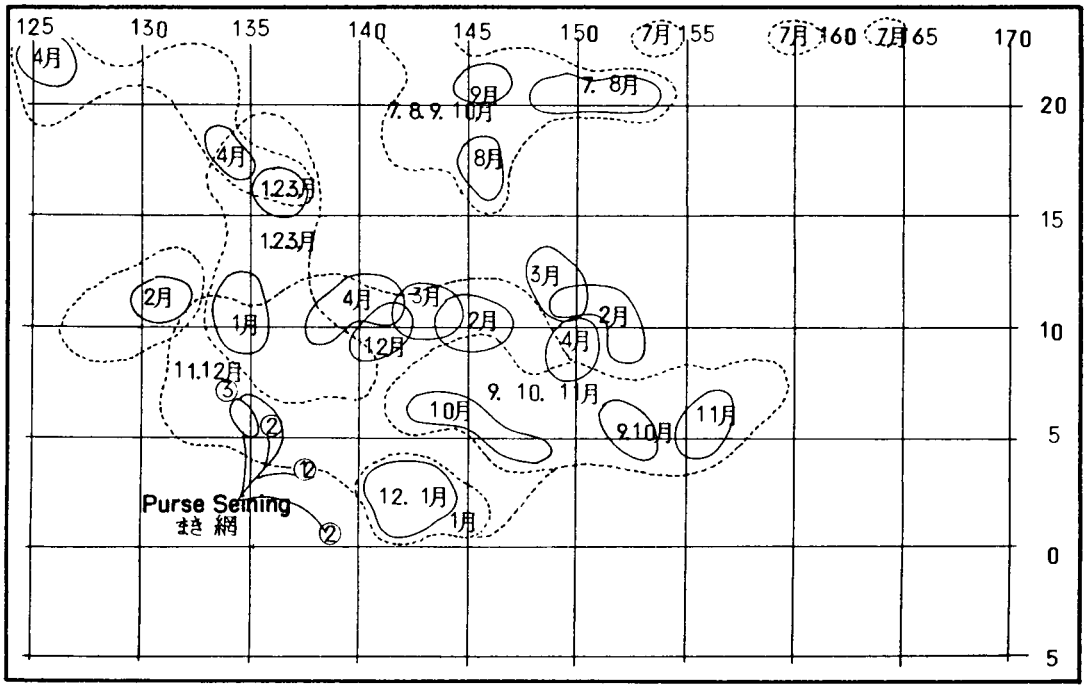


Figure 54.--Continued.

1970 SEASON

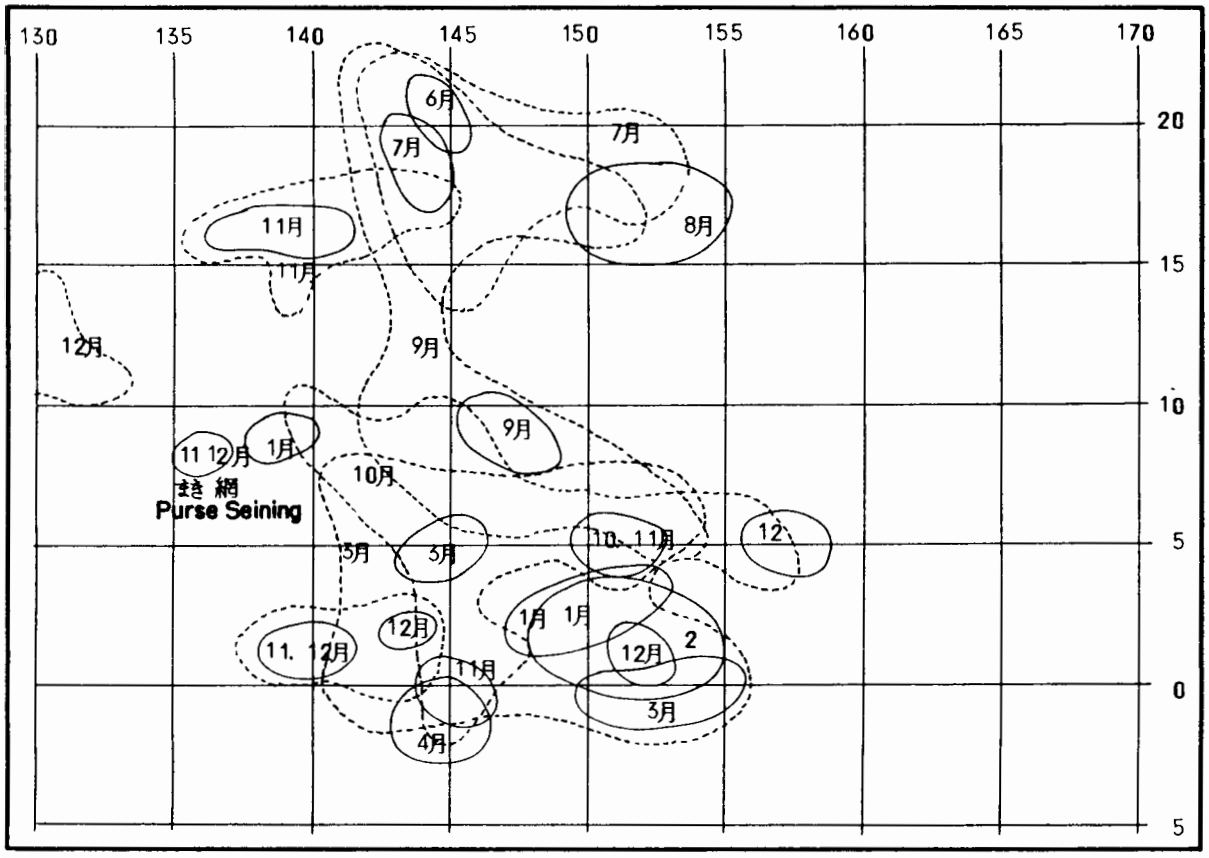


Figure 54.--Continued.

1971 SEASON

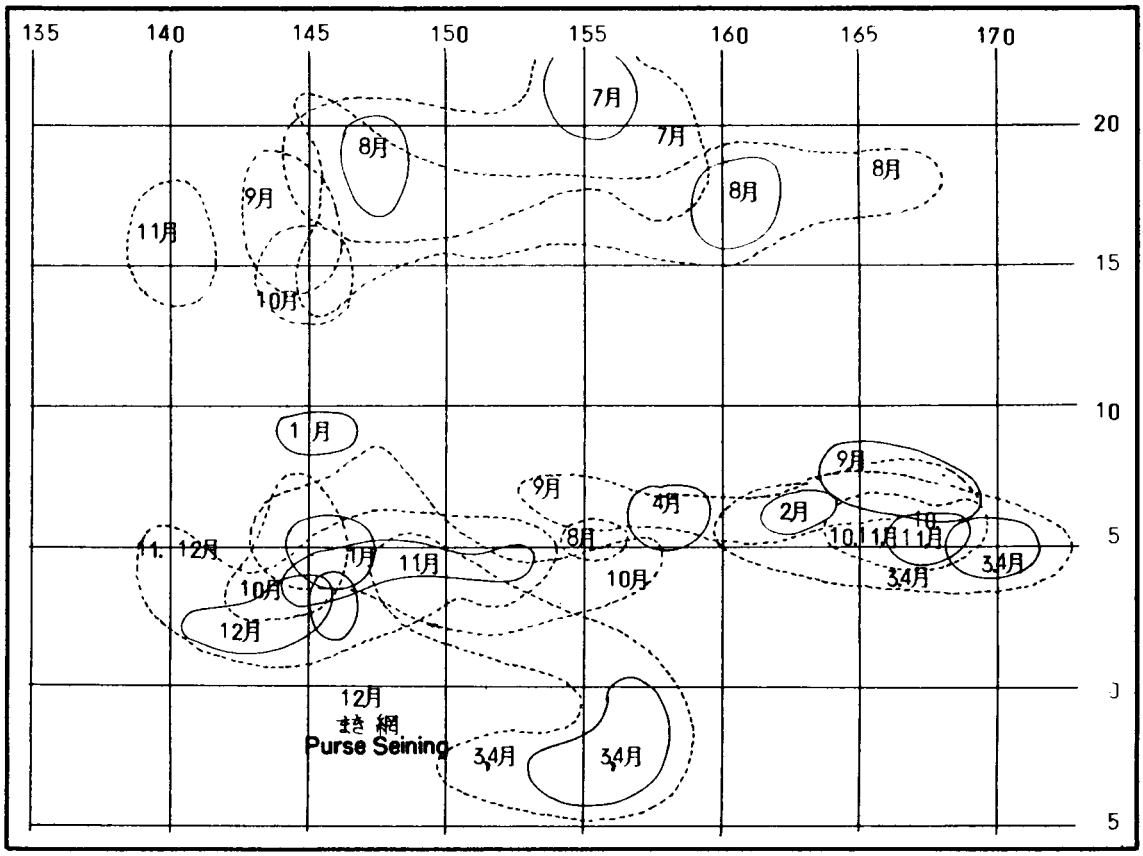


Figure 54.--Continued.

and 157°E. Generally, large vessels (>300 MT) tended to seek out and develop new, more distant fishing grounds, where the medium-sized vessels (about 200 MT) remained on the established grounds in spite of poor fishing. Figure 55 shows the extent of the fishing grounds for skipjack tuna not only in the southern water area but also throughout the Pacific basin in 1973.

Figure 56 shows the statistical areas established for the principal fishing ground in the southern water fishery whereas Table 27 shows percentage of fishing effort and catch per day's fishing in these statistical areas in 1963-69. In general, areas west of the Marianas and around the Western Carolines received a large proportion of the fishing effort.

The supply of live bait is an extremely important factor in the survival of the southern water fishery (U.S. National Marine Fisheries Service (NMFS), 1974d). Presently, all the bait used in this fishery is obtained in southern Japan and carried by the vessels to the fishing grounds. Bait-carrying capacity varies with vessel size; for example, a 190-ton vessel carries about 370 buckets of bait whereas a 350-ton vessel carried 500-600 buckets.

A trip to the southern water fishing grounds requires about 30 days but only a third of that time is spent fishing (U.S. NMFS, 1974d). The result of such long trips is high bait mortality which until recently varied from 30% to 60%. The major cause of bait mortality is the rapid rise in sea-surface temperature as the vessels steam southward from cold to warm water (U.S. NMFS, 1974d). Some Japanese researchers believe that higher water temperature is conducive to disease outbreak whereas others feel that increased temperature will promote spawning and, therefore, weaken the baitfish (Otsu, in press). To reduce bait mortality, Japanese improved bait-tank design and refrigerated the bait-tank water. Also, taking on "seasoned" anchovy which had been held in bait compounds and fed regularly for periods of a week to a month significantly reduced mortality. Survival rates in recent years have been 70%-80%.

Monitoring the southern water catches of skipjack tuna which were being landed at the port of Yaizu, Kasahara (1971) showed a pattern evolving among returning vessels. Generally, very few returning vessels fished the southern waters in May-June (Figure 57). In July, there was an increase followed by a slight decrease until October and another increase until December. There was a sudden decrease in January followed by another increase in February and March. The low numbers fishing in southern waters in May-June reflects the shift to albacore fishing in Japanese coastal waters. The increase in October reflects the end of the skipjack tuna season in coastal waters off Japan and many vessels then enter the southern water fishery. The January low reflects the tie-up of many vessels during the New Year's holidays.

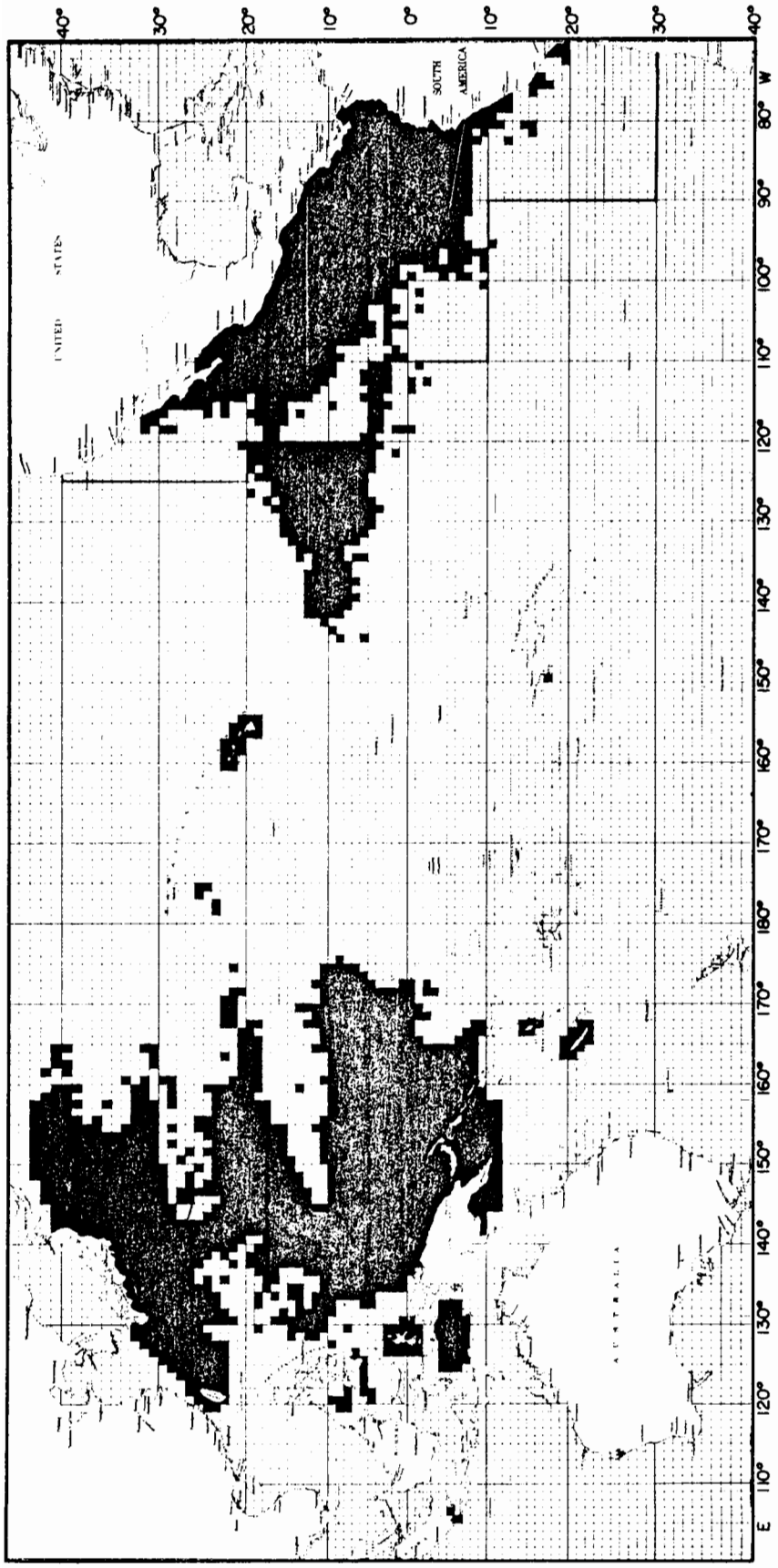


Figure 55.--Location of skipjack tuna fisheries and fishing areas in the Pacific Ocean in 1973.

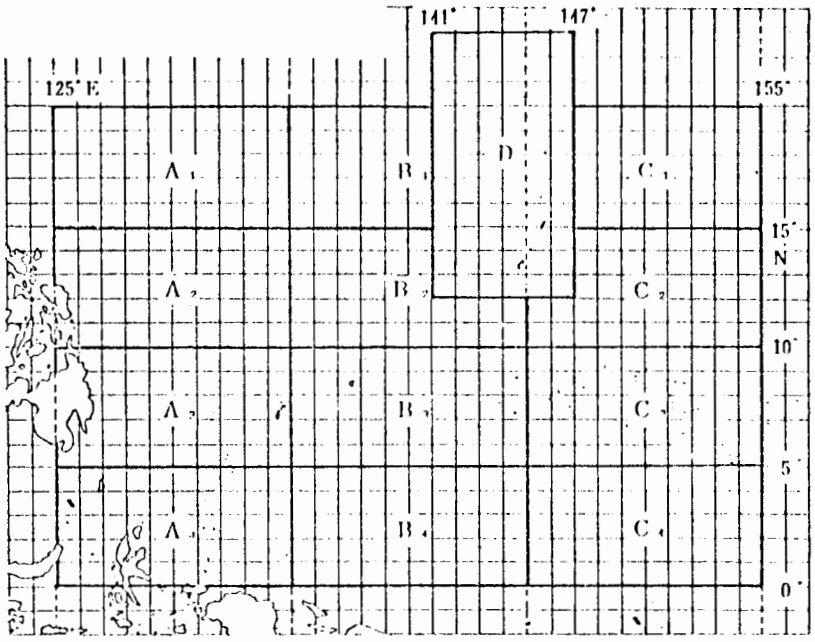


Figure 56.--The subdivision of the principal fishing area in southern waters from November through April (Kasahara, 1971).

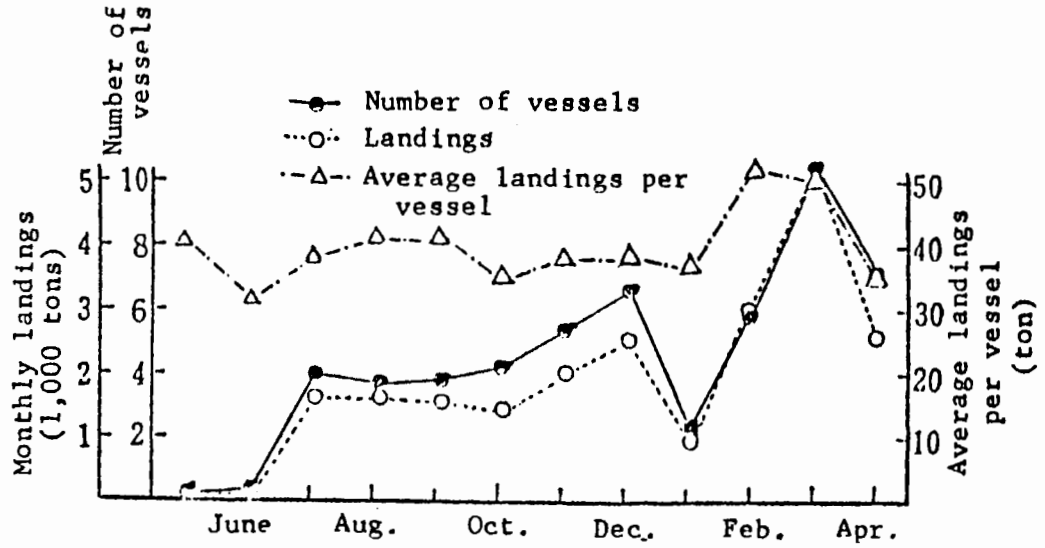


Figure 57.--The monthly average number of vessels, landings, and landings per vessel of vessels returning to Yaizu Port from the southern water fishery (averaged for the years 1964-70) (Kasahara, 1971).

Table 27.--The percentage fishing effort (upper row) and the catch per day's fishing (lower row), in tons, shown by sub-areas as designated in Figure 56 from November through April (Kasahara, 1971).

Sub-area	Season						
	1963	1964	1965	1966	1967	1968	1969
A_1		3.3 3.2	5.9 3.6	5.7 4.4	0.5 5.4	5.5 4.1	11.1 5.2
A_2		1.5 3.1	21.6 4.9	6.8 3.6	0.5 5.9	26.3 4.0	8.0 6.7
A_3		0.6 3.5	3.6 6.1	1.8 3.9	0.8 5.9	3.4 6.6	4.6 5.5
A_4						1.9 4.2	0.2 2.4
B_1		11.1 4.1	5.8 3.0	14.5 4.0	0.7 3.9	2.3 2.4	7.1 5.4
B_2		42.0 7.3	42.4 5.8	25.0 6.1	17.1 5.2	39.3 4.5	12.2 6.7
B_3	37.0 7.6	3.7 7.1	6.4 8.8	12.3 5.3	32.0 6.0	7.8 4.1	23.7 5.2
B_4				2.5 8.7	6.2 7.7	3.5 2.6	6.5 6.1
C_1						1.1 6.5	
C_2		0.6 9.1	0.3 5.7	0.3 9.2	1.4 4.4	0.3 2.8	5.5 9.0
C_3		0.3 5.6	0.8 5.7	8.4 8.5	30.7 7.2	1.1 4.6	8.6 4.3
C_4					4.6 10.8	1.1 4.9	3.0 4.2
D	50.0 3.4	36.6 4.6	12.4 3.8	21.4 3.7	4.7 4.2	1.6 2.3	0.5 3.4

The number of vessels returning from southern waters to Yaizu also reflects the landings at this port (Tohoku Regional Fisheries Research Laboratory, undated b). Usually, landings were high in November-December and February-March. Landings per trip show small variation ranging between 33 and 55 ST (30 and 50 MT) At the end of the 1971 fishing season, it was estimated that the southern water fishery for skipjack tuna contributed from 20% to 30% of the total Japanese skipjack tuna landings.

Table 28 gives the number of vessels returning monthly to Yaizu, monthly landings, landings per trip, and the seasonal landings in 1964-71. For the southern water fishery, a season extends from May to the following April. It should also be mentioned that landings of skipjack tuna caught in southern waters area are, at best, minimal because at Yaizu, they represent roughly 50%-80% of the total southern water fishery landings (U.S. NMFS, 1974d).

Based on Yaizu figures, it is apparent that the landings, except for 2 years, have grown from 15,454 ST (14,020 MT) in 1964 to 56,532 ST (51,286 MT) in 1971. The drop in landings in 1966 was attributed to a decrease in fishing intensity as many of the pole-and-line vessels experienced good fishing in coastal waters and remained there instead of heading for southern waters. In 1968, a typhoon in the Marianas curtailed fishing. Furthermore, it is believed that many vessels fishing further west in southern waters chose to unload at the ports of Makurazaki and Yamakawa.

Iwasaki (1970), who analyzed the variation in catch among vessels fishing in southern waters, noted that the trend toward higher seasonal landings does not necessarily reflect better average catches. Calculating the average annual catch of all vessels over 150 tons, Iwasaki found considerable annual variation (Figure 58). By area, Iwasaki found that in the Bonin-Mariana area the average catch per vessel was good in 1963-67 and poor in 1959-61 and 1968. In the Carolines area, average catches were rather stable; the exceptions were a very good season in 1967 and a very poor season in 1968.

Recognizing that when the average catch per vessel in the Bonin-Mariana area was high in July-September the catches were also above average in the Carolines in November-March, Iwasaki (1970) indicated that it may be possible to estimate the Carolines catches on the basis of the Bonin-Mariana catches. For the Bonin-Mariana area, Iwasaki found that variations in surface temperature and catch per vessel showed similar tendencies (Figure 59). Low temperature in 1963 and 1968 correlated positively with very poor fishing seasons. Temperatures were relatively high in 1964, 1967, and 1969, when fishing was good. He concluded that fishing condition for skipjack and yellowfin tunas in the Bonin-Mariana area in any given year is largely influenced by prevailing water temperature.

Table 28.--Monthly number, total landings (estimated), and landings per vessel of vessels operating in southern waters and returning to Yaizu Port (Tohoku Regional Fisheries Research Laboratory, undated d).

MONTH	1964			1965			1966			1967		
	NO. OF VESSELS	LANDINGS (TONS)	LANDINGS PER VESSEL	NO. OF VESSELS	LANDINGS (TONS)	LANDINGS PER VESSEL	NO. OF VESSELS	LANDINGS (TONS)	LANDINGS PER VESSEL	NO. OF VESSELS	LANDINGS (TONS)	LANDINGS PER VESSEL
MAY										8	277	34.5
JUNE	9	328	37.4	3	58	19.3				5	161	32.2
JULY	26	1,050	40.4	63	2,225	35.3	6	264	44.0	46	1,853	40.3
AUG.	37	1,771	47.8	49	1,724	35.2	24	903	37.6	29	1,363	47.0
SEPT.	40	1,559	39.0	43	2,084	48.4	23	972	42.3	30	1,225	40.9
OCT.	38	1,044	27.5	44	1,312	29.8	31	1,022	32.9	54	1,844	34.2
NOV.	38	1,215	32.0	52	1,528	29.4	56	1,929	34.5	67	3,110	46.5
DEC.	52	1,852	35.6	60	1,445	24.1	59	2,033	34.4	64	3,162	49.5
JAN.	7	305	43.6	19	702	36.9	26	1,090	42.0	67	1,754	26.2
FEB.	13	667	51.3	63	2,547	40.4	76	3,684	48.5	78	5,628	72.2
MAR.	86	3,443	40.1	136	6,484	47.5	123	5,881	47.8	100	4,729	47.3
APR.	24	735	30.6	66	2,212	33.5	53	1,883	35.6	61	3,216	52.7
TOTAL	370	14,020	37.9	598	22,321	37.3	477	19,661	41.2	609	28,292	46.7

MONTH	1968			1969			1970			1971		
	NO. OF VESSELS	LANDINGS (TONS)	LANDINGS PER VESSEL	NO. OF VESSELS	LANDINGS (TONS)	LANDINGS PER VESSEL	NO. OF VESSELS	LANDINGS (TONS)	LANDINGS PER VESSEL	NO. OF VESSELS	LANDINGS (TONS)	LANDINGS PER VESSEL
MAY	4	232	58.0									
JUNE	9	303	33.7	4	73	18.3				8	208	26.0
JULY	67	2,609	39.1	32	1,542	48.2	45	2,657	59.0	60	4,193	70.0
AUG.	44	1,897	43.1	38	1,847	48.6	35	1,833	52.4	89	6,049	68.0
SEPT.	35	1,178	33.7	40	1,864	46.6	35	1,652	44.4	45	2,673	59.5
OCT.	37	1,364	36.9	43	1,975	45.9	35	1,959	56.0	82	4,594	56.0
NOV.	46	1,561	34.0	48	2,516	52.4	71	3,613	50.9	94	6,857	73.0
DEC.	80	2,586	32.4	67	3,693	55.1	1/ 62	3,654	58.9	94	6,456	68.7
JAN	11	719	65.4	9	588	65.3	12	927	77.2	15	1,243	82.9
FEB.	61	2,598	42.6	51	2,777	54.5	65	6,423	98.8	54	3,975	73.7
MAR.	74	3,058	41.3	108	7,421	68.8	78	6,065	77.7	77	6,183	80.3
APR.	71	3,123	44.0	86	3,934	45.7	63	4,454	71.0	66	6,152	93.2
TOTAL	539	21,228	39.5	526	28,230	53.9	501	33,237	66.5	2/ 713	51,286	71.9

1/ INCLUDES 55 TON CATCH OF 1 PURSE SEINER.
2/ INCLUDES 2,703 TONS TAKEN BY 29 VESSELS IN MAY 1972.

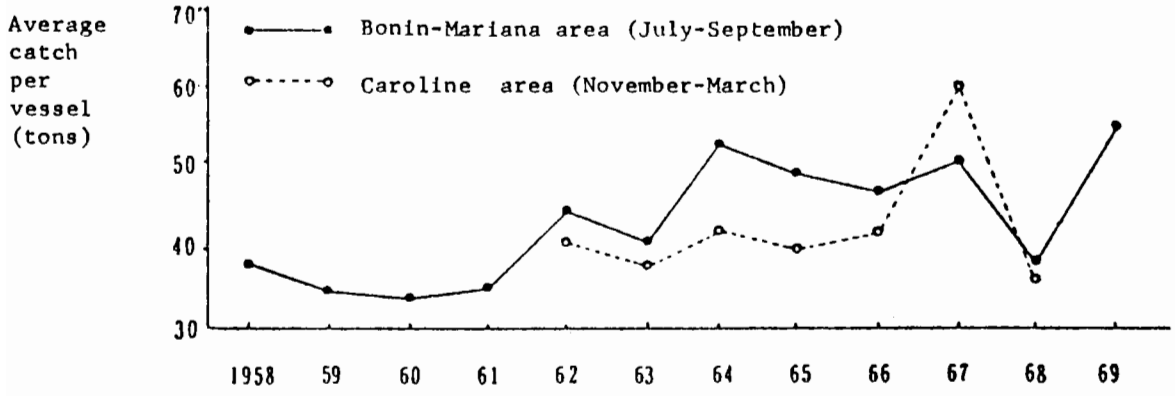


Figure 58.--The variations in annual average catch (Iwasaki, 1970).

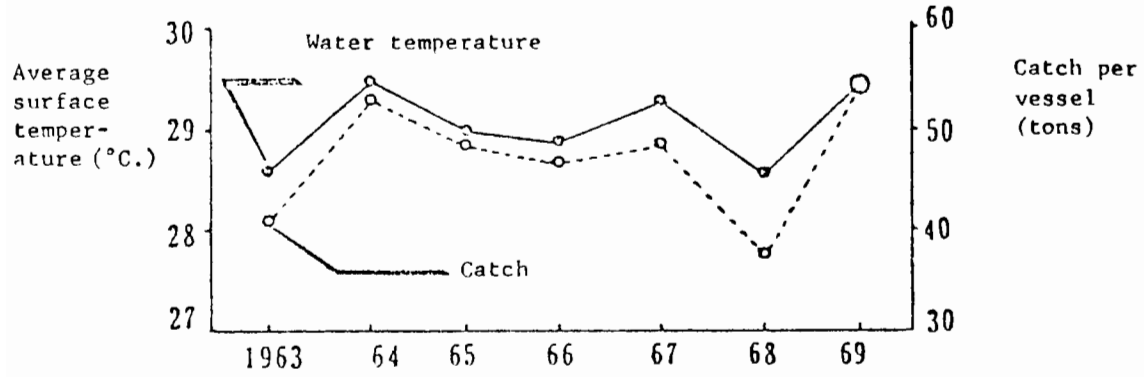


Figure 59.--Annual variations in water temperature and catches (Iwasaki, 1970).

In areas where fishing is good, the Japanese pole-and-line vessels average up to 8.8 ST (8 MT) of fish per vessel per day of fishing (Figure 60) (U.S. NMFS, 1971c). In October 1971, for example, the vessels reported that on the main fishing ground located near the equator and lat. 8°N between long. 150° and 160°E (between Truk and Greenwich Islands south of Ponape), the catch was 3.3-6.6 ST (3-6 MT) of skipjack tuna per vessel per day. Further north near lat. 14°-20°N and between long. 142° and 148°E (between Guam and Uracas Island in the Marianas), the catch per vessel per day was slightly better, averaging between 4.4 and 8.8 ST (4 and 8 MT).

Although small, the landings of yellowfin tuna caught by the pole-and-line vessels operating in southern waters should be mentioned. Kikawa and Warashina (1972) have studied the landings of yellowfin tuna and found that they averaged 4.9% of the total landings with monthly averages varying between 1.6% and 9.9%. The sizes of these yellowfin tuna ranged from 1 to 43 lb (0.5 to 19.5 kg) but most were between 3 and 5 lb (1.4 and 2.3 kg). Kikawa and Warashina also estimated that the number of fishing days with catches of yellowfin tuna averaged 30.1% with monthly averages between 16.8% and 48.3%.

Japanese Southern Water Purse Seine Fishery

In 1972, Yabe reported that anchovy, which are used as live bait by Japanese pole-and-line vessels, survive for a maximum of 50 days, but more normally for only about 5 weeks. Therefore, even if larger pole-and-line vessels are built, their operating range will still be limited and their eastern limit will probably be around the Marshalls. Yabe estimated that about 40 Japanese tuna longline vessels will be replaced each year by pole-and-line vessels and that within 3 years there may be as many as 200 large pole-and-line vessels fishing in southern waters. He anticipated serious problems from the standpoint of scarcity of bait for all the large vessels. Since purse seiners are not dependent on live bait, Yabe encouraged more rapid development of the tuna purse seine fishery in Japan.

Japanese attempts to capture surface schools of tuna with purse seine in southern waters started in 1964 when Taiyo Fishing Company dispatched the 240-ton seiner, Kenyo Maru, to the New Guinea-New Zealand area (Watakabe, 1970). Attempts to seine large- and medium-sized schools of skipjack tuna in waters north of New Guinea failed. In 1966, the Japanese Fisheries Agency undertook the development of tuna purse seining, and a full-scale test was started in the western equatorial Pacific during the slack, winter months (early November through mid-March) in the coastal waters of Japan.

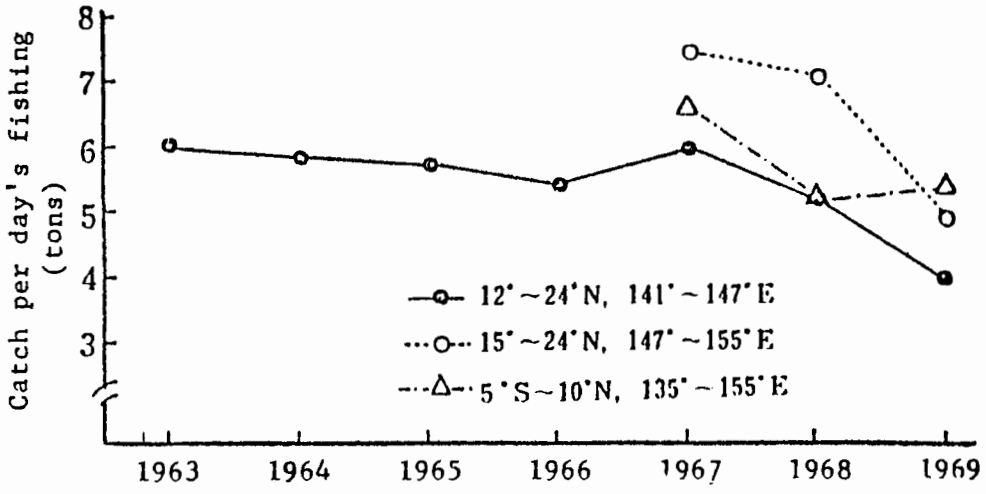


Figure 60.--The catch per day's fishing of skipjack tuna vessels in southern waters from May through October (Kasahara, 1971).

Watakabe (1970) reported on these early trials, which were held near the equator (lat. 0°-5°N, long. 137°-140°E) to the north of New Guinea and near Palau Islands. The Japanese purse seiners experienced a success rate of only 30% in these early trials. Problems with variable weather, clear water, deep thermocline, and subsurface currents have all hindered the progress of exploratory purse seining in the western Pacific.

The erratic behavior of skipjack tuna schools in the western Pacific has also been mentioned as a cause of failure in purse seining (Watakabe, 1970). Many of the schools in the vicinity of islands and banks are feeding on young sardine or flying fish and can be seen breaking the surface and causing the water to "boil." These fish aggregate in large schools. Offshore schools appear to be moving faster and often the direction of movement is unpredictable. The catch records of four seiners that operated in Trust Territory waters in 1966-69 are given in Table 29.

In the early 1970's the semi-government Japan Marine Fishery Resources Research Center (JAMARC) assumed responsibility for the developmental work in purse seining (U.S. NMFS, 1974d). In October 1970-March 1971, two seiners were chartered to continue exploratory fishing. And although these seiners captured up to 19.8 ST (18 MT) of skipjack tuna in a single set, most of the catches were smaller (Table 30). The conclusions drawn from these tests were that skipjack tuna schools can be seined in tropical waters under certain conditions, that seinable schools are found associated with floating logs, and that purse seine success rate is increased if sets are made at dawn or dusk rather than during midday (Yabe, 1972).

In 1974, JAMARC chartered the 499-GT purse seiner, Fukuichi Maru, which made three exploratory purse seining cruises around the Marshalls and Carolines (U.S. NMFS, 1974a, 1974b). During the first 2-month survey, the seiner caught 252 ST (229 MT) of skipjack tuna and 58 ST (53 MT) of yellowfin tuna, a total of 310 ST (282 MT) of tuna in 27 sets or an average of 11.5 ST (10.4 MT) per set (U.S. NMFS, 1974c; Otsu, in press). On her second cruise to the southeast of Palau, Fukuichi Maru found fishing slower. In 10 sets, 24 ST (22 MT) of skipjack tuna and 36 ST (33 MT) of yellowfin tuna were taken or an average of 6.1 ST (5.5 MT) of tuna per set. The third cruise started in the Eastern Carolines (lat. 4°-8°N and long. 145°-151°E) where three sets yielded 20 ST (19 MT) of fish. Heading to waters southeast of Palau, the seiner continued to experience poor fishing. Fourteen sets yielded 140 ST (127 MT) or an average of 10.0 ST (9.1 MT) per set. Toward the end of the survey, Fukuichi Maru caught 22 ST (20 MT) in one set at lat. 2°N and long. 144°E.

Table 29.--Catch records of four Japanese purse seiners operating in southern waters, 1966-69 (Watakabe, 1970).

Vessel	Year			
	1966	1967	1968	1969 (1 trip only)[1]
No. 3 Hayabusa Maru		(3 trips) Skipjack 80 tons Yellowfin 50 tons	(1 trip) Skipjack 60 tons	Skipjack 67 tons
No. 23 Taikei Maru	(3 trips) Skipjack 104 tons Yellowfin 31 tons	(2 trips) Skipjack 43 tons Yellowfin 5 tons	(3 trips) Skipjack 80 tons Yellowfin 36 tons	Did not fish
Nissho Maru	(1 trip) No catch	(4 trips) Skipjack 146 tons Yellowfin 56 tons	(1 trip) Skipjack 26 tons Yellowfin 56 tons	Skipjack 53 tons Yellowfin 25 tons
No. 58 Tokiwa Maru		(3 trips) Skipjack 73 tons Yellowfin 102 tons	Did not fish	Skipjack 81 tons

[1]Translator's note: These figures for 1969 do not exactly correspond with data presented on preceding page.

Table 30.--Results of experimental purse seining by Japanese Government chartered vessels, Taikei Maru No. 23 (210 gross tons) and Tokiwa Maru No. 58 (358 gross tons) (Japan Fisheries Agency, undated).

DATE	POSITION	TIME OF DAY	TYPE OF SCHOOL SET ON	CATCHES MADE	VESSEL
11/9/70	00°09'S, 143°36'E.	0455	Drift log; small YF; found by fish finder.	No catch.	No. 23 TAIKEI
11/11/70	05°53'N, 144°57'E	0814	do	do	Do
11/12/70	07°02'N, 146°49'E	1625	With whale shark; small YF jumping.	10 YF (30-40 kg.) 2 tons of small YF (4-6 kg.)	Do
11/14/70	06°37'N, 149°39'E	1243	Skipjack jumping.	3 tons of small YF (3-4 kg.)	Do
11/15/70	06°37'N, 150°20'E	1200	Skipjack with bird flock.	5 tons of small YF (3-4 kg.)	Do
11/16/70	06°50'N, 151°12'E	1200	Drift log and small YF.	No catch.	Do
11/22/70	03°06'S, 149°26'E	0755	Skipjack jumping; bird flock.	No catch.	Do
11/23/70	03°00'S, 149°23'E	1141	Drift log; skipjack jumping; many schools in vicinity.	No catch; Auxis escaped net.	Do
11/30/70	03°58'S, 147°01'E	1438	Skipjack jumping.	0.5 ton of skipjack (3 kg.)	Do
12/2/70	02°54'S, 145°07'E	1400	Skipjack jumping; bird flock.	7 tons of skipjack (2-3 kg.)	Do
12/15/70	08°34'N, 141°45'E	1550	With whale shark; small YF jumping.	No catch	Do
11/30/70	09°29'N, 133°32'E	0840	Drift log and YF.	11 YF (20-25 kg.)	No. 58 TOKIWA
12/10/70	02°16'N, 140°14'E	1040	Drift log and YF.	1 YF	Do
12/12/70	05°06'N, 139°33'E	1020	With drifting bamboo; school on fish finder.	1.5 tons of skipjack (3-4 kg.)	Do
12/16/70	09°36'N, 133°59'E	1216	Skipjack with whale shark.	17 tons of skipjack (4-5 kg.)	Do
1/21/71	02°46'N, 138°47'E	1140	Skipjack breezing school.	No catch.	No. 23 TAIKEI
2/3/71	03°43'S, 149°07'E	0615	Small skipjack school.	2 tons of skipjack (2-3 kg.)	Do
2/5/71	03°48'S, 146°19'E	1055	do	1.5 tons of skipjack (3 kg.)	Do
2/9/71	01°41'S, 143°35'E	0800	Skipjack breezing school.	No catch.	Do
2/9/71	01°36'S, 143°35'E	1200	do	No catch.	Do
2/10/71	02°00'S, 142°25'E	1610	Small school skipjack with bird flock.	1 ton skipjack (2-3 kg.)	Do
2/11/71	02°07'S, 142°21'E	0805	"Boiling" skipjack school with bird flock.	No catch.	Do
2/12/71	02°00'S, 141°35'E	1330	Small breezing school of skipjack.	No catch.	Do
2/13/71	02°31'S, 142°28'E	1505	Small breezing SJ school with birds.	5 tons of SJ (2-3 kg.)	Do
3/5/71	03°12'N, 139°15'E	0525	Drift log, small school.	1 ton of YF (10-15 kg.)	Do
3/7/71	03°38'N, 135°20'E	1345	Drift log, small school.	0.3 ton of YF (1-1.5 kg.); 0.7 ton rainbow runner.	Do

Table 30.--Continued.

DATE	POSITION	TIME OF DAY	TYPE OF SCHOOL SET ON	CATCHES MADE	VESSEL
3/11/71	06°00'N, 140°00'E	1300	Jumping yellowfin with birds.	No catch	No. 23 TAIKEI
3/11/71	05°54'N, 140°08'E	1745	do	9 YF (40 kg.)	Do
3/12/71	05°38'N, 140°31'E	1715	do	No catch.	Do
3/13/71	05°49'N, 140°36'E	0645	School with drift log.	6 tons YF; 2 tons small YF; 2 tons SJ	Do
3/15/71	05°49'N, 140°10'E	0615	do	1 ton YF; 4 tons small YF; 10 tons SJ	Do
1/25/71	06°46'N, 139°43'E	0947	"Boiling" school of SJ with birds.	8 tons SJ (3 kg.)	No. 58 TOKIWA
2/8/71	00°05'S, 146°47'E	0520	Small school YF with drift log.	1 ton YF (25-30 kg.)	Do
2/23/71	00°11'S, 141°05'E	0545	SJ-YF mixed school with drifting bamboo.	1.5 ton YF (2-3 kg.); 1.5 ton SJ (3-4 kg.)	Do
3/13/71	05°56'N, 140°24'E	0532	do	18 tons SJ (3-4 kg.); 2 tons YF (10-20 kg.)	Do
3/13/71	05°50'N, 140°28'E	1328	Jumping YF school.	No catch.	Do
3/15/71	06°10'N, 140°05'E	0512	SJ-YF mixed school with drift log.	2 tons SJ (3-4 kg.); 6 tons YF (3-20 kg.)	Do

1/ The Government (Japan Fisheries Agency) chartered the two purse seiners to conduct experimental purse seining in tropical waters. The specifications on the vessels and on the nets used by the two vessels are as follows:

	No. 23 Taikei Maru (210 tons)	No. 58 Tokiwa Maru (358 tons)
Length	34.0 m	43.7 m
Width	7.8 m	9.0 m
Speed	10 knots	10.5 knots
No. in crew	16	21
Purse seine depth	240 m	300 m
Bunt	150 m long	150 m long
Main body	1,395 m long	1,305 m long

(At completion of charter, the vessels apparently began commercial seining in same general areas and results appear to be rather encouraging (--personal communication).

For three cruises, then, Fukuichi Maru set on 53 schools associated with drifting objects and caught 185 ST (168 MT) of yellowfin tuna, 353 ST (320 MT) of skipjack tuna, and 13 ST (12 MT) of miscellaneous species.

Because of the success of Japanese seiners in setting around skipjack tuna and yellowfin tuna schools that are associated with drifting objects, Japanese researchers have initiated studies on the possibility of aggregating tuna under artificial drifting objects (Otsu, in press). Preliminary results have already indicated that there is some merit in this approach.

At present, Japanese fishermen consider purse seining to be commercially feasible and several commercial seiners are operating in the western Pacific and in the Coral Sea (Otsu, in press). Overall, the catches are averaging 11 ST (10 MT) per set and about 80% of the sets are successful in catching tuna. Compared to United States seiners in the eastern tropical tuna fishery, Japanese seiners are considerably smaller, varying from 250 to 500 GT, and average smaller catches per set. The Japanese fishermen believe that they can achieve success under the following conditions:

1. Schools must be associated with drifting objects (driftwood, etc.).

2. Sets must be made either early in the morning or at dusk.

3. Nets must be larger than those used in the eastern Pacific.

When a school is found associated with a drifting object, a seiner may often follow it until dusk or early morning (Otsu, in press). Marking the drifting object with a radio buoy or lights, the seiner may track a school overnight and set on it in the early morning.

Table 31 gives the dimensions of the nets used by Japanese tuna purse seiners.

Japanese Longline Fishery Development

Longline fishing for subsurface tunas in the western Pacific was reestablished by the Japanese after the end of World War II in the area authorized for Japanese fishing by the Supreme Commander for the Allied Powers (SCAP) on 22 June 1946 (Figure 61). On 11 May 1950, roughly 4-1/2 years after the war, a new phase of the Japanese tuna longline fisheries was launched when the Commander-in-Chief, U.S.

Table 31.--Dimension of nets used by Japanese purse seiners operating in the western equatorial Pacific Ocean (Otsu, in press).

Vessel	Area used	Size of net
Nippon Maru	Eastern Pacific and West Africa (U.S.-type seiner)	110 m deep x 1,025 m long or 118 m deep x 1,350 m long
Hayabusa Maru	North of Papua New Guinea	220 m deep x 1,600 m long
No. 58 Tokiwa Maru	North of Papua New Guinea	250 m deep x 1,960 m long
No. 55 Hakuryu Maru	Japan coastal waters for skipjack and yellowfin tunas	150 m deep x 1,500 m long or 220 m deep x 1,500 m long
Wakaba Maru	do.	220 m deep x 1,500 m long
No. 23 Taikei Maru	do.	200 m deep x 1,500 m long
No. 28 Kohoku Maru	do.	261 m deep x 2,025 m long
No. 85 Seishin Maru (two-boat seining)	do.	350 m deep x 1,700 m long
No. 7 Konpira Maru (two-boat seining)	do.	240 m deep x 2,400 m long

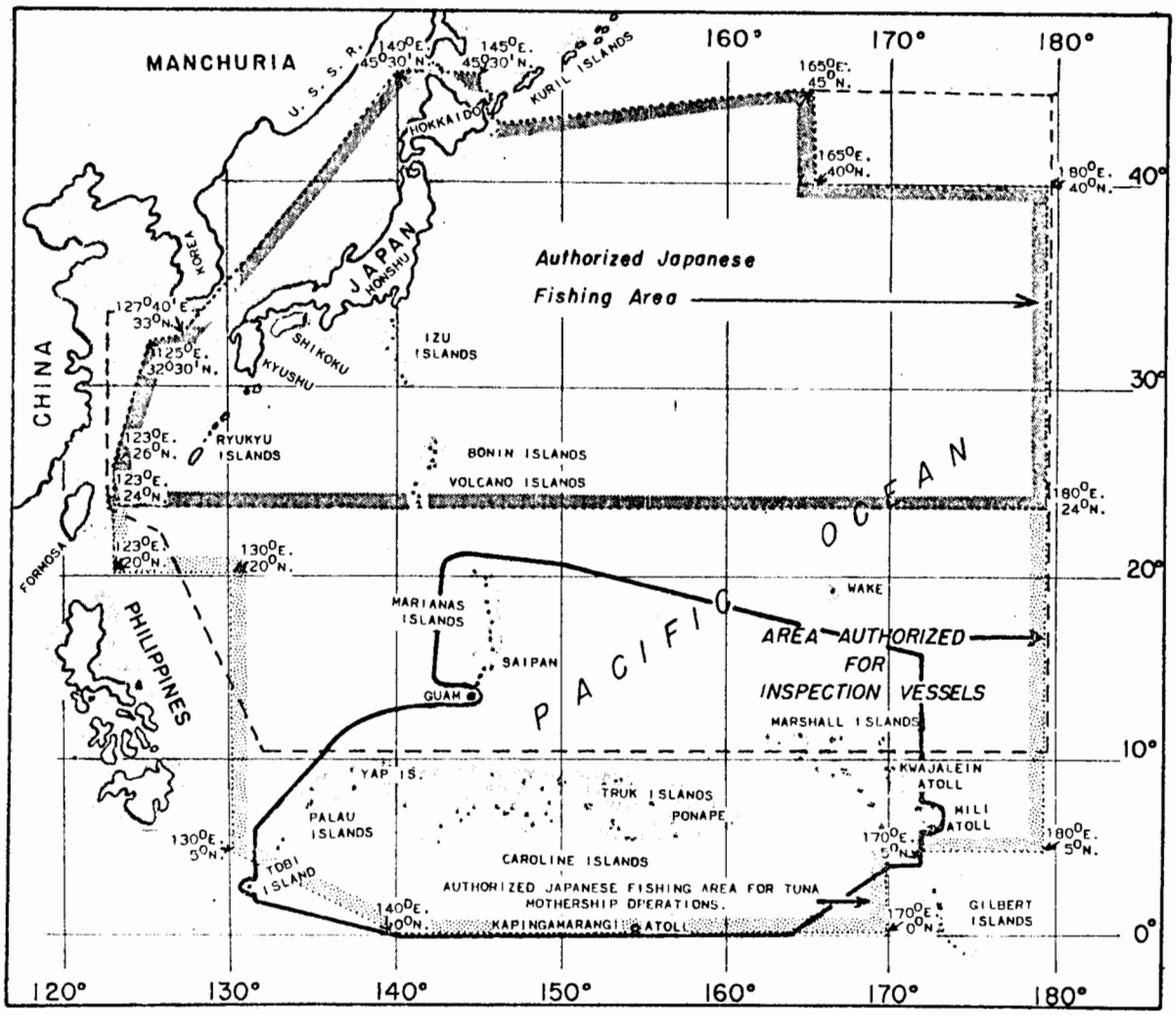


Figure 61.--Horizontally lined border indicates extent of the CINCPAC-SCAP authorized Japanese fishing area as of 11 May 1950. Broken black line indicates area authorized for Japanese inspection vessels. Dotted-stippled border shows extension south of lat. 24°N to the equator for Japanese tuna mother ship operations. Solid black line around Mariana, Marshall, and Caroline Islands shows the U.S. Trust Territory of the Pacific Islands (Shimada, 1951).

Pacific Fleet (CINCPAC) and SCAP permitted the Japanese to send tuna mother ship expeditions to defined areas of the high seas adjacent to the Carolines, Marianas, and Marshalls (Shimada, 1951).

Figure 61 shows not only the original area authorized by SCAP, but also the area authorized for inspection vessels and that designated for mother ship operations. The first mother ship fleet, consisting of a large refrigerated carrier and 25 longline vessels, was outfitted in Japan and began fishing on 17 June 1950 (Shimada, 1951). The general area of operation in Trust Territory waters is shown in Figure 62.

The total catch in 79 days of operation in waters south of the Carolines (between 17 June and 5 September) reached 8,118,834 lb (3,683 MT) (Shimada, 1951). Table 32, which shows the catch by species, indicates that among the subsurface tunas in Trust Territory waters, the yellowfin tuna was by far the most abundant, comprising 50% of all the fish landed. Next in importance was the bigeye tuna. Albacore, bluefin, and skipjack tunas comprised only a small percentage of the catch.

Shimada (1951) noted that the catcher boats attached to the expedition experienced catches that fluctuated widely. The average catch per vessel, shown in Figure 63, was high when operations first commenced but fell to about 2.2-2.8 ST (2.0-2.5 MT) per vessel per day as the peak fishing season in May-June passed. The expedition moved eastward and found new productive grounds. In mid-July, the vessels had several days of good fishing in waters adjacent to Kapingamarangi near lat. 1°-2°N between long. 153° and 154°E. In late July and early August, some of the best fishing was encountered near Kapingamarangi. Based on current drifts, Shimada believed that the zone of good fishing was probably within the Equatorial Countercurrent and close to its southern border. In late August, catches fell to lower levels at the close of the season and as the expedition shifted northward out of the productive area.

Catch rates, according to Shimada (1951), were 3.23 tunas and spearfishes per 100 hooks and 3.85 fish for all species. In contrast, Nakamura (1943) reported an average of 6.05 fish per 100 hooks from Trust Territory waters in prewar years. According to the fishermen, changes in hydrographic conditions were probably most responsible for the lower catches made by the expedition.

After the initial tuna mother ship operation and until October 1951, eight others took place (Murphy and Otsu, 1954). General observations on the methods, catch, and area fished during these expeditions have been published in Ego and Otsu (1952) and Van Campen (1952). Table 33 shows the size, operating area, and period

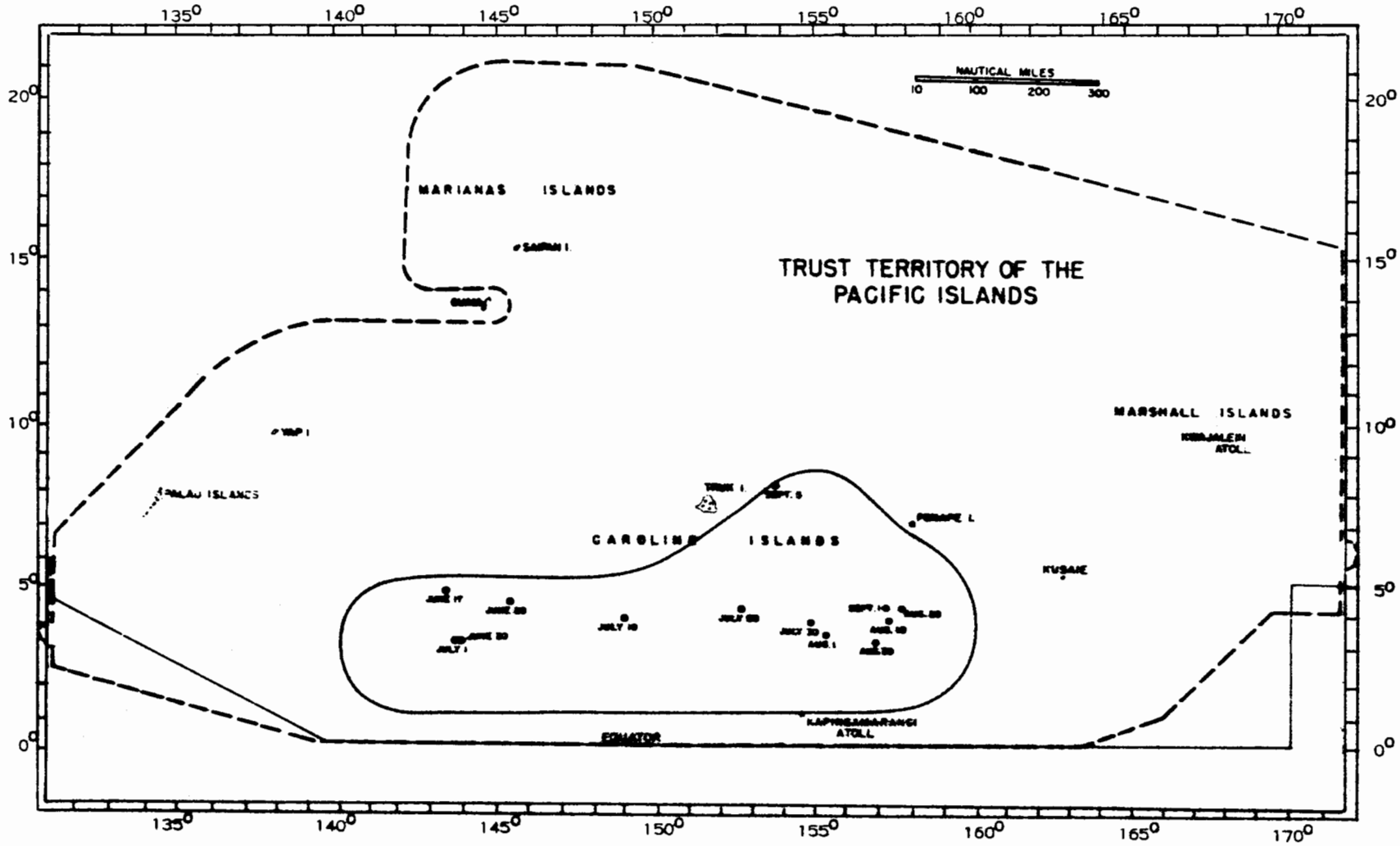


Figure 62.--General area of operations (solid black line) in waters surrounding Trust Territory of the Pacific Islands (dotted line) of the first Japanese tuna mother ship expedition. Dated positions are those of the mother ship during the season, from 17 June to 5 September 1950 (Shimada, 1951).

Table 32.--Total catch, by species, of the first Japanese tuna mother ship expedition, June-September 1950 (Shimada, 1951).

Species	Quantity Caught
	Lbs.
Yellowfin tuna (Neothunnus macropterus)	4,574,358
Big-eyed tuna (Parathunnus sibi)	699,014
Albacore (Thunnus germo)	65,378
Bluefin tuna (Thunnus orientalis)	3,430
Skipjack (Katsuwonus pelamis)	6,968
Black marlin (Makaira mazara)	1,760,389
White marlin (Makaira marlina)	48,182
Striped marlin (Makaira mitsukurii)	1,229
Sailfish[2] (Istiophorus orientalis)	28,160
Swordfish (Xiphias gladius)	13,656
Shark	895,022
Others[3]	23,048
Total	8,118,834

1/ STATISTICS PROVIDED BY THE JAPANESE FISHERY AGENCY AND CONVERTED TO POUNDS, USING THE CONVERSION FACTOR OF 8.27 LBS. = 1 KAN.
2/ INCLUDES SHORT-NOSED MARLIN (TETRAPTURUS BREVIROSTRIS).
3/ INCLUDES BARRACUDA (SPHYRAENA ARGENTEA), WAHOO (ACANTHOCYBIUM SOLANDRI), AND DOLPHIN (CORYPHAENA HIPPURUS).

Table 33.--Size, operating area, and period of the Japanese tuna mother ship expeditions in the western equatorial Pacific Ocean (June 1950-June 1951) (Ego and Otsu, 1952).

Expedition	Motherships		No. Catcher Vessels	Area Fished	Period Fished
	Name	Gross Tonnage (Metric tons)			
I	Tenyo Maru No. 2	10,619	25	1°-9°N. lat.; 140°-157°E. long.	June 17, 1950 - September 5, 1950
II	Kaiko Maru	2,940	13	1°-7°N. lat.; 157°-169°E. long.	July 20, 1950 - September 30, 1950
III	Tenryu Maru	577	6	1°-5°N. lat.; 134°-141°E. long.	December 1, 1950 - December 26, 1950
IV	Tenryu Maru Tosui Maru	577 362	11	1°-6°N. lat.; 156°-161°30'E. long.	February 1, 1951 - February 24, 1951
V	Tenyo Maru No. 3 Banshu Maru No. 35	3,689 999	16	1°-6°N. lat.; 137°-165°E. long.	March 21, 1951 - June 13, 1951
VI	Tenryu Maru Tosui Maru	577 362	8	1°-6°N. lat.; 157°-163°E. long.	April 22, 1951 - May 25, 1951

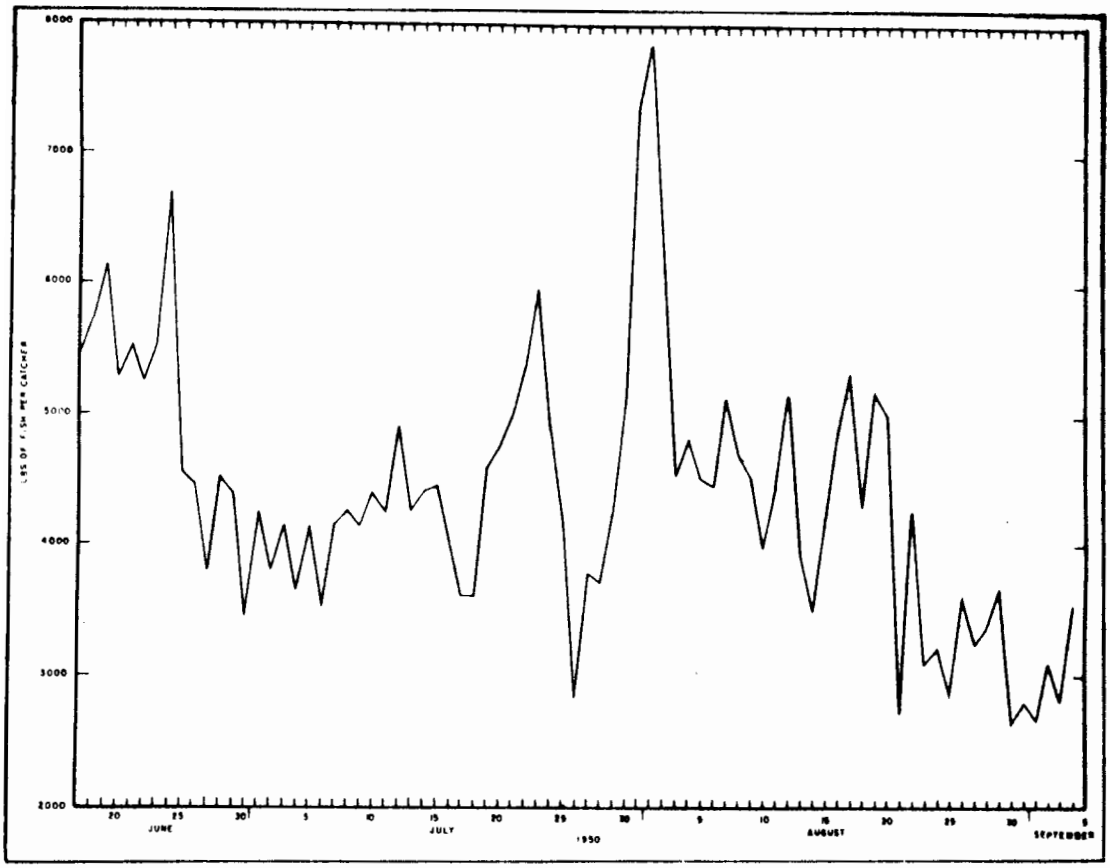


Figure 63.--Average catch of fish per day per catcher based on daily reported landings (Shimada, 1951).

of fishing of the six tuna mother ship expeditions between June 1950 and June 1951. Ego and Otsu (1952) published data from six expeditions and these are given in Table 34. Table 35 shows that the catch rates among the six expeditions did not vary by much. The first expedition achieved the lowest catch rate for all species with 3.85/100 hooks whereas the third recorded the highest of 4.76/100 hooks (Ego and Otsu, 1952). Van Campen (1952), reporting on three subsequent expeditions, found catch rates of 4.47 in the seventh, 4.04 in the eighth, and 3.55 in the ninth (Table 36). The overall average of all species for the nine expeditions was 4.10/100 hooks (Table 37).

Murphy and Otsu (1954) analyzed the catches of the nine tuna mother ship expeditions and the results indicated that yellowfin tuna were most abundant between the equator and lat. 4°N whereas the abundance of bigeye tuna and black marlin appeared to increase north of lat. 4°N. Examination of temperature sections revealed no signs of upwelling as contrasted with the central Pacific; however, the relative distribution of yellowfin tuna latitudinally in the western Pacific was similar to that in the central Pacific. On the other hand, the absolute level of the population of yellowfin tuna was higher in the central Pacific in 1951 than in the western Pacific in 1950-51.

The similarity in the relative latitudinal distribution of yellowfin tuna in the central and western Pacific suggested a possible conflict with the upwelling-plankton-forage tuna cycle proposed for the central Pacific by Murphy and Shomura (1953). Murphy and Otsu (1954), however, suggested that this conflict may not be real and that there may be upwelling in the western Pacific during some months and during some years as suggested by Mao and Yoshida (1955). An integration of average conditions rather than the momentary ecological situation measured by hydrographical and biological data may also be responsible for the distribution pattern of yellowfin tuna. Murphy and Otsu also suggested the possibility that peculiar ecological conditions near the equator favor yellowfin tuna at the expense of other fishes with or without upwelling. Slight or occasional upwelling superimposed on this background may have permitted the expansion of the yellowfin tuna population.

Nakamura (1951) dealt with fishing conditions for subsurface tunas and spearfishes in waters of the former mandated islands in considerable detail. Among his findings was that there were conspicuous differences in fishing conditions in different parts of this region. Table 38 shows that in the area south of lat. 5°N, which comes under the influence of the Equatorial Countercurrent, yellowfin tuna were distributed very densely, whereas north of lat. 5°N or in the region of the North Equatorial Current, their density fell off very sharply. Nakamura concluded that this region has superior grounds for longline fishing. Changes in fishing conditions accompanied changes in season, but these changes were comparatively slight, indicating generally stabilized fishing grounds.

Table 34.--Japanese tuna mother ship expeditions, catches and average weights (in pounds), by species (Ego and Otsu, 1952).

Species	EXPEDITIONS											
	First		Second		Third		Fourth		Fifth		Sixth	
	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.	Total	Avg.
Yellowfin tuna	4,572,698	75	3,246,486	101	395,889	67	805,609	78	2,362,692	74	710,739	75
Big-eyed tuna	698,761	80	396,913	98	58,279	90	138,979	96	863,066	86	158,597	98
Albacore	65,355	45	24,223	48	8,027	42	10,015	46	11,706	48	888	36
Black tuna	3,428	343	-	-	-	-	-	-	727	364	-	-
Skipjack tuna	6,966	8	16,671	12	1,234	9	502	7	835	10	2,540	7
Black marlin	1,759,751	131	1,447,517	149	72,609	117	295,098	132	658,987	131	211,412	125
White marlin	48,164	171	2,486	166	5,493	172	7,966	150	20,932	146	2,273	126
Sailfish[1/]	28,150	44	11,901	32	3,156	40	8,605	37	35,002	37	10,818	39
Swordfish	13,651	76	6,308	91	3,656	58	2,363	98	11,640	85	3,576	102
Striped marlin	1,228	123	1,605	123	190	80	231	116	521	87	370	123
Sharks	894,698	56	402,518	72	37,025	94	28,917	73	385,738	66	41,746	69
Others[2/]	23,045	28	21,298	29	4,095	18	12,234	23	23,396	19	16,604	23
Total	8,115,895		5,577,926		589,653		1,310,519		4,375,244		1,159,563	

1/ INCLUDES SHORT-NOSED SPEARFISH (TETRAPTERUS BREVIROSTRIS).
2/ INCLUDES MISCELLANEOUS SPECIES, SUCH AS WAHOO, DOLPHIN, AND BARRACUDA.

Table 35.--Catch rates of Japanese tuna mother ship expeditions (Ego and Otsu, 1952).

Species	NUMBER OF FISH CAUGHT PER 100 HOOKS PER DAY FISHED					
	EXPEDITION					
	First	Second	Third	Fourth	Fifth	Sixth
Yellowfin tuna	2.28	2.50	3.38	2.71	2.24	2.49
Big-eyed tuna	0.33	0.32	0.37	0.38	0.70	0.43
Albacore	0.05	0.04	0.11	0.06	0.02	<0.01
Black tuna	<0.01	-	-	-	<0.01	-
Skipjack tuna	0.03	0.11	0.08	0.02	<0.01	0.09
Black marlin	0.50	0.76	0.36	0.59	0.35	0.45
White marlin	0.01	0.01	0.02	0.01	0.01	<0.01
Sailfish and Shortnosed spearfish	0.02	0.03	0.04	0.06	0.07	0.07
Broadbill swordfish	<0.01	0.01	0.04	0.01	0.01	<0.01
Striped marlin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Sharks	0.60	0.44	0.23	0.10	0.41	0.16
Others	0.03	0.06	0.13	0.14	0.08	0.19
Tunas and marlins	3.23	3.77	4.40	3.84	3.40	3.55
Total	3.85	4.27	4.76	4.08	3.89	3.89

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Table 36.--Essential data on the seventh, eighth, and ninth Japanese tuna mother ship expeditions (Van Campen, 1952).

	EXPEDITION		
	Seventh	Eighth	Ninth
Managing concern	Nippon Suisan K. K.	Taiyo Gyogyo K. K.	Nansei Suisan K. K.
Mothership	Settsu Maru (9,329 tons)	Tenyo Maru No. 2 (10,620 tons)	Tenryu Maru (577 tons)
Number of catchers	26 (and 2 boats)	25 (and 1 boat)	3 (and 2 boats)
Left port	May 31, 1951	July 30, 1951	September 3, 1951
Returned to port	September 5, 1951	November 4, 1951	November 1, 1951
Fishing began	June 5, 1951	August 2, 1951	September 17, 1951
Fishing ended	August 26, 1951	October 24, 1951	October 20, 1951
Area fished	1° - 13° N. lat. 153° - 179° E. long.	1° - 13° N. lat. 151° - 179° E. long.	1° - 10° N. lat. 162° - 179° E. long.
Tuna catch	6,228,286 lbs.	4,348,407 lbs.	326,276 lbs.
Spearfish catch	2,149,787 lbs.	1,526,229 lbs.	173,042 lbs.
Sharks and miscellaneous	854,341 lbs.	1,173,497 lbs.	23,404 lbs.
Total catch	9,232,414 lbs.	7,048,133 lbs.	522,722 lbs.
Total boat/days fished	1,312	1,219	126
Average catch rate (fish per 100 hooks per day)	4.47	4.04	3.55

Table 37.--Catch rates by the seventh, eighth, and ninth Japanese tuna mother ship expeditions (Van Campen, 1952).

Species	Number of Fish Caught Per 100 Hooks Per Day Fished			
	Expedition			Average For Expeditions 1 Through 9
	7th	8th	9th	
Yellowfin tuna ..	2.09	1.64	1.40	2.14
Big-eyed tuna ...	0.93	0.80	0.88	0.62
Albacore	0.06	0.16	0.10	0.07
Black tuna	<0.01	<0.01	<0.01	<0.01
Skipjack tuna ...	0.07	0.06	0.08	0.05
Black marlin	0.60	0.48	0.75	0.53
White marlin	<0.01	<0.01	<0.01	<0.01
Sailfish and short-nosed spearfish	0.04	0.04	0.03	0.04
Broadbill swordfish	<0.01	<0.01	<0.01	<0.01
Striped marlin ..	<0.01	<0.01	<0.01	<0.01
Sharks	0.57	0.75	0.14	0.54
Others	0.09	0.10	0.16	0.08
Total	4.47	4.04	3.55	4.10

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Table 38.--Comparison of fishing conditions on either side of lat. 5°N (Nakamura, 1951).

Area	Number of hooks	Yellowfin		Bigeye		Spearfishes		Total	
		Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate	Number of fish	Catch rate
0° - 5° N.	417,851	16,706	3.99	2,059	0.49	2,928	0.70	21,819	5.22
5° -10° N.	229,838	5,022	2.19	1,226	0.53	1,824	0.79	8,088	3.52

Note: Longitude is not taken into consideration in this table.

Table 39.--Catches, in thousand metric tons, of spearfishes and tunas from the western central Pacific Ocean (D. W. Hagborg, FAO, Rome, pers. commun.)

	1966	1967	1968	1969	1970	1971	1972
Pacific striped marlin	1.9	1.7	1.2	0.9	1.3	0.7	0.8
Indo-Pacific sailfish	1.2	1.4	0.4	0.3	0.3	0.5	0.6
Black/Indo-Pacific blue marlin	6.3	4.5	4.1	3.8	4.5	4.5	4.6
Broadbill swordfish	0.9	1.0	2.3	1.8	1.4	0.9	0.6
Bluefin tuna	1.0	0.5	0.5	0.3	0.2	0.0	0.0
Yellowfin tuna	37.8	21.0	20.4	22.1	19.3	24.7	23.8
Albacore	14.3	9.2	7.8	5.8	8.9	1.6	2.1
Bigeye tuna	17.0	16.3	12.4	12.9	12.4	11.5	19.6

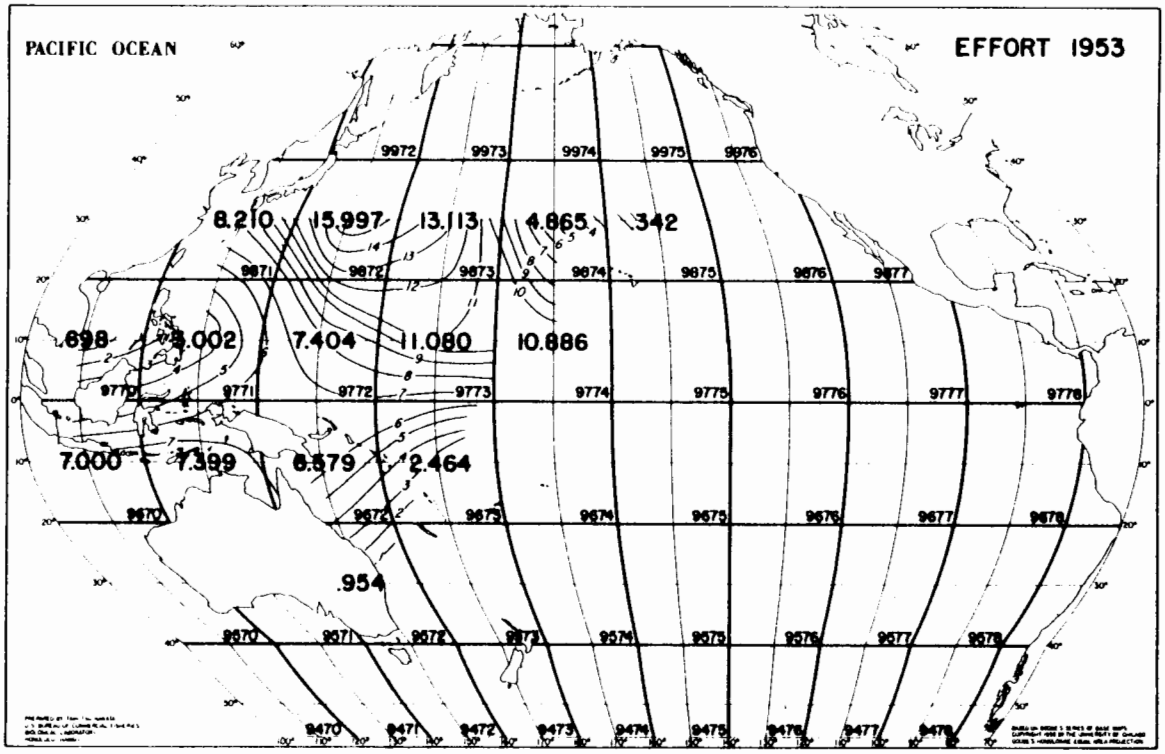
The subsequent development of the longline fishing grounds not only in the western central Pacific but also in the central and eastern Pacific resulted from the lifting of restrictions imposed immediately after the war. According to Nippon Suisan Shimbun (1953), the SCAP fishing area, also called the MacArthur Line, severely restricted the operating radius of the Japanese longliners. But on 25 April 1952, the MacArthur Line was removed so that Japanese vessels were no longer restricted. International complications with Korea and Communist China followed and the result was that the Japanese vessels could not operate freely in Korean waters, the East China Sea, and the Yellow Sea. Furthermore, the North Pacific fisheries was also markedly restricted. Thus, the Japanese longliners spread southward into Micronesian waters and the South Pacific, and eastward into the central and eastern Pacific.

The eastward expansion of the Japanese longline fishing effort after 1952 was reported by Rothschild (1966a). He showed that effort tended to be concentrated off Japan in the western Pacific in the early 1950's, tended more toward the central Pacific in the mid-1950's, and was largely concentrated at the longitude of Baja California in the southwestern Pacific by the early 1960's (Figure 64). By latitude, the expansion went from the North Pacific in 1953 to the South Pacific by 1963. Table 39 shows the catches of tunas (except skipjack tuna) and spearfishes from the western central Pacific.

DEVELOPMENTAL POTENTIAL

In a study of the tuna resources of the oceanic regions of the Pacific Ocean, Rothschild and Uchida (1968) found increasing longline effort correlated with changes in apparent abundance, average size, and total catch for the three most important species of tuna--yellowfin tuna, bigeye tuna, and albacore--that are taken on the longline gear. With the exception of the South Pacific albacore, all three species showed declines in apparent abundance and a leveling or stabilization of total catch. They concluded on the basis of this qualitative examination that with the present method of fishing (with respect to gear, the size of fish that the gear selects, and the distribution and intensity of effort) substantial increases in the catches of yellowfin tuna, bigeye tuna, and albacore in the Pacific are unlikely.

Skipjack tuna, on the other hand, has an exploitation status that is different from the other subsurface tunas that are taken commercially (Rothschild and Uchida, 1968). Whereas yellowfin tuna, bigeye tuna, and albacore all show the effects of exploitation, there



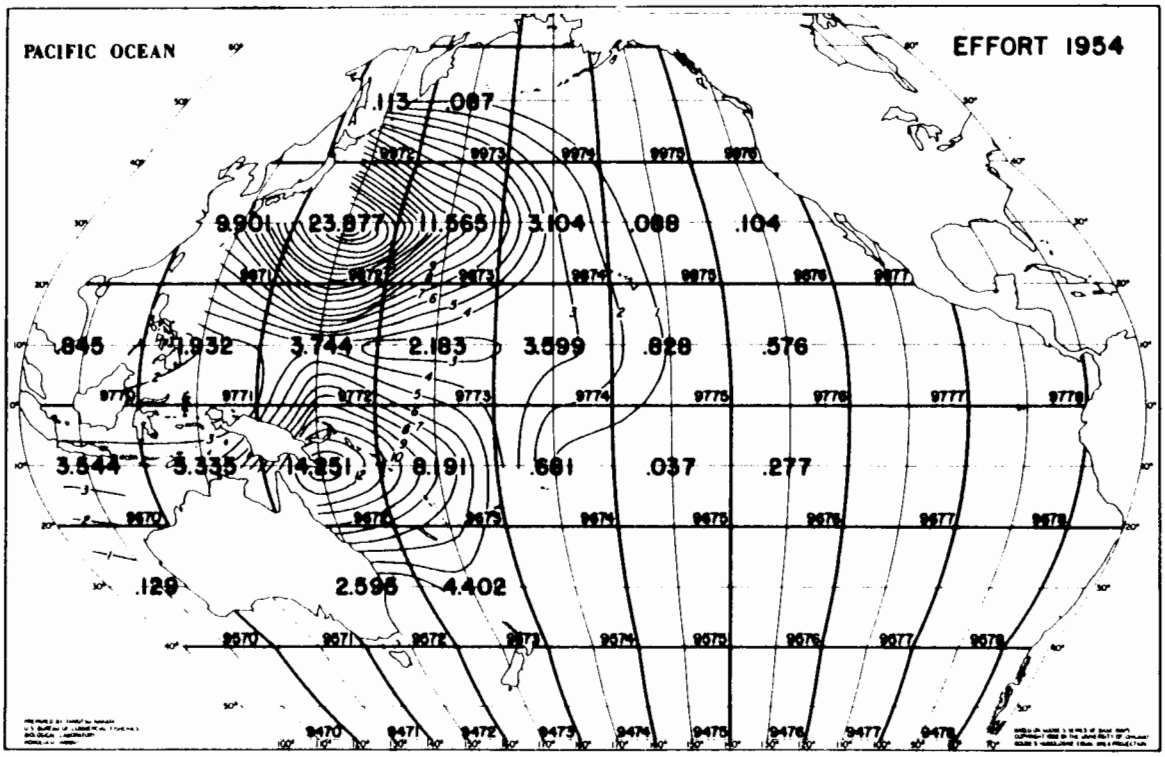
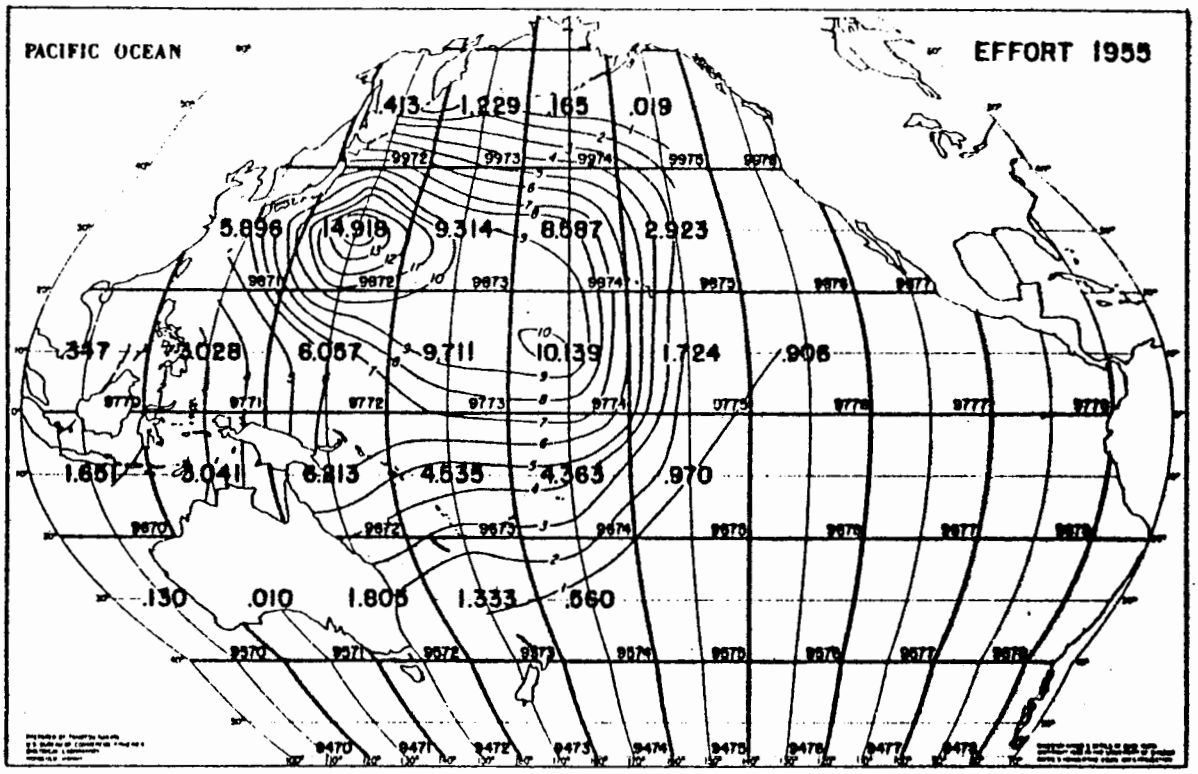
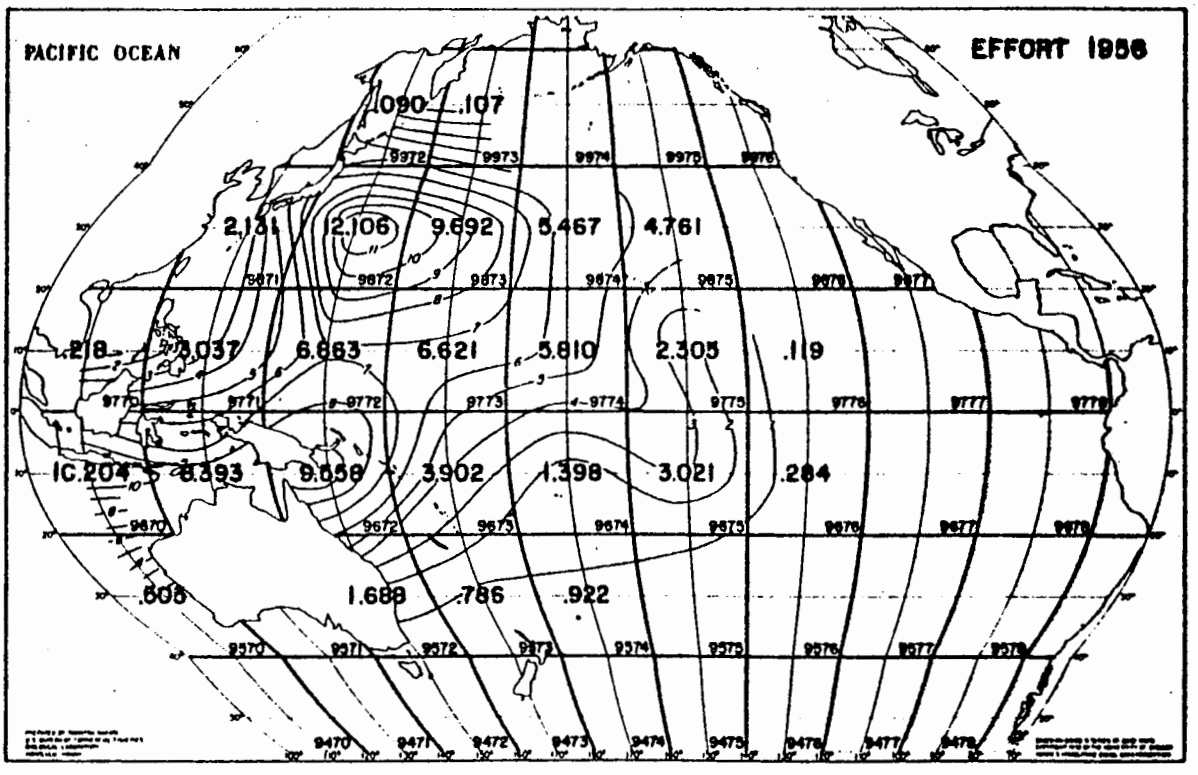


Figure 64.--Percentage of reported total annual effort (numbers of hooks) expended in each 20° quadrangle (Rothschild, 1966a).





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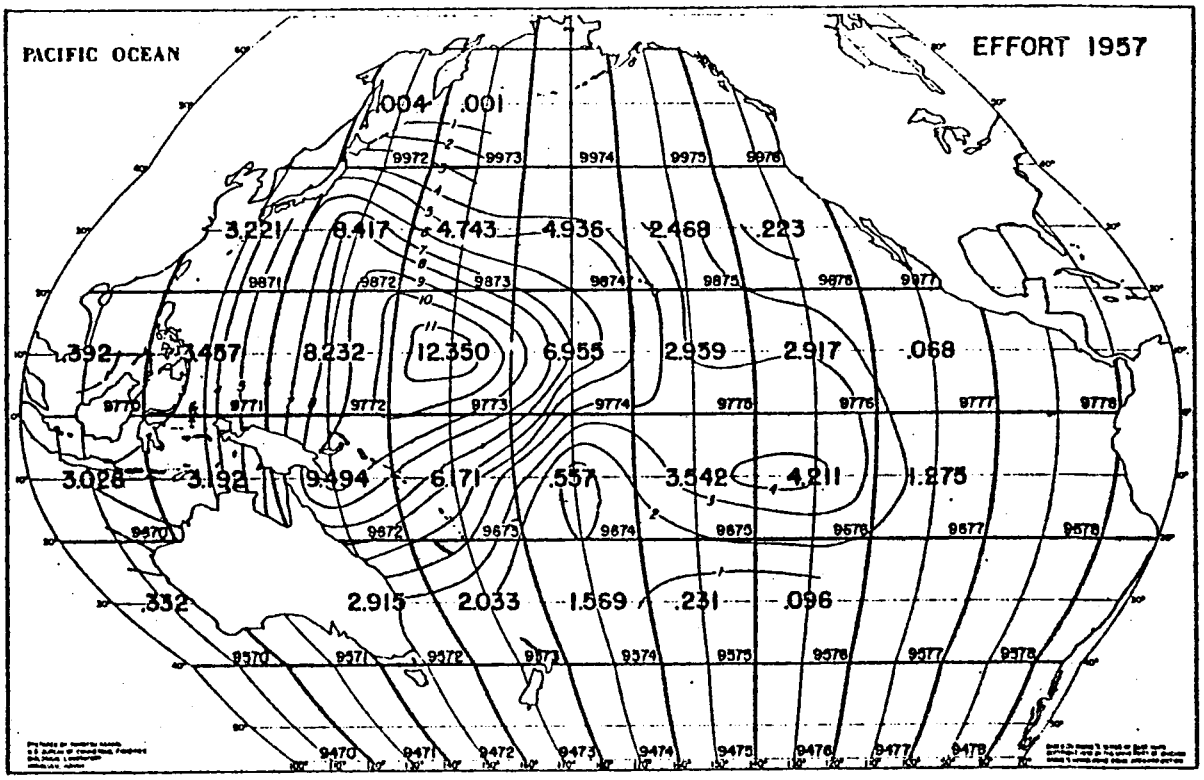

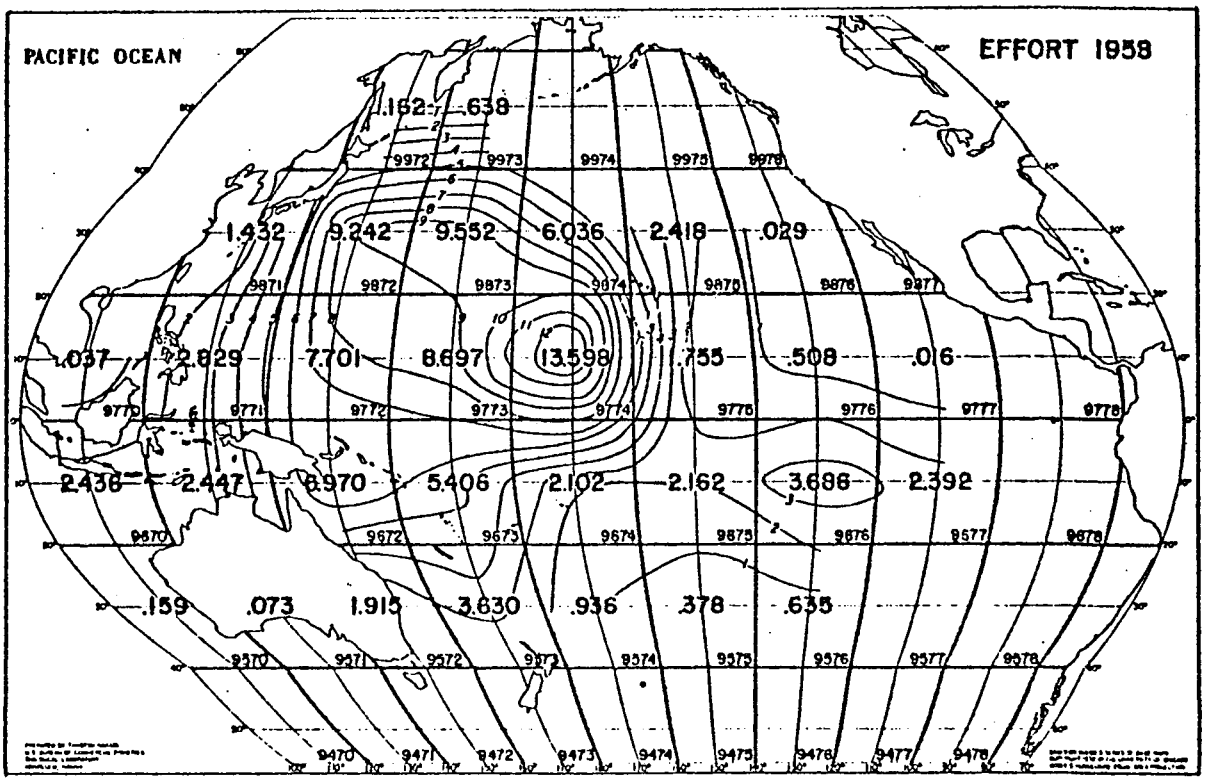

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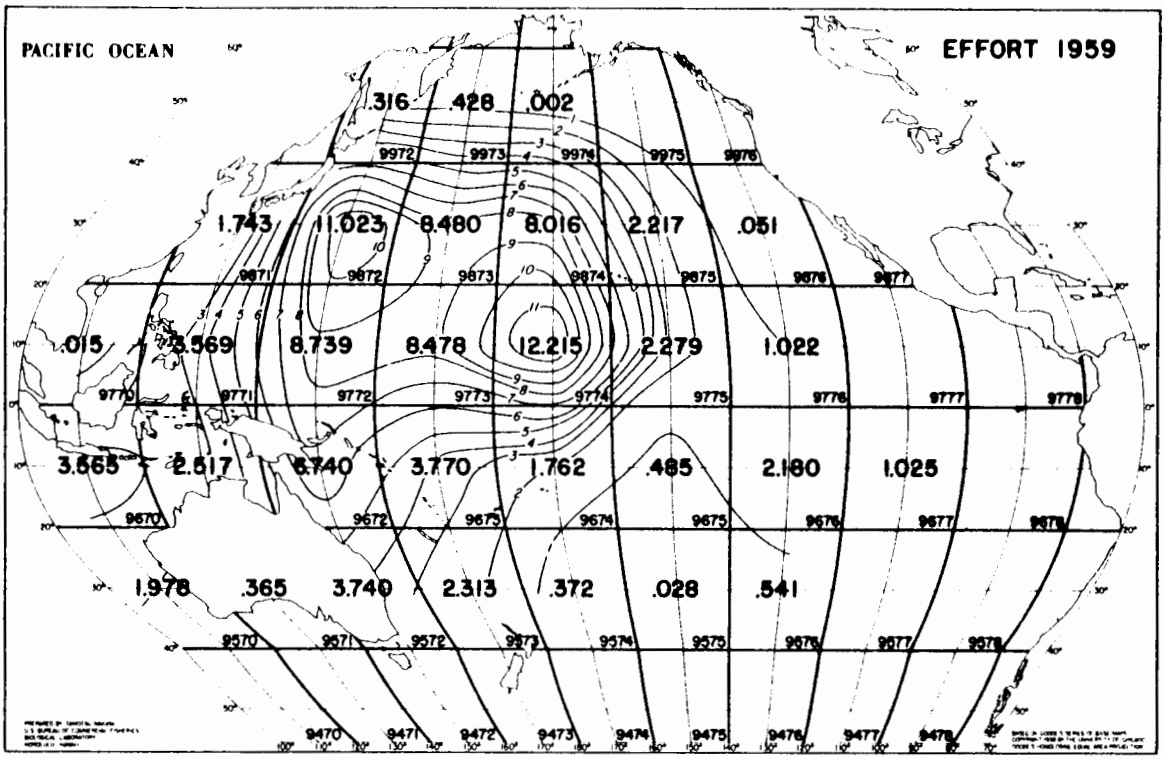

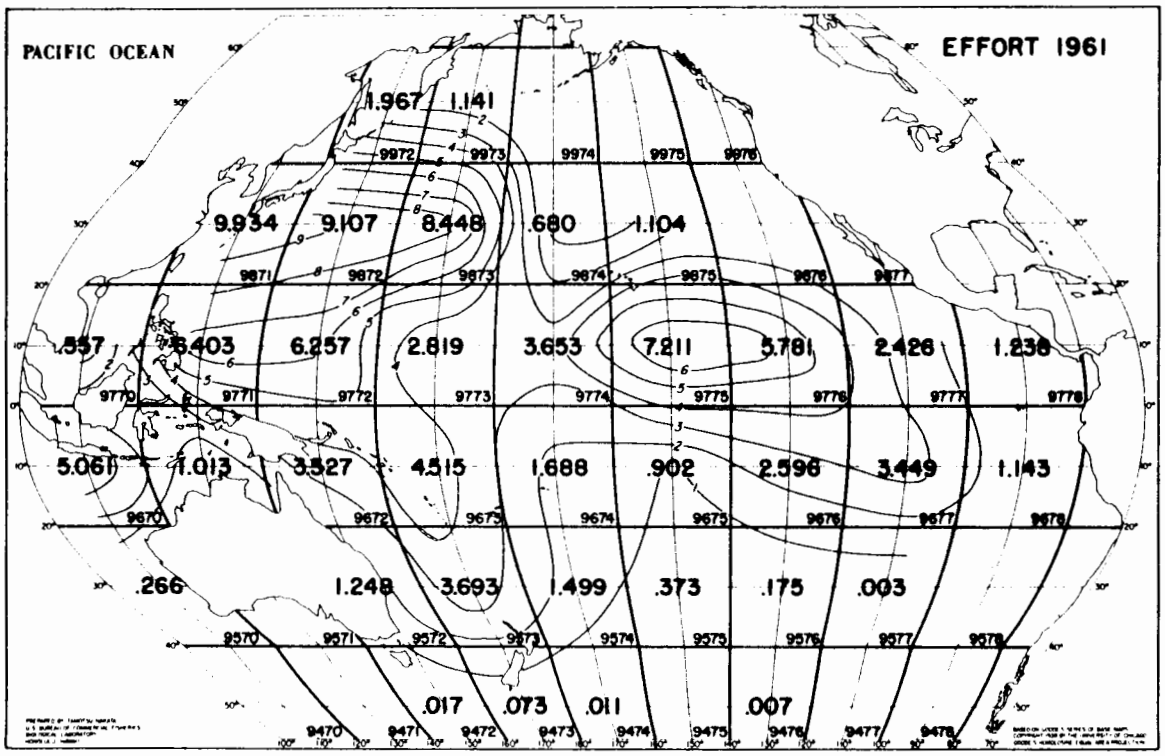

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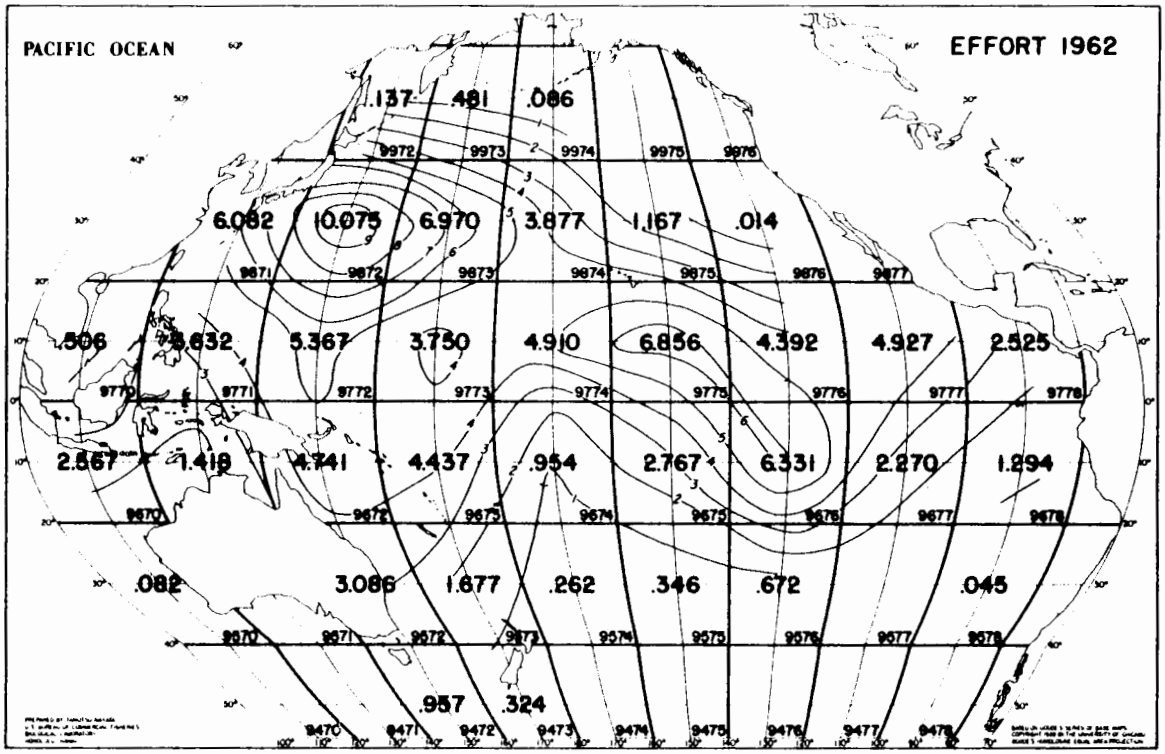

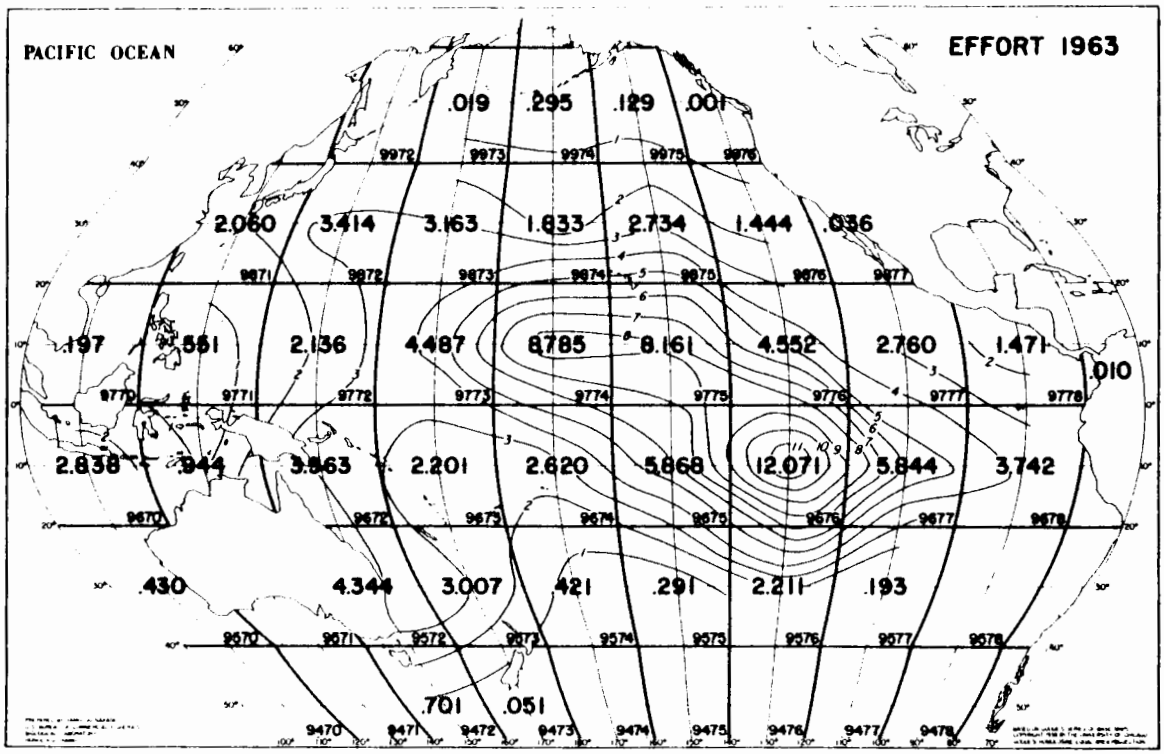

Figure 64.--Continued.

is no evidence in the literature that fishing has had any measurable effect on the stocks. This observation, that there are no observable effects of fishing on the established fisheries in Japan or the coasts of the Americas and that there is sizable potential skipjack tuna yield, has induced the tuna-producing nations to turn to this species for increased production.

The constraints on harvesting skipjack tuna mostly involve our ignorance or uncertainty about their potentials and about more efficient ways of capturing them. We have seen earlier that the major effort in the tremendous expansion of skipjack tuna fishing has come from the Japanese in the western Pacific in waters surrounding the island groups of Micronesia. There is, however, growing interest within the United States tuna fishing industry in the development of resources in areas such as Micronesia.

In developing their southern water fishery, the Japanese have been active not only in research to keep baitfish alive longer, but also in attempting to locate new sources of bait close to the fishing grounds. By 1971, Japanese firms were actively pursuing the establishment of joint skipjack tuna fishing ventures in Micronesia. Two Japanese firms negotiated an agreement with a Trukese businessman and began fishing out of Truk with two pole-and-line vessels in the 20- and 25-GT class accompanied by one mother ship (U.S. NMFS, 1971a). At Ponape, two other Japanese firms jointly negotiated an agreement with the local government and began operations with one mother ship and three 30-ton pole-and-line vessels. Fishing reportedly began in late July 1971. Soon afterwards, a third Japanese firm proposed still another joint venture in Ponape (U.S. NMFS, 1971b). In early 1972, a five-man Japanese team, dispatched by another Japanese firm to survey Ponape's baitfish resources, found the outlook for skipjack tuna fishery development very favorable (U.S. NMFS, 1972). The Ponape District Fishery Corporation agreed to a joint-venture agreement under which four 39-GT skipjack tuna vessels and one 1,000-GT refrigerated mother ship began fishing in June 1972. Future plans also included the construction of a cold storage and processing plant at Ponape.

Bait surveys have also been made on several of the other islands and atolls in the Trust Territory. Wilson (1971) reported on a bait survey of Truk lagoon. Among those species that could be used for live-bait fishing were snapper, Gymnocaesio argenteus; cardinalfish, Rhabdamia cypselurus; sardine, Herklotsichthys punctatus; round herring, Spratelloides delicatulus and S. gracilis; silversides, Allanetta ovalaua and Pranesus pinguis; and damselfish, Pomacentrus pavo. Townsend Cromwell, an NMFS research vessel dispatched from Honolulu, surveyed islands to the south and west of Truk but found no substantial amounts of bait except round herring, S. delicatulus, which, as bait, are weak and do not survive long in baitwells (Hida, 1971). Also observed along the shoreline were small goatfish, mostly Mulloidichthys

samoensis; jack, Caranx spp.; cardinalfish, Apogonidae; bananafish, Caesionidae; silverside, Atherinidae; damselfish, Pomacentridae; and anchovy, Stolephorus indicus.

In the Marshalls, Cromwell surveyed Majuro and Jaluit atolls and found large concentrations of sardines, Herklotsichthys sp. and possibly Sardinella sp. in both areas. An NMFS-chartered fishing vessel, Anela, fishing out of Honolulu, confirmed that there were large concentrations of bait at Majuro and Jaluit (Uchida and Sumida, 1973). Anela exploring the possibility of developing commercial pole-and-line fisheries for skipjack tuna in the Marshalls and American Samoa, found good concentrations of both silverside, P. pinguis, and sardine, H. punctatus. At Majuro, Anela caught 205 buckets in five sets or 41 buckets per set whereas at Jaluit she caught 189 buckets in two sets or 94.5 buckets per set.

Subsequent investigations of bait resources in the Marshalls, however, indicated that distribution and apparent abundance of baitfish such as silversides and sardines varied considerably. Hida and Uchiyama (MS),[3] reporting on the results of quarterly field trips to sample and observe concentrations of baitfish in Majuro lagoon, discovered that from November 1972 through May 1973, there were no signs of any baitfish in the lagoon. In April 1974, reports from an observer aboard a fishing vessel conducting experimental fishing in the Marshalls indicated that silversides and sardines were again present in large concentrations in the lagoon.

Turning to the Western Carolines, there appears to be some doubt that the pole-and-line fleet in Palau could be expanded much beyond 12 vessels. Muller (MS),[2] who studied the population of Stolephorus heterolobus from Palau, concluded that the bait fishery in Palau is operating at the optimum level for the main baiting area. He speculated that if bait catches are at their maximum sustainable level, then the vessels will need to switch from 1-day to multi-day trips in order for the fishery to expand. Fleet size can be doubled without increasing fishing pressure on the bait by baiting every other day. From the industry's standpoint multi-day trips are desirable; lost time due to traveling to and from the baiting and fishing grounds, and baiting time will be reduced whereas fishing time would increase. More conservative use of bait would also help to extend the Palau bait supply.

A 190-GT skipjack tuna vessel, Akitsu Maru No. 20, surveyed waters around Ponape from 5 August to 2 October 1974 (Japan Marine Fishery Resource Research Center, 1975; Otsu, in press). Briefly, the survey showed the following:

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[3]Hida, T. S., and J. H. Uchiyama. Baitfish study in Majuro, Marshall Islands. Draft report distributed for information in connection with Tuna Baitfish Workshop, 4-6 June 1974, Honolulu, HI 96812.

1. Anchovies, 200 buckets of which were loaded aboard the vessel at Tateyama port of Chiba Prefecture, suffered mortalities of about 19% during the outgoing trip from Japan to the Caroline Islands.

2. In waters around Ponape, Akitsu Maru baited 79 times in 45 nights with a stick-held dip net, or an average of 1.8 times per night. Catching a total of 1,056 buckets (6.6 lb or 3 kg per bucket) or an average of 23.5 buckets per night, the vessel caught predominantly "tarekuchi," S. heterolobus (23.5%). Other species included S. indicus, Harengula ovalis, Allanetta forskali, Dussumieria hasseltii, Spratelloides delicatulus, Trachurops mauritianus, Decapterus sp., Caesio pisang, and Siganus sp.

3. Survival rate of "tarekuchi" in the baitwells was very poor with only a few lasting more than 12 h. Among the other species, T. mauritianus and Siganus sp. were the most durable in the baitwells.

4. Near the Bonin Islands, the vessel landed about 8.8 ST (8 MT) in 8 days of fishing or 1.1 ST (1 MT) per day. Fish size varied between 3.7 and 14.1 lb (1.7 and 6.4 kg).

5. Around Ponape, the vessel fished with locally caught bait for 34 days and produced a catch of 37 ST (34 MT) of skipjack tuna and 335 lb (154 kg) of yellowfin tuna. Catch per day was about 1.1 ST (1 MT). Ten percent of the schools sighted were yellowfin tuna. The vessel usually operated within 10-30 mi (18.5-55.6 km) of Ponape because of poor bait survival. The survey also revealed that skipjack tuna schools around Ponape responded actively usually in the morning and late afternoon.

A recent report of baitfish being taken on the high seas has evoked considerable interest within the Japanese tuna fishing industry (Otsu, in press). No. 3 Inari Maru, a 299-GT skipjack tuna fishing vessel, reported capturing 50-60 buckets of "doku-uroko ibodai," Tetragonurus atlanticus, at night at lat. 3°51'N and long. 161°15'E. Using a 500-W lamp, Inari Maru caught the baitfish on the high seas roughly 180 mi (334 km) south of Ponape. With this bait, the vessel caught 11 ST (10 MT) of skipjack tuna. Since then, two other vessels have baited successfully in the same area.

Japanese researchers believe that these coal-black fish inhabit deep water. At a size of about 1.5-2.8 in. (4-7 cm) when captured, the ibodai showed several qualities of a good baitfish; they swam slowly at the surface when chummed, were readily taken by skipjack tuna, and survived at least up to 16 days in the baitwells. The Japanese reported that there is a need to study the abundance, distribution, and seasonality of this species. Not only the bait resource but also methods to improve bait survival have been under

investigation. After capture, baitfish are usually transferred from the net to the baitwells by scoops or buckets. Handling during the transfer is one of the major causes of baitfish mortality. To improve baitfish survival after capture, a naval architect of the Trust Territory Marine Resources Division, after consulting with fishermen and industry personnel, has designed a skipjack tuna pole-and-line fishing vessel around the baitwells (Pacific Islands Monthly, 1974). The unique features of this vessel, which will have a range of 1,500 mi (2,780 km), travel at 9 knots, and carry 14 crew members, are specially designed baitwells that will allow captured live bait to "swim" into them through underwater doors, thus eliminating the need to scoop or bucket the bait.

SIZE OF FISH

The size frequencies of the tunas can be used to detect areal and temporal changes in the fish population and also to describe the segment of the population that a particular fishing gear sampled. But technologically, a fisherman is interested in fish size, because he can use size data to estimate the numbers that need to be captured to achieve a particular tonnage. To a processor, knowledge of fish size provides a means of anticipating problems that may arise in processing fish from a particular area. In this section, all fish lengths reported in the literature have been converted to weight in pounds and kilograms.

BY LONGLINE

Longline samples only the large mature tunas. In the western Pacific, Murphy and Otsu (1954) found that the bigeye tuna landed during the nine mother ship expeditions ranged widely from 3 to 292 lb (1.4 to 132 kg), but almost 90% were within 34 and 173 lb (15 and 78 kg) (Figure 65). Longitudinal differences are apparent in the size of bigeye tuna. Yukinawa (1958) found that larger fish were more commonly taken toward the east (Figure 66) and latitudinally those fish caught in lat. 6°-12°N were slightly larger than those taken further south in lat. 2°S-6°N.

Concerning yellowfin tuna, Murphy and Otsu (1954) found considerable variation from sample to sample, but it did not appear to be related to time or space. Figure 65 shows that yellowfin tuna ranged from 6 to 204 lb (2.7 to 93 kg), but 90% of the fish sampled were within a relatively narrow range between 45 and 124 lb (20 and 56 kg).

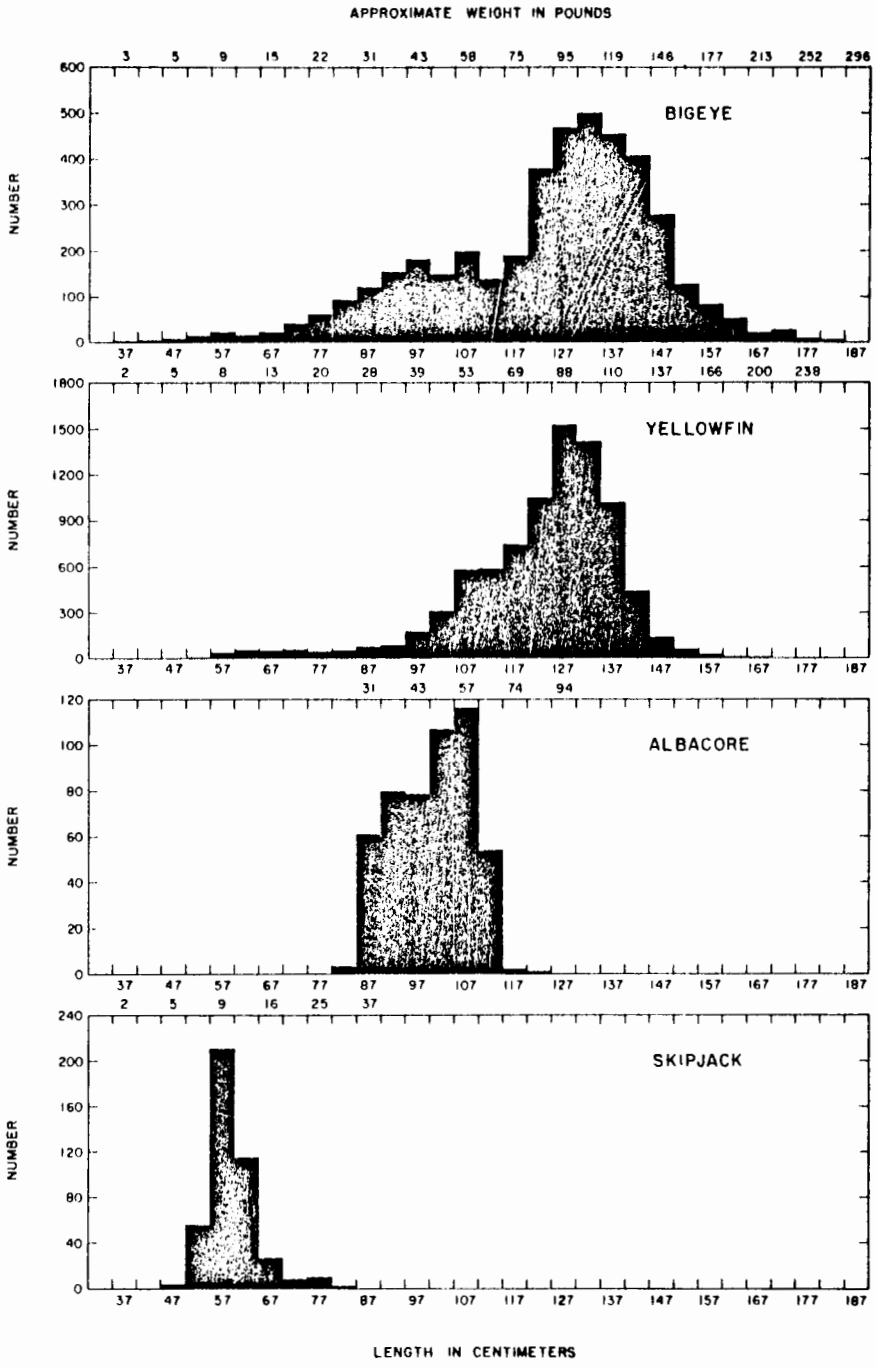

Figure 65.--Length frequencies of the four species of tuna commonly taken during the mother ship operations (Murphy and Otsu, 1954).

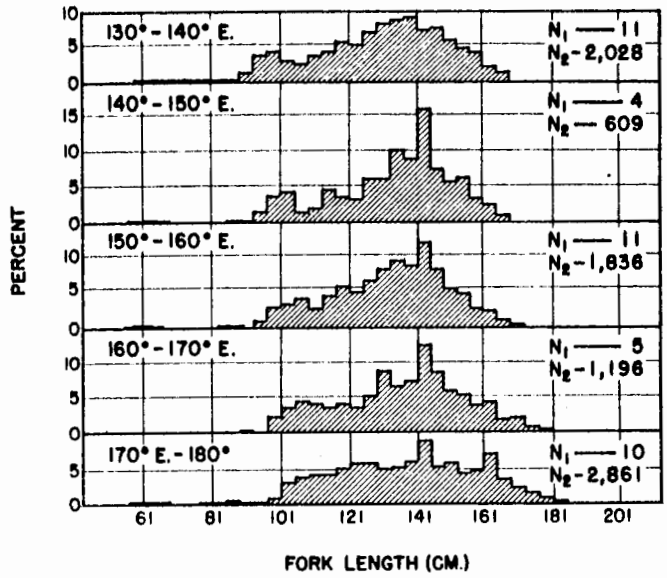

Figure 66.--Length-frequency distribution of bigeye tuna caught by Japanese longlines in 1954, for every 10° of longitude from 130°E to 180° along lat. 6°-12°N. N_1 is the number of samples and N_2 is the total number of fish (adapted from Yukinawa, 1958).

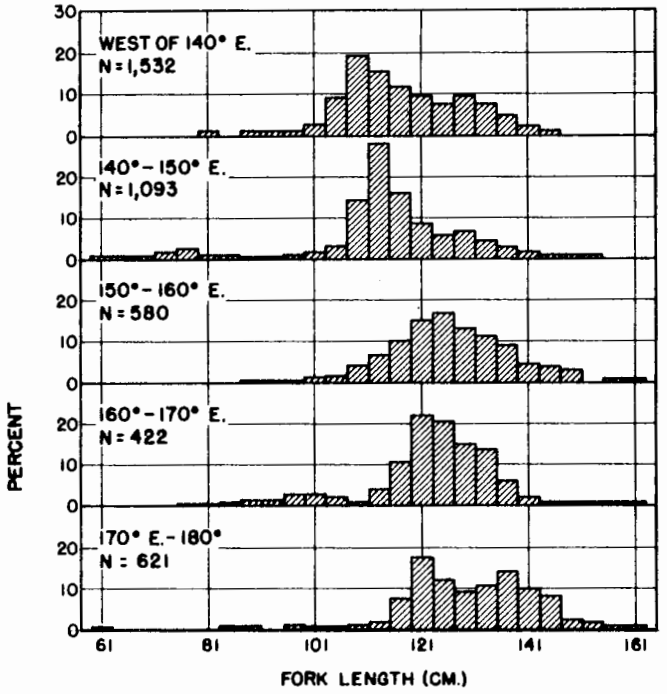

Figure 67.--Length-frequency distribution of yellowfin tuna taken by Japanese longlines, for every 10° of longitude from west of 140°E to 180° between lat. 2° and 8°N. Data for long. 160°-170°E were collected from October 1953 to March 1954 (based on Yabuta and Yukinawa, 1958).

Yabuta and Yukinawa (1958), who sampled longline-caught yellowfin tuna taken in waters of the Eastern Caroline Islands, reported that in the area bounded by lat. 12°N and 4°S between long. 150° and 170°E, size did not vary significantly from one current system to another (Figure 67). There was, however, a longitudinal gradient; the major modal group of fish taken west of long. 140°E was 55 lb (25 kg) compared to 112 lb (51 kg) for fish taken east of long. 180°.

Figure 65 also shows that albacore varied from 27 to 86 lb (12 to 39 kg) but the bulk of the catch consisted of fish from 29 to 63 lb (13 to 29 kg) (Murphy and Otsu, 1954). These fish are much larger than those taken by surface trolling off San Pedro, California where size usually varies between 10 and 35 lb (4.5 and 16 kg) (Brock, 1943). The skipjack tuna, according to Figure 65, varied from 5 to 30 lb (2.3 to 14 kg).

BY POLE AND LINE

The sizes of skipjack tuna taken by pole-and-line fishing have been well documented in several publications. The annual "Atlas of skipjack tuna fishing grounds in southern waters," published by the Tohoku Regional Fisheries Research Laboratory (undated a, b, c, d, e), gives a good description of the monthly changes in size composition of the fish caught by Japanese vessels in the western Pacific.

Briefly, the data from Tohoku Regional Fisheries Research Laboratory show that there are significant differences in skipjack tuna size in the various fishing grounds within the waters of Micronesia. For example, during the 1970 season, the Japanese skipjack tuna vessels encountered 7.7- to 9.2-lb (3.5- to 4.2-kg) fish at lat. 7°-9°N, 6.8- to 7.7-lb (3.1- to 3.5-kg) fish in lat. 3°-5°N, and 5.6- to 6.0-lb (2.5- to 2.7-kg) fish between lat. 2°N and 1°S (Figure 68). Thus, fish were usually smaller toward the equator and this size differentiation by latitude can be detected in size samples collected each year. Furthermore, in 1971, it became apparent that skipjack tuna sizes also differed in an east-west direction. Fishing in a wide expanse from west to east across Micronesia, the pole-and-line vessels in the Western Carolines caught largely medium-size skipjack tuna of about 8 lb (3.6 kg) and some small fish of about 3 lb (1.4 kg) throughout the season. On the other hand, the catches of vessels operating to the east around the Marshalls consisted predominantly of larger fish of about 10 lb (4.5 kg).

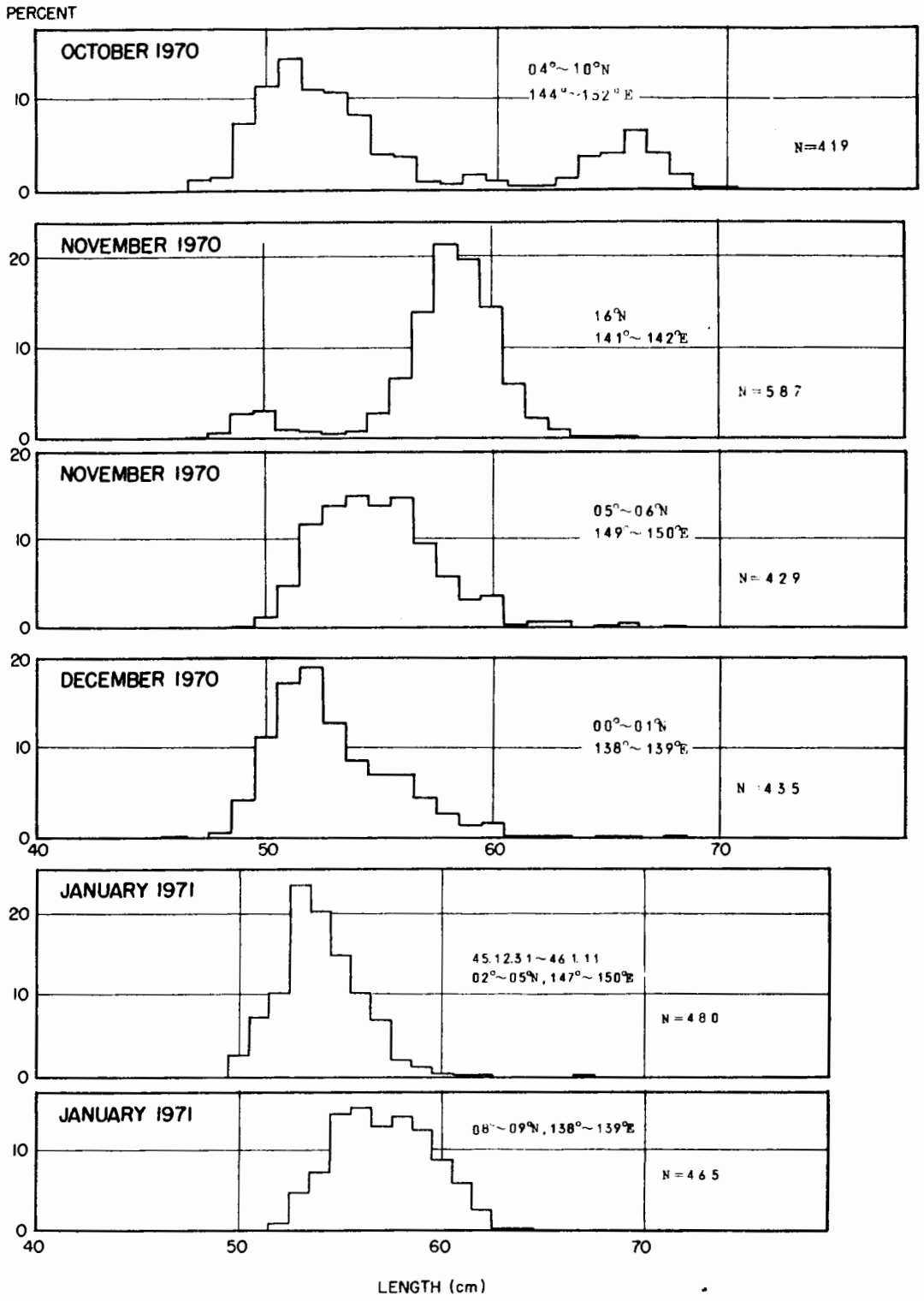

Figure 68.--Continued.

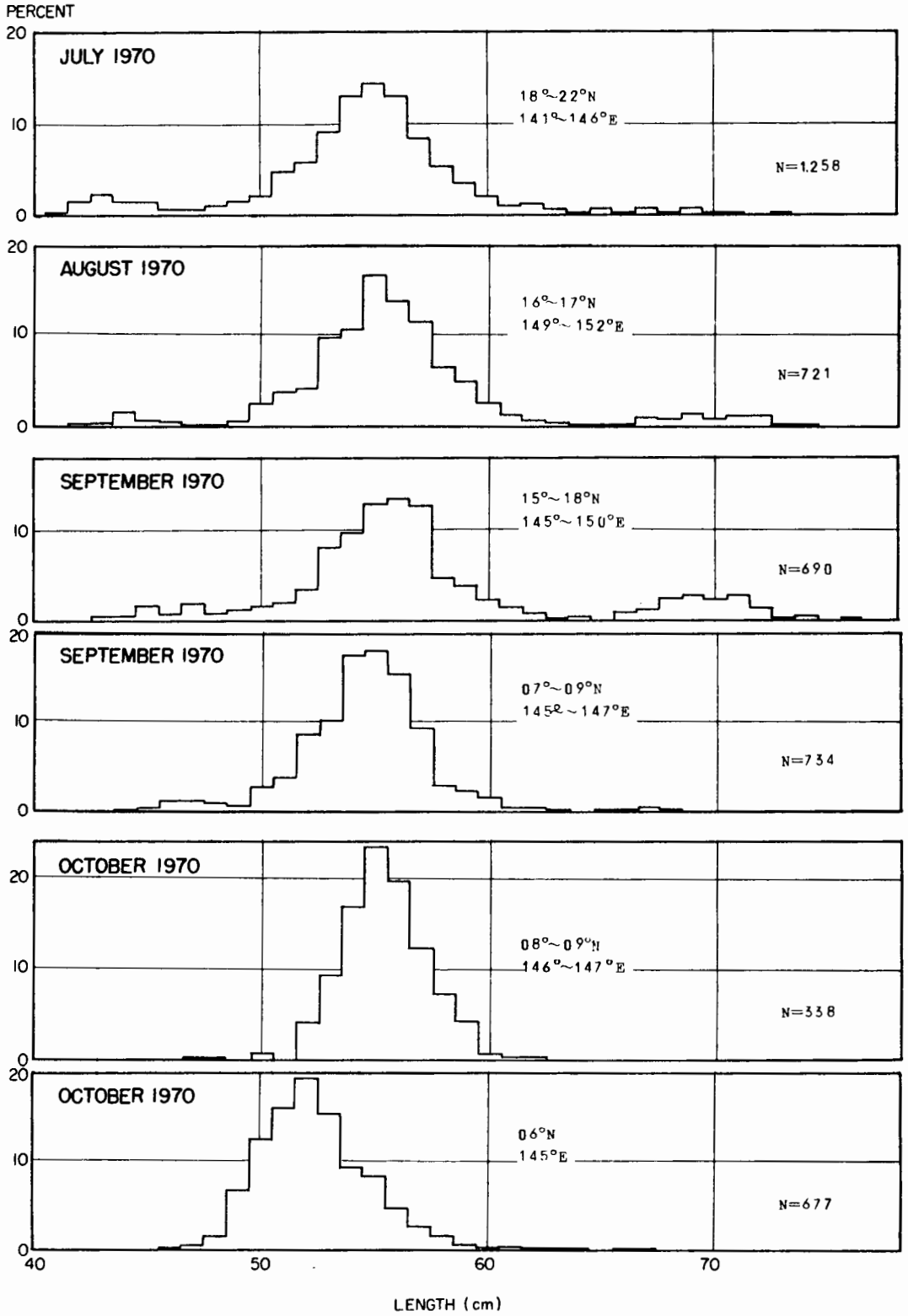

Figure 68.--Length-frequency distributions of skipjack tuna taken in southern waters (Tohoku Regional Fisheries Research Laboratory, undated d).

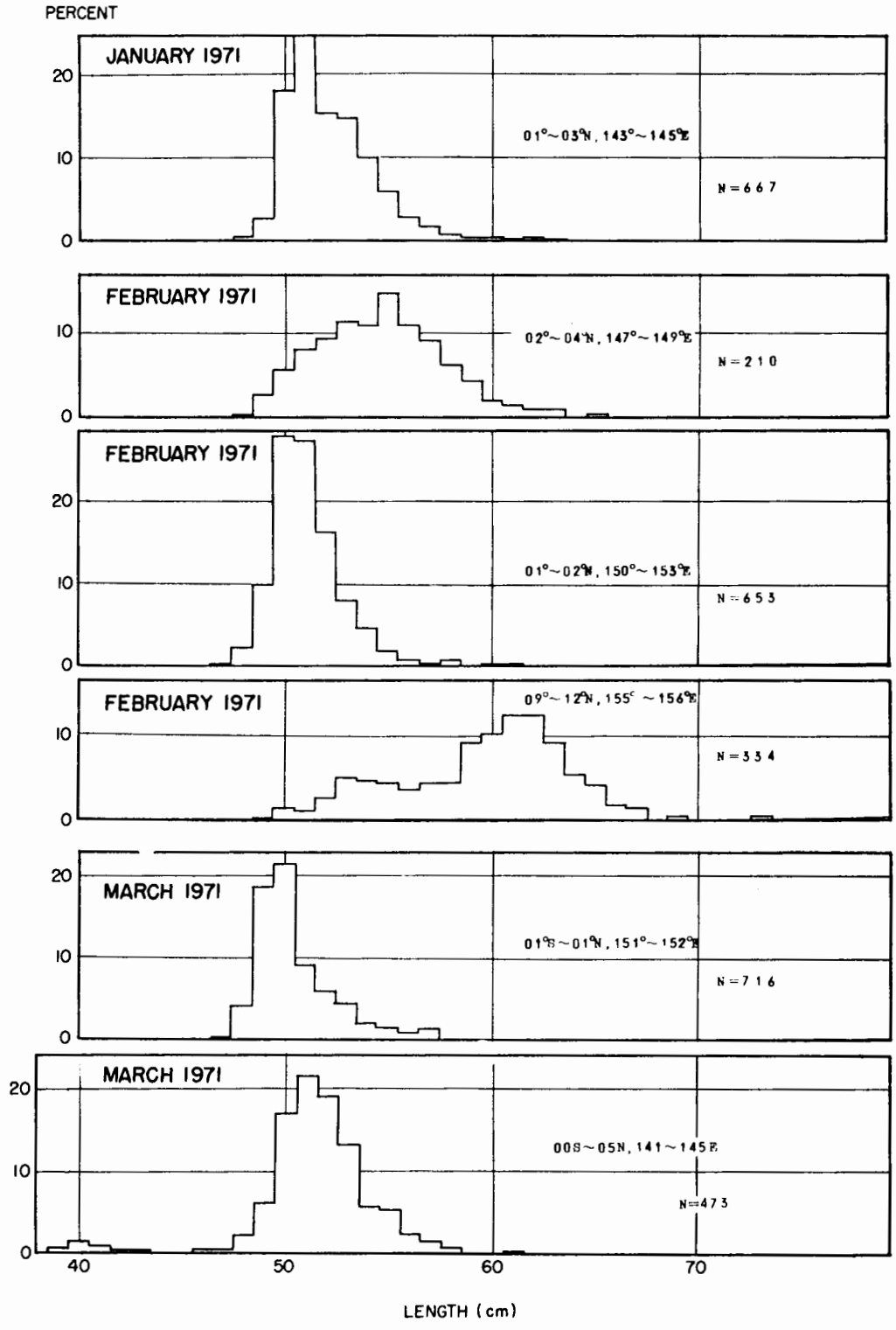

Figure 68.--Continued.

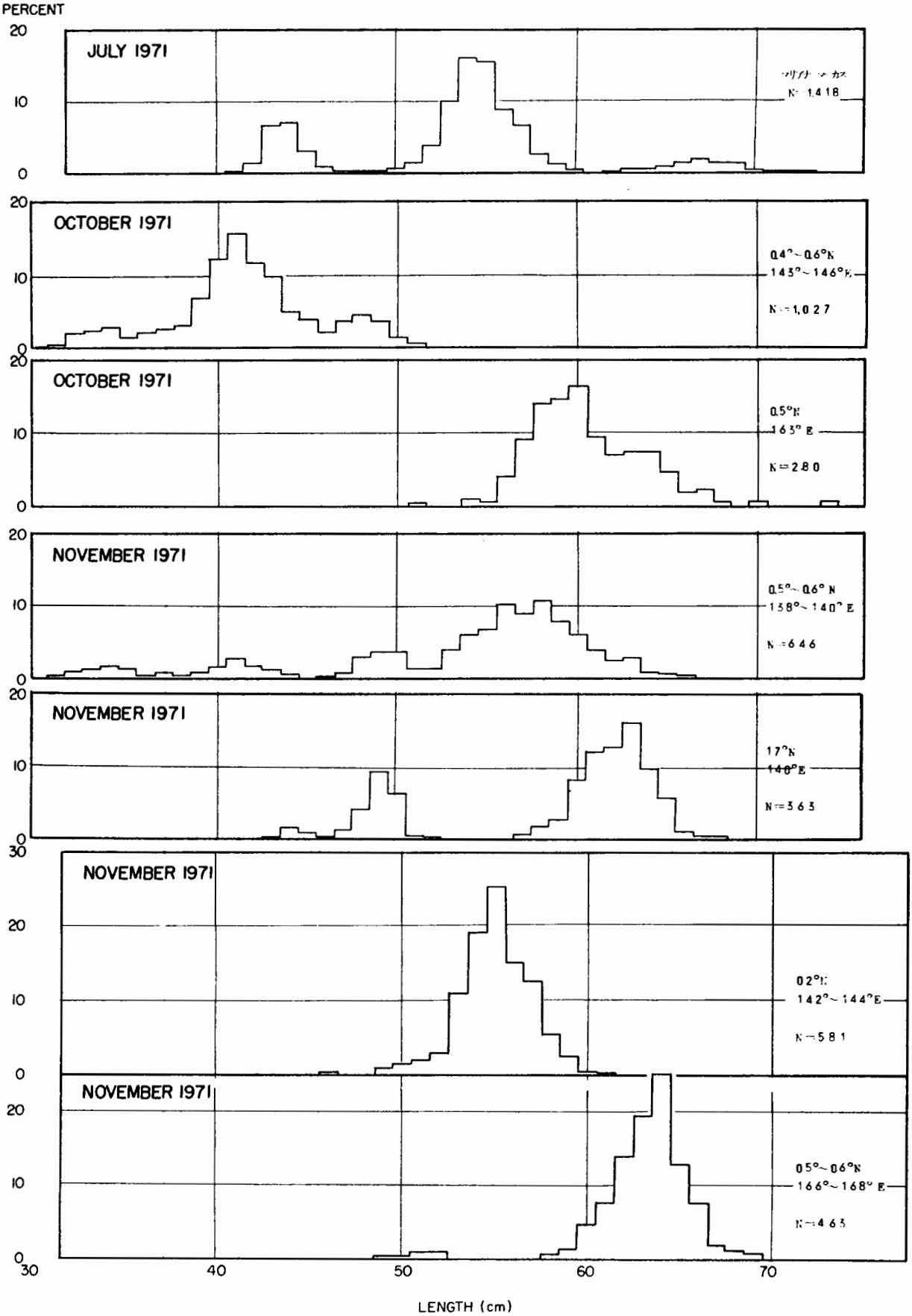

Figure 68.--Continued.

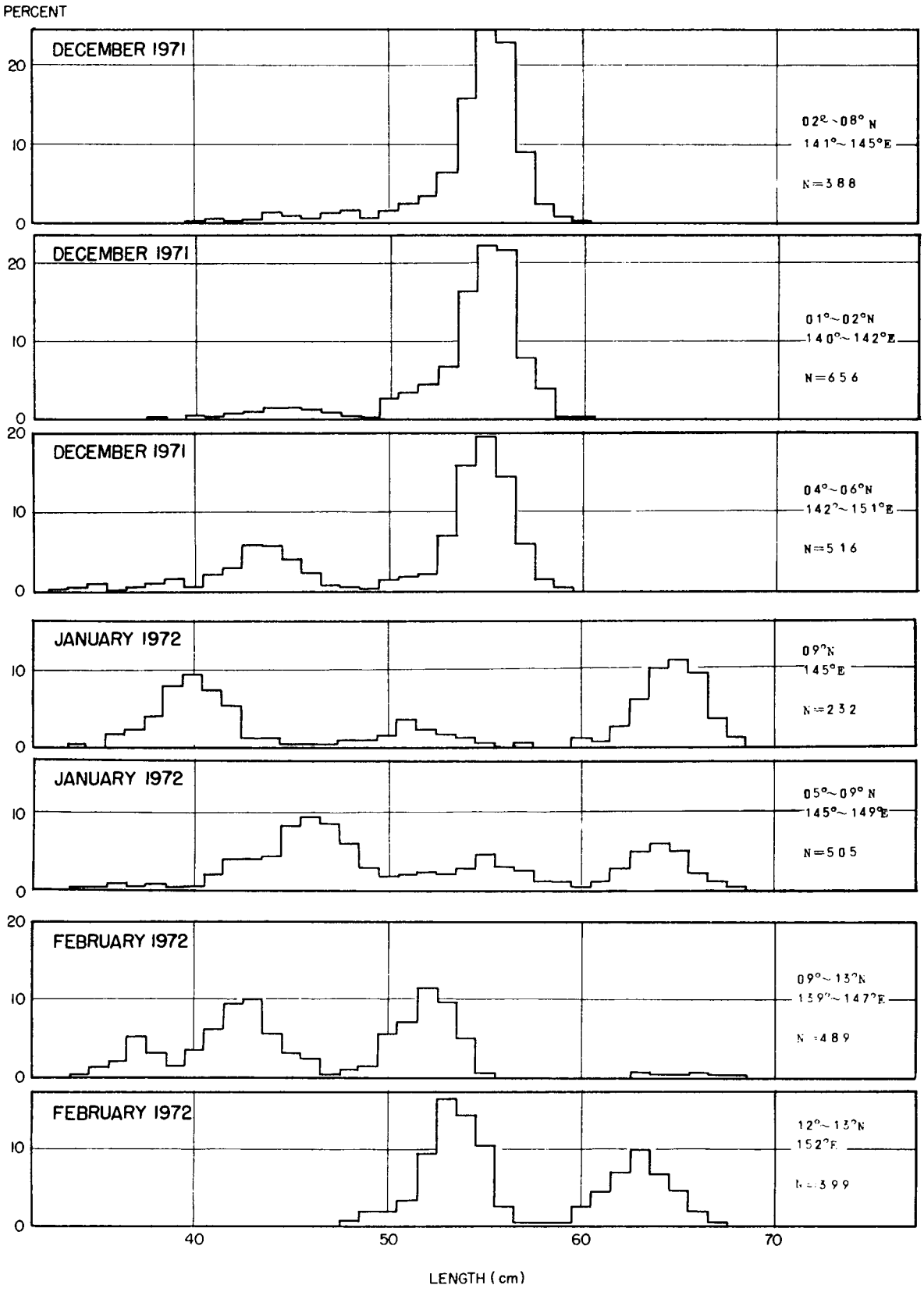

Figure 68.--Continued.

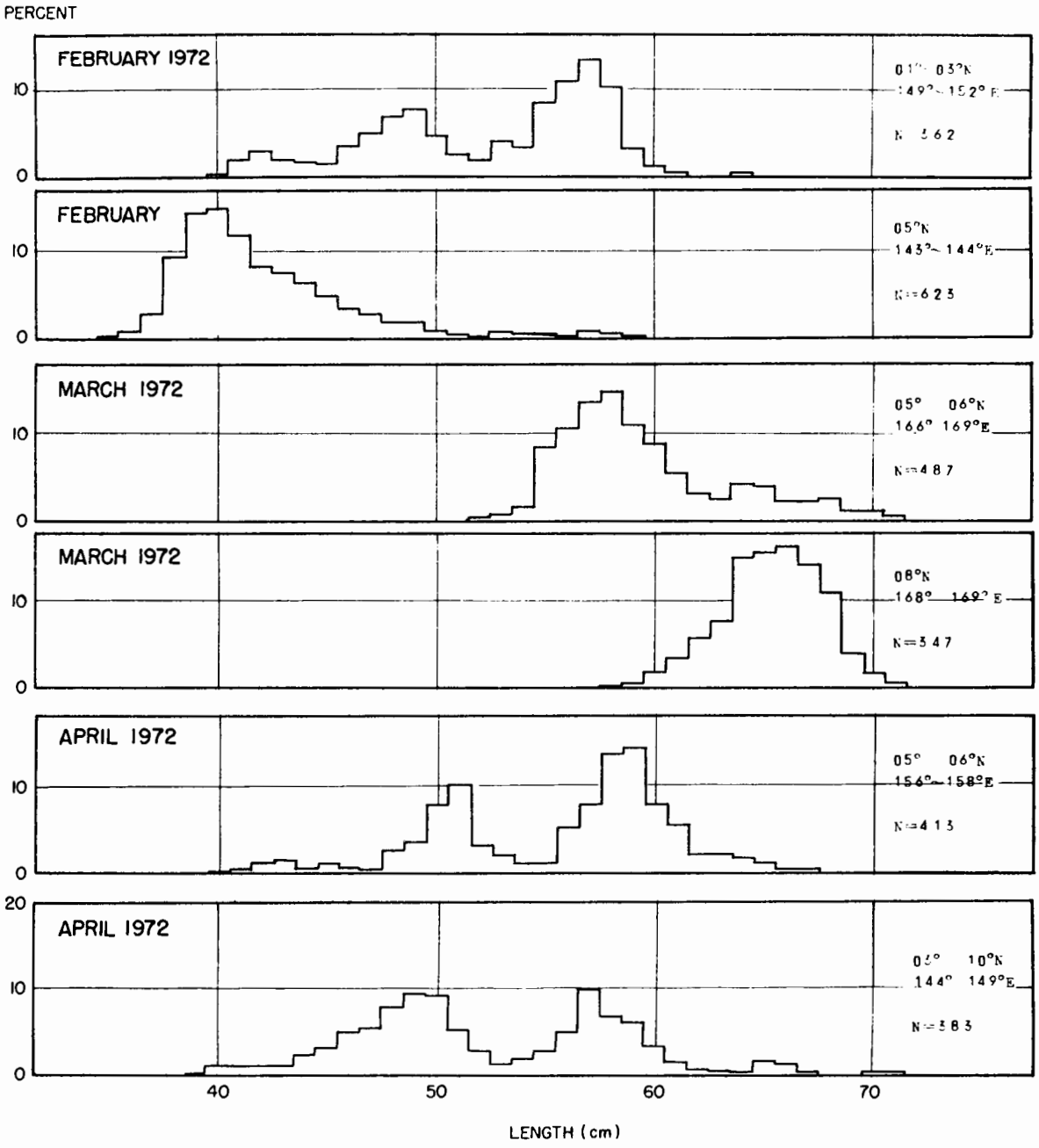

Figure 68.--Continued.

Vessels fishing in Micronesian waters may expect to find skipjack tuna varying in size from about 1 to 27 lb (0.4 to 12.2 kg). In some years, three modal groups can be seen in the length-frequency distribution. In June-December 1964, the 3.4-lb (1.5-kg) group predominated and was considered to be 2-year olds. But by March 1965, they were replaced in the catch by older fish. In 1965, the 6.0-lb (2.7-kg) group predominated in the catch.

The minimum, maximum, and average lengths of skipjack tuna taken in the Palau pole-and-line fishery in 1965-67 are given in Table 40. In general, the vessels caught fish over a wide range of sizes--from 1.2 to 25.4 lb (0.5 to 11.5 kg) but the average size each month fluctuated within a fairly narrow range from 5.6 to 10.4 lb (2.5 to 4.7 kg) (Uchida, 1970). Figure 69 shows that in 1966, two size groups--5.6 lb (2.5 kg) and 11.0 lb (5.0 kg)--predominated in the catch. The bulk of the 1966 catch, however, came from the larger size group. In 1967, three size groups were identified in the length-frequency distribution. These groups had modes at 4.9, 8.7, and 11.6 lb (2.2, 3.9, and 5.3 kg) and all three appeared to be equally represented in the catch.

In the Marshalls, Uchida and Sumida (1973) reported that the skipjack tuna landed by Anela ranged from 3.5 to 23.4 lb (1.6 to 10.6 kg) and averaged 12.3 lb (5.6 kg) whereas yellowfin tuna ranged from 12.3 to 30.0 lb (5.6 to 13.6 kg) and averaged 18.1 lb (8.2 kg) in February. In April-May, however, most of the skipjack tuna taken were medium-sized fish--between 13.0 and 16.5 lb (5.9 and 7.5 kg) and averaging 14.8 lb (6.7 kg). One school of yellowfin tuna fished during this period had fish from 26.9 to 39.7 lb (12.2 to 18.0 kg) and averaging 31.7 lb (14.4 kg).

BY PURSE SEINE

Watakabe (1970) reported on size of skipjack tuna taken by Japanese purse seiners in the western Pacific. In the vicinity of islands and banks, where skipjack tuna "boiler" schools are sometimes seen feeding on bait, the fish are usually large, weighing from 15 to 18 lb (6.8 to 8.2 kg). In waters southeast of Palau at about lat. 4°N, there were numerous reports of schools containing fish varying in size from 7 to 9 lb (3.2 to 4.1 kg) and often mixed with smaller fish of about 4 lb (1.8 kg).

In 1975, Fukuichi Maru, a Japanese seiner, reported that her catch of 187 ST (170 MT) from waters around the Marshall-Caroline Islands consisted of 60% skipjack tuna averaging 7 lb (3.2 kg) and 40% yellowfin tuna varying widely in size from 22 to 66 lb (10.0 to 29.9 kg) (U.S. NMFS, 1974a).

Table 40.--Minimum, maximum, average lengths, and the total number of skipjack tuna sampled in the Palau fishery, by months, May 1965-December 1967 (Uchida, 1970).

Year	Month	Minimum length	Maximum length	Average length	Total number measured
		Cm.	Cm.	Cm.	No.
1965	May	40.7	64.5	50.2	793
	June	31.6	65.4	51.3	3,681
	July	44.6	66.4	53.1	485
	August	31.6	65.6	52.3	1,843
	September	38.8	69.5	52.1	382
	October	45.9	73.4	59.1	786
	November	56.4	74.5	62.1	398
	December	-	-	-	-
1966	January	44.5	65.7	56.4	535
	February	41.1	70.3	54.2	1,054
	March	42.9	70.0	56.2	821
	April	45.3	68.9	53.2	755
	May	42.8	74.0	55.1	1,011
	June	45.0	74.7	56.8	889
	July	38.8	73.5	57.2	2,050
	August	44.2	76.8	57.4	3,337
	September	46.5	68.2	58.1	1,819
	October	47.4	76.3	58.1	2,011
	November	49.7	69.4	60.5	708
	December	49.8	69.9	60.4	346
1967	January	50.0	69.4	61.1	546
	February	38.0	78.3	56.6	334
	March	41.4	68.3	52.9	542
	April	39.8	69.9	53.9	900
	May	40.3	68.2	48.1	1,413
	June	42.0	68.5	51.5	1,256
	July	38.9	69.3	53.6	1,127
	August	44.3	70.0	56.4	1,787
	September	44.4	69.0	56.5	648
	October	43.8	69.1	54.3	777
	November	47.8	72.6	60.9	450
	December	45.8	71.1	58.5	1,278

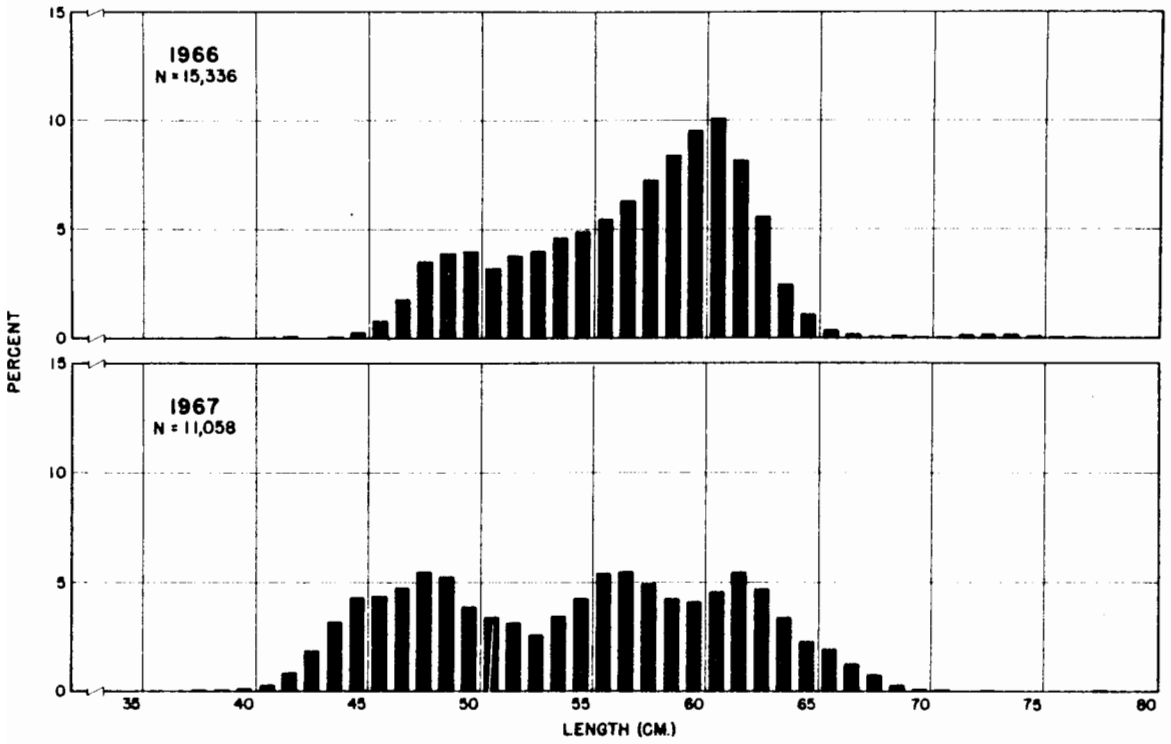

Figure 69.--Length-frequency distributions of skipjack tuna caught by pole-and-line and live bait in Palau waters, 1966 and 1967 (Uchida, 1970).

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Appendix 1

NORTHWESTERN PACIFIC OCEAN

SURFACE CURRENTS AND TEMPERATURES

SOURCE OF INFORMATION

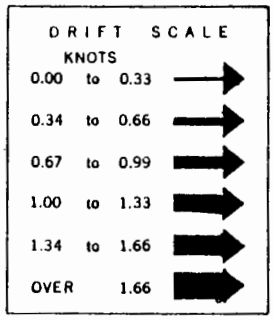
The information relating to monthly surface currents shown on this chart was compiled from observations made during the month for all years prior to 1936 by the co-operating observers of the Hydrographic Office. Observations were not considered reliable where tidal currents prevailed; where winds, sea, or swell of force 6 or above were recorded; where the vessel's draft or trim would cause excessive leeway; or when doubt existed as to the meaning of the entry "Nil" on the current report. All current calculations are based on the MEDIAN POSITION method; namely, each observation is applied at only one point, that point being midway between the beginning and end of the ship's run for which the current observation was made.

RESULTANT CURRENTS

The black arrows and numerals show the mean direction and force of the surface current in each 1-degree quadrangle for the month under average normal conditions. The accuracy of the resultant current in any quadrangle is necessarily determined by the number of observations used in the computation. The Hydrographic Office considers a resultant to be fairly accurate if computed from five or more observations in an area of 3,600 square miles. But on this chart all reliable information is shown, for the benefit of the navigator, even where less than the desired five observations were obtained.

The resultant currents in each 1-degree quadrangle are shown as follows:

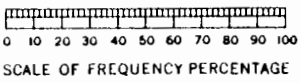
The number in the upper right hand corner of the quadrangle represents the total current observations used in the computation. The numerals in the lower left hand corner of the quadrangle give the resultant drift in miles per day to the nearest tenth of a mile. The direction of the arrow in the center of the quadrangle shows the resultant set.



PREVAILING CURRENTS

The current roses shown in green on this chart were computed from the same information as the 1-degree resultants shown in black. The eight-point rose presents a graphical picture of the frequency of direction and the average drifts within the directions for each area outlined by the heavy brown lines.

The arrows point in the direction towards which the current sets. When the frequency of direction is less than 5 percent, no arrow is shown. The length of the arrow, from the base of the arrow head to the inner edge of the circle, when placed on the attached frequency scale gives the number of times in each 100 observations that the current has been setting in or near the indicated direction. In instances where the full length of the arrow cannot be shown, the shaft is broken and the true percentage inserted in numerals within the break. The width of the shaft when placed on the attached drift scale gives the average drift in knots. The numeral in the center circle gives the percent of "nils" (no appreciable current observed). The approximate number of observations from which the current rose was computed can be obtained by adding the number of observations within the 1-degree quadrangles covered by the rose.



For example the attached rose should be read as follows:

Of the currents observed; 5 percent were setting northeast, the average drift was between 0.33 and 0.66 of a knot; 5 percent were setting east, the average drift was between 0.33 and 0.66 of a knot; 9 percent were setting southeast, the average drift was less than 0.33 of a knot; 5 percent were setting south, the average drift was between 1.33 and 1.66 knots; 57 percent were setting west, the average drift was between 0.67 and 1 knot; 5 percent were setting northwest, the average drift was less than 0.33 of a knot. The percent of "nils" was zero.

SEA TEMPERATURES

The monthly mean sea surface 5-degree isotherms shown in MAGENTA were compiled from the same source and for the same period as the resultant currents shown on this chart.