Investigation of the Benthic Marine Flora of Hood Canal, Washington[1]

RONALD C. PHILLIPS and BILL FLEENOR[2]

HOOD CANAL is a fjord (Kollmeyer, 1965) connected to Puget Sound (Fig. 1). Water in the canal was reported as highly stratified owing to a large volume of freshwater runoff from the Olympic Mountains (Kollmeyer, 1965). The water mass is relatively isolated from that of Puget Sound proper by an entrance sill at Vinland, 44 meters deep, 22.36 km (12 nautical miles) south of Admiralty Inlet.

Owing to a lack of investigation of the plants in this unique area, a study was initiated in summer 1966. Purposes of the study were to assemble a list of plants, to assess distribution and vertical zonation within the canal, and to compare the flora with that of greater Puget Sound.

DESCRIPTION OF THE AREA

Hood Canal averages 165 meters deep. It is 93 km long (50 nautical miles) and 1.86 to 3.72 km wide (1 to 2 nautical miles). The entrance sill at Vinland isolates deeper basin water from water at the same depth outside the sill.

Five large rivers drain into Hood Canal from Dabob Bay to the Great Bend portion of the canal: Quilcene, Dosewallips, Duckabush, Hamma Hamma, and Skokomish. These five rivers contribute approximately 6 percent of all the fresh water which enters Puget Sound (University of Washington, 1954). This flow maintains a low salinity surface layer and a net outflow of surface water.

The salinity stratification is strongest in summer when a dilute surface layer is warmed. The layering is maintained in winter owing to a large amount of runoff (Glancy, 1960). The stratification tends to be destroyed near the sills owing to turbulence (Damkaer, 1964).

Surface salinity may at times approach fresh water (P. S. Dixon, personal communication). On 2 March 1968 we recorded a surface salinity of 8.64 ‰ at Hoodsport, at the southern end of Hood Canal near the mouth of the Skokomish River. The record came during a period of heavy mountain snow melt and runoff. We observed that this diluted layer was 6 meters deep. On ebb tide the diluted layer extended to at least Beacon Point (Fig. 1). On flood tide the layer seemed to be limited to the area just north of Hoodsport. The amount of silt precipitation and water mixing occurring north of Beacon Point is unknown to us. In February 1968, following a week of heavy rain, we recorded a surface salinity at Hoodsport between 24 and 28 ‰. Overall, salinities in Hood Canal varied from 25 to 28 ‰ on the surface and 28 to 31 ‰ at a depth of 9 meters. It is probable that the runoff from snow melt in the Olympic Mountains influences Hood Canal salinity more than runoff from rain. Sublittoral water is very similar to that of greater Puget Sound in salinity and temperature (Glancy, 1960).

A feature of the less dense surface layer is that it warms more in summer (up to 17° to 20°C in isolated areas) and cools more in winter (below 7°C in isolated areas) than does more saline water (University of Washington, 1954).

Tidal currents in Hood Canal are weaker than those in Puget Sound. At Hazel Point the average maximum flood is 0.5 knot and the average maximum ebb is 1.0 knot. South of Hazel Point the water moves more slowly. It is probable that the weakness of currents also contributes to the greater temperature extremes of the shallow surface waters. Hood Canal tides are similar to those of Puget Sound proper (Glancy, 1960).

METHODS AND MATERIALS

Reconnaissance and other work was performed using SCUBA equipment. A total of 22

[1] Manuscript received July 2, 1969.

[2] Department of Biology, Seattle Pacific College, Seattle, Washington 98119.

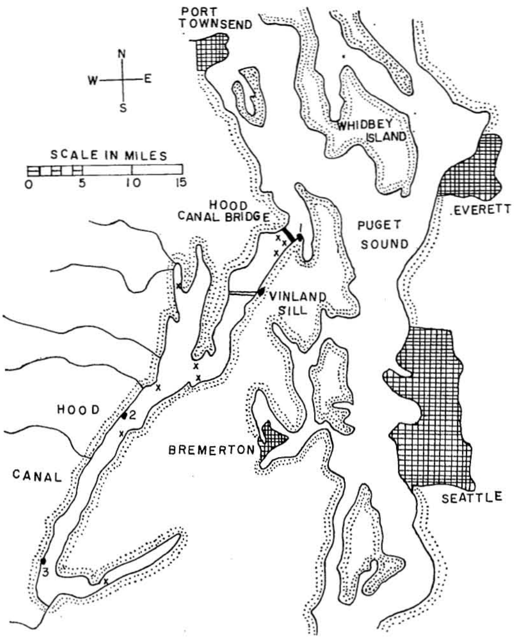

FIG. 1. Map of Hood Canal. Small 'x' designations represent locations of incidental collections. Numbers indicate locations of the three transect stations: *1*, just north of each end of Hood Canal Bridge, *2*, Beacon Point, *3*, just north of Hoodsport.

SCUBA dives were made in winter and summer from 1966 to 1968. One additional shore collection was made in June 1967. We are also incorporating data provided by the North Kitsap High School biology class of Mr. Clayton Hamm. This group collected from 15 stations in Hood Canal in May and July 1966, all north of the Vinland entrance still.

Collections were made from haphazardly chosen locations covering the entire length of Hood Canal (Fig. 1). They began in the upper littoral and ended when plants became very sparse and poorly developed, approximately 12.2 meters (40 feet) below mean lower low water (MLLW).

In winter and summer 1968 three locations spaced equidistantly in Hood Canal were surveyed by means of a line transect (Fig. 1). Only one line was surveyed at each location owing to time limitations. One reconnaissance dive was made to select a site representative of each area and to survey the vertical gradient. Measurements were recorded on succeeding dives, with summer and winter records being made over the same line.

The line transect extended from first plant growth in the littoral to the lowest limit of plant occurrence. Depth gauges (SCUBA-PRO #506) were calibrated against a measured line and found to be accurate to 0.33 meter, and depths recorded here have been corrected. Owing to lack of benchmarks, depths were estimated by interpolating time of measurement with stage of tide as predicted by the U. S. Coast and Geodetic Survey Tide Tables, 1968.

RESULTS

The littoral substrates of most stations consisted of pebbles and cobbles. At Beacon Point and the Sisters Rock, the littoral and sublittoral was composed of mixed mud and sand and scattered rocks and boulders.

An apparent zonation of algae was found. The zones in order from highest to lowest levels were: littoral ulvoid, and sublittoral *Zostera*, *Sargassum*, kelp, and red algal. Table 1 lists the zones and the depths for the three line transect stations.

Littoral algae were poorly developed in Hood Canal, but *Ulva* and *Enteromorpha* were common. *Fucus* was occasionally found near the MLLW level. On three occasions *Porphyra perforata* was found in the littoral. Littoral algae were much more abundant and better developed on the two reefs and in general at locations north of the Vinland entrance sill. Littoral plants were also much more abundant in winter south of the sill than in summer.

The *Zostera* zone exhibited little vertical change in extent. The substrate was a mixture of sand and mud, with occasional scattered rocks. *Agardhiella* and *Gracilaria* were occasionally noted on the rocks. *Zostera* was present at all locations except the Beacon Point and Sisters Rock reefs.

Sargassum was found at all locations in summer, but usually disappeared in winter. At Beacon Point, winter plants averaged 15 to 50 cm in length. They appeared to be shortened summer plants. Summer plants were approximately 2 meters long and were extremely dense. There were no other algae in this zone in

TABLE 1

LOCATIONS AND DEPTHS OF ALGAL ZONES FOR THREE LINE TRANSECT STATIONS IN HOOD CANAL, WASHINGTON

SEASON	ZONE	LOCATION AND DEPTH IN METERS		
		BRIDGE	BEACON POINT	HOODSPORT
Winter	Ulvoid	3 to MLLW	3 to MLLW	3 to MLLW
	Zostera	MLLW to —3.5	Not present	MLLW to —6.5
	Sargassum	Not present	—1 to —3	Not present
	Kelp	Not present	—3 to —12	—6.5 to —12
	Red	—3.5 to —24.0	—12 to —24	—12 to —18
Summer	Ulvoid	MLLW	MLLW	MLLW to —1
	Zostera	MLLW to —3.5	Not present	—1 to —6
	Sargassum	—3.5 to —6	—1 to —4.5	—6 to —10
	Kelp	—6 to —8	—4.5 to —12	Poorly defined
	Red	—8 to —18	—12 to —22	—10 to —16

summer. In winter, rocks in this zone were colonized by *Ceramium*.

The kelp zone, characterized by large plants of *Laminaria saccharina* and *Agarum fimbriatum*, was poorly defined. Depth seemed to depend on local factors such as current, clear water, and available rocks. Occasionally kelps were found much deeper than expected. These kelps invariably were attached to small rocks that could have rolled or been forced down the slope. Plants of the two principal species were commonly 0.45 to 0.6 meter wide and 1.8 to 3.0 meters long. All locations exhibited the kelps, but none were found in winter at the floating bridge.

The lowest zone was characterized by small red algae on rocks, shells, and other forms of litter on a bottom of mixed sand and mud. The red algal zone extended to 24 meters below MLLW in winter. In summer this lower limit decreased by 5 to 6 meters at all stations. The most conspicuous red algae observed were: *Fryeella, Callophyllis flabellulata, Gracilaria, Botryocladia,* and *Polyneura* (in winter).

Table 2 is a list of the 125 species found. The list included one seagrass, *Zostera marina,* one blue-green alga, 16 species of green algae (over half were ulvoids), 20 species of brown algae, and 87 species of red algae.

DISCUSSION

The most striking floristic feature was the paucity or, in some cases, lack of intertidal algae. Certain intertidal species common in Puget Sound, such as *Spongomorpha coalita, Odonthalia floccosa, Odonthalia washingtoniensis, Iridaea cordata, Iridaea heterocarpa, Rhodomela larix, Porphyra perforata, Gigartina papillata, Laurencia spectabilis, Alaria marginata,* and *Prionitis lyallii* were either absent entirely or present in reduced quantities. Two sublittoral kelps, *Laminaria setchellii* and *Pterygophora,* were absent, and two others, *Nereocystis* and *Pleurophycus,* were limited each to one site north of the Vinland sill.

It is certain that the lack of littoral growth was not due to inimical currents, extreme tidal fluctuations, or a lack of rocky substrates. A substrate of small cobbles in the littoral could limit plant growth by grinding.

The best explanation of the lack of littoral algae is the extreme dilution of surface salinity which occurs during the spring snow melt in the contiguous Olympic Mountains. This 6-meter dilute surface layer coincided with what we believe to be a spring period of spore germination in the Puget Sound area. Hurd (1917) found that the majority of algae from two locations in Puget Sound produced young plants all winter, but that some produced young plants only in spring (Laminariaceae as a group, *Odonthalia floccosa, Soranthera*) or predominantly in spring (*Iridaea, Prionitis, Fucus, Ulva*). Our observations over eight years tend to confirm that in spring (March to early April) a multitude of young plants of several forms can be observed on Puget Sound beaches

TABLE 2

SPECIES OF ALGAE COLLECTED IN HOOD CANAL

SPECIES[1]	FREQUENCY AND PLACE OF OCCURRENCE[2]	SPECIES[1]	FREQUENCY AND PLACE OF OCCURRENCE[2]
CHLOROPHYTA			
Chaetomorpha cannabina	1–N	*Botryoglossum ruprechtiana*	1–N
Cladophora gracilis	1–S	*Callithamnion endovagum**	2–N
Codium fragile	1–N	*Callithamnion* sp.*	1–S
Enteromorpha clathrata	3–S	*Callophyllis edentata*	4–N
Enteromorpha compressa	4–N, 2–S	*Callophyllis firma*	4–N, 2–S
Enteromorpha crinita	2–S	*Callophyllis flabellulata*	5–N, 10–S
Enteromorpha intestinalis	2–S	*Callophyllis heanophylla*	2–N, 5–S
Enteromorpha linza	12–N, 5–S	*Ceramium californicum**	1–N, 2–S
Monostroma fuscum	5–N, 1–S	*Ceramium pacificum*	4–N, 8–S
Rhizoclonium riparium	2–S	*Ceramium washingtoniense*	3–N, 3–S
Spongomorpha saxatilis	1–N	*Conchocelis rosea* (stage of *Porphyra*)	1–N
Ulva expansa	1–S	*Cryptonemia borealis*	3–N, 8–S
Ulva fenestrata	1–N	*Cryptosiphonia woodii*	2–N
Ulva lactuca	19–N, 6–S	*Endocladia muricata*	1–S
Ulva rigida	1–N	*Erythrocladia subintegra**	2–N, 1–S
Urospora wormskjoldii	1–N	*Erythrotrichia kylinii**	1–S
PHAEOPHYTA		*Erythrotrichia parksii**	1–S
Agarum fimbriatum	3–N, 9–S	*Erythrotrichia* sp.*	1–S
Alaria marginata	1–S	*Fauchea fryeana*	1–S
Colpomenia sinuosa	1–S	*Fauchea laciniata*	1–N, 2–S
Costaria costata	11–N, 2–S	*Fryeella gardneri*	6–N, 11–S
Desmarestia herbacea	1–S	*Gelidium robustum*	4–S
Desmarestia intermedia	2–N	*Gigartina californica*	1–N
Desmarestia munda	6–N, 2–S	*Gigartina exasperata*	12–N, 7–S
*Elachistea fucicola**	1–S	*Gigartina papillata*	9–N, 2–S
Fucus distichus	20–N, 11–S	*Gonimophyllum skottsbergii*	2–N
Laminaria farlowii	2–N	*Goniotrichum cornu-cervi**	1–N
Laminaria saccharina	17–N, 11–S	*Gracilaria verrucosa*	20–N, 10–S
Leathesia difformis	1–N	*Grateloupia* sp.	1–S
Nereocystis luetkeana	2–N	*Griffithsia pacifica*	2–N
Pilayella littoralis f. *rupincola*	1–S	*Gymnogongrus norvegicus*	1–S
Pleurophycus gardneri	1–N	*Halymenia californica*	1–N, 6–S
Punctaria expansa	1–S	*Herposiphonia grandis*	1–S
Sargassum muticum	13–N, 14–S	*Herposiphonia parva**	3–N, 4–S
Scytosiphon lomentaria	1–N, 1–S	*Heterosiphonia laxa*	1–S
Sphacelaria racemosa	1–S	*Hildenbrandia prototypus**	1–N, 5–S
Streblonema sp.	1–N	*Iridaea cordata*	2–N
RHODOPHYTA		*Iridaea heterocarpa*	5–N
*Acrochaetium macounii**	1–S	*Janczewskia gardneri*	2–N
*Acrochaetium pacificum**	2–S	*Kallymenia oblongifructa*	1–N, 3–S
*Acrochaetium variable**	1–S	*Laurencia spectabilis*	3–N, 1–S
Agardhiella tenera	11–N, 11–S	*Lithophyllum* sp.	1–S
Amplisiphonia gardneri	1–N	*Lithothamnion californicum*	2–N, 5–S
Antithamnion gardneri	1–N	*Microcladia coulteri**	1–N
*Antithamnion pygmaeum**	3–N, 3–S	*Myriogramme pulchra*	5–N, 2–S
*Antithamnion subulatum**	1–S	*Myriogramme spectabilis*	1–N, 1–S
Bonnemaisonia nootkana	1–N, 7–S	*Nienburgia borealis*	2–N
Botryocladia pseudodichotoma	5–S	*Odonthalia washingtoniensis*	1–N
Botryoglossum farlowianum	4–N	*Opuntiella californica*	3–N

[1] A species marked with an asterisk is an epiphyte.
[2] Recorded as number of collections north or south of the Vinland sill. For example, the entry 4–N indicates that the species was found four times north of the sill.

TABLE 2 (*continued*)

SPECIES[1]	FREQUENCY AND PLACE OF OCCURRENCE[2]
Pleonosporium vancouverianum	1–N, 2–S
Plocamium coccineum var. *pacificum*	2–N, 3–S
Polyneura latissima	7–N, 6–S
Polysiphonia hendryi	1–N, 1–S
Polysiphonia mollis	2–S
Polysiphonia pacifica	2–N, 1–S
Polysiphonia paniculata	15–N, 4–S
Porphyra amplissima	1–N
Porphyra miniata var. *cuneiformis*	1–N
Porphyra perforata	5–N, 4–S
Prionitis lanceolata	2–N, 1–S
Prionitis lyallii	1–N
Pseudogloiophloea confusa	2–S
*Pterosiphonia dendroidea**	4–N, 1–S
Pterosiphonia gracilis	1–N, 4–S
Pugetia fragilissima	1–S
Rhodomela larix	(Floating fragment)
*Rhodophysema elegans**	1–S
*Rhodophysema georgii**	1–N
Rhodoptilum plumosa	5–N, 3–S
Rhodymenia pacifica	2–N
Rhodymenia palmata	1–N
Rhodymenia pertusa	4–N, 11–S
Sarcodiotheca furcata	4–S
*Smithora naiadum**	1–N
Stenogramme interrupta	1–N, 1–S
CYANOPHYTA	
*Microcoleus lyngbyaceus**	2–S
SEAGRASS	
Zostera marina	6–N, 9–S

(*Nereocystis, Laminaria, Iridaea, Gigartina, Spongomorpha, Odonthalia, Ulva, Enteromorpha, Costaria, Alaria, Cymathere, Polysiphonia, Rhodomela, Laurencia*). We feel that the springtime influx of fresh water may be detrimental to spore germination and could be an isolating mechanism of major importance for littoral Hood Canal algae. It is also possible that this dilute layer could limit spore survival of certain sublittoral forms.

We suggest that most algae which penetrate Hood Canal are euryhaline, but probably cannot tolerate the extreme dilution of water which occurs during the spring melt. The result is an almost total limitation of algae in Hood Canal to the sublittoral.

Thirty-eight species were limited to the region north of the Vinland entrance sill; 39 species were found only south of the Vinland sill; and 48 were found both north and south of the sill (Table 2). This seeming limitation of two-thirds of the flora to either north or south of the sill is peculiar inasmuch as all or most species recorded are found generally in Puget Sound or nearby waters. More extensive collecting might eliminate some of these geographical distinctions, but some forms are too conspicuous to miss, for example, *Codium, Spongomorpha, Nereocystis, Pleurophycus, Botryoglossum, Odonthalia, Opuntiella, Prionitis, Porphyra,* and *Smithora.* Other species common in the Puget Sound littoral were found only occasionally north of the Vinland sill, and only rarely as two or three depauperate plants south of the sill. These species included *Gigartina papillata* and *Porphyra perforata,* and it is interesting that they were found south of the sill only in winter.

A marked sublittoral zonation of algae was noted. Several factors could explain this, such as light penetration, lack of substrate, inimical surface currents or turbulent water, or heavy grazing pressure. Vadas (1968) stressed that herbivores exert a major controlling effect on the benthic algae in the San Juan Islands.

The usual sublittoral substrate in Hood Canal is scattered rocks and boulders, but there is no zone in which suitable substrate is lacking. We do not feel that a lack of substrate is responsible for sublittoral zonation in Hood Canal.

Currents in Hood Canal are weak and water does not often become turbulent. Thus, these two factors do not seem to control zonation.

It is interesting that in 22 SCUBA dives we did not find a single sea urchin, which is an extremely heavy grazer on algae. Vadas (1968) reported that selective urchin grazing on *Laminaria* in the San Juan Islands led to the establishment and dominance of *Agarum.* In Hood Canal, however, both *Laminaria* and *Agarum* grow side by side at all stations. In California, Leighton (1960*a,* 1960*b,* 1967) and Leighton et al. (1966) studied the effects of urchins on a number of kelp species. They found that urchins were voracious eaters and exerted a major effect on community composition. Leighton et al. (1966) reported that in California the sunstar (*Pycnopodia helianthoides*) is a natural predator on urchins. This sunstar is very common at all locations we visited in Hood Canal, but studies on the biology of our urchins in relation to growth in Hood Canal are needed, as well as studies on possible exclusion of urchins by the sunstar.

Other grazers are also known to devour marine algae—amphipods, isopods, and a variety of molluscs. It is possible that the abundance of starfish in Hood Canal could aid in controlling the mollusc populations, but we have no data to suggest crustacean influence on community composition. We do not feel that crustaceans could control sublittoral zonation, but much work is needed to give data in this regard.

We do suggest that light is a major factor in causing the observed sublittoral zonation. Our transect studies indicated that summer depth limits were decreased by 5 to 6 meters as compared with winter limits. This reduction followed the general spring plankton bloom which occurs generally in Puget Sound. It also followed the extremely turbid dilute surface layer of water, 6 meters deep, in which the visibility was less than 0.3 meter. Obviously this layer acts as a filter, affecting both the intensity and the spectral quality of light.

Shelford and Gail (1922) determined that the majority of brown algae in Puget Sound grew at depths between 5 and 15 meters (mostly 10) where the shorter light waves were about 10 percent and the red about 0.99 percent of full sunlight. They also determined that the deeper red-algal zone was located at depths between 10 and 30 meters. Most of the red algae were found in water between 15 and 25 meters deep where the shorter wave lengths were between 10 and 2 percent and the red between 0.99 and 0.0032 percent of full sunlight. We have not measured light in Hood Canal, but in general we agree with their reports of algal depths for Hood Canal algae. Shelford and Gail (1922) did not relate their depths to a reference, but if they used mean sea level as their reference point, their measurements are quite similar to ours.

Kain (1962) suggested that a slope angle of 20° or more limited the presence of some algae. We have constructed profiles based on our transect measurements and can find only one instance which might possibly confirm his suggestion. *Zostera* stopped at two stations as the bottom slope angle exceeded 20°. However, this cessation could as well be interpreted as a result of light extinction for the species. Depths of *Zostera* in Hood Canal agree perfectly with those for the Puget Sound area. As far as we can determine, the slope angle exerts no conspicuous exclusion effect.

We conclude that the zonation of sublittoral algae in Hood Canal is related to light, and not to grazers, currents, turbulent water, or to unfavorable slope angles. The possibility that grazing by crustaceans on sublittoral algae may act in concert with the physical effect of light cannot be overlooked. This aspect should be pursued.

Also to be studied are transect studies where biomass per square meter will be sampled. Assessment of seasonal variation of the species and community in terms of biomass in relation to depth would be valuable.

SUMMARY

An assessment of the marine plants of Hood Canal, Washington, has revealed a dearth of littoral growth and a marked sublittoral zonation. It is likely that runoff from snow melt in spring, which results in greatly diluted surface salinity, limits littoral algal growth. It is concluded that light is the controlling factor in sublittoral zonation.

LITERATURE CITED

DAMKAER, D. M. 1964. Vertical distribution of Copepoda in Dabob Bay, December 1960. Unpublished M. S. thesis, Department of Oceanography, University of Washington, Seattle.

GLANCY, T. J. 1960. Microstructure in Dabob Bay, September 1959. Unpublished M. S. thesis, Department of Oceanography, University of Washington, Seattle.

HURD, A. M. 1917. Winter condition of some Puget Sound algae. Publications of the Puget Sound Marine Biological Station, vol. 1, no. 20, pp. 341–348.

KAIN, J. M. 1962. Aspects of the biology of *Laminaria hyperborea*. I. Vertical distribution. Journal of the Marine Biological Station of the United Kingdom, vol. 42, pp. 377–385.

KOLLMEYER, R. C. 1965. Water properties and circulation in Dabob Bay. Unpublished M. S. thesis, Department of Oceanography, University of Washington, Seattle.

LEIGHTON, D. L. 1960*a*. Studies of kelp grazing organisms. Quarterly Progress Report, 1 Jan.–31 Mar. 1960. Kelp Investigation Program, University of California Institute of Marine Research, IMR Ref. 60-7, pp. 13–22.

——— 1960*b*. Studies of kelp grazing organisms. Quarterly Progress Report, 1 Oct.–31 Dec. 1959. Kelp Investigation Program, University of California Institute of Marine Research, IMR Ref. 60–3, pp. 1–5.

——— 1967. Ecological investigations of sea urchin populations along the Palos Verdes Peninsula. Annual Report Kelp Habitat Improvement Project, 1966–1967. California Institute of Technology. Pp. 41–54.

LEIGHTON, D. L., L. G. JONES, and W. J. NORTH. 1966. Ecological relationship between giant kelp and sea urchins in southern California. Proceedings of the 5th International Seaweed Symposium, pp. 141–153.

SHELFORD, V. E., and F. W. GAIL. 1922. A study of light penetration into sea water made with the Kunz photo-electric cell with particular reference to the distribution of plants. Publications of the Puget Sound Marine Biological Station, vol. 3, pp. 141–176.

VADAS, R. L. 1968. The ecology of *Agarum* and the kelp bed community. Unpublished Ph. D. dissertation. University of Washington, Seattle. 280 pp., 25 figs.

UNIVERSITY OF WASHINGTON, DEPARTMENT OF OCEANOGRAPHY. 1954. Puget Sound and approaches. A literature survey. Vol. III. ONR Contract No. NONR-447(00), Task Order 477(06).