Spatial distribution of invertebrates in Carmel Lagoon, Carmel, California

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Abstract

The preservation of lagoons is a key component of coastal areas in relation to the naturally occurring ecosystem and the species diversity that lagoons support (Gonenc, 2005). The Carmel Lagoon is a natural habitat to many species including the threatened Central-California Coast Steelhead (*Oncorhynchus mykiss*) (NMFS 2006). Since juvenile *O. mykiss* feed on major lagoon invertebrates and are a threatened species in the Central Coast region of California, the preservation and species richness of *O.* mykiss is dependent on the presence of major lagoon invertebrates. To determine the spatial patterns of major lagoon invertebrates in relation to the different substrate types, the different substrate types were carefully identified and located, and the invertebrates within each substrate type were be sampled. Results showed that *Neomysis* was more abundant among sandy substrates with grass; *Eogammarus* was more abundant among fine sand with mud, Coarse Particulate Organic Matter (CPOM) with mud and sand substrate with grass. Lastly, *Corophium* was more abundant among CPOM with mud and sandy substrate with grass. The awareness of spatial patterns of epibenthic invertebrates among the different substrate types will allow for more efficient management to commence and therefore provide optimal habitat conditions for the food sources of steelhead.

Introduction

Lagoons are ecologically sensitive ecosystems within the coastal area that support a wide array of species diversity and many forms of natural resources that are both ecologically and economically significant. Coastal lagoons are distinguished by their shallow aquatic habitats that materialize at the interface of terrestrial, and marine ecosystems. Lagoons are also ecologically significant in relation to their hydrological and physical functions; such as flood relief, aquifer revitalization, trapping of sediment (Williams, 1990).

Studies by the Environmental Protection Agency (EPA), suggest that U.S. wetlands have decreased by one-half in the last fifty years. In forty-eight states within the U.S., approximately one hundred million acres of wetlands remain with seventy-percent of the remaining wetlands being privately owned. Wetland degradation within the U.S. is continuously being lost at a rate of approximately sixty-thousand acres per year (EPA 2009). Anthropogenic sources such as urbanization, industrialism, aquaculture, cultivation, and fisheries are credited with wetland degradation and the reduction in water quantity, quality and flow rates (Gonenc, 2005). Anthropogenic sources also increase the input of pollutants which effect both ecological and species composition (EPA 2006).

In 2004, the California Department of Parks and Recreation (CDPR) began the their planning process of the Carmel River Lagoon Enhancement Project (CRLEP) to expand the area of the Carmel Lagoon through the disinterring of a new channel on the preexisting artichoke fields of Odello farmland (CDPR, 2003). The expansion of the Carmel Lagoon sought to provide habitats for two Federally Threatened Species: the Steelhead Trout (*Oncorhynchus mykiss*) and the California red-legged frog (*Rana aurora draytonii)* (Larson et al, 2005).

The Carmel Lagoon, located at the end of the Carmel River Watershed is separated from the ocean by a closed sand bar, and experiences less precipitation during warm summer months. In contrast, the Carmel lagoon is connected to the ocean with higher amounts of precipitation during colder winter months (Casagrande, 2006). During the winter months, the Carmel Lagoon increases in size; this forces the sand bar to break open therefore allowing the brackish water of the Carmel Lagoon to flow freely into the ocean (Perry et al, 2007).

On August 18, 1997, steelhead were listed as a threatened species and were declared endangered as of January 2, 2006 in-part because they live an anadromous life cycle (NMFS 2005) (NMFS, 2006) (Lufkin et al. 1991). An anadromous life style is characterized by two different life stages where *O. mykiss* migrate from fresh water to salt water. *O. mykiss* are first born into fresh water streems where they remain until adulthood. Upon reaching maturity they shift habitats from aquatic to marine where they remain until returning for spawning season. Steelhead occupy the lagoon during an intermittent juvenile stage in between the fresh water stage and the salt water stage; the intermittent stages of steelhead are known as both smelts and summer residents (Dettman, 1984). Steelhead are economically important to both consumers and the fishing community. The declining populations of the steelhead are the result of local habitat degradation such as water modifications, agriculture, and urbanization (NMFS 2006). Another form of human disturbance that has a significant impact on steelhead is the artificial breaching of the sand bar; this form of disturbance can hinder or advance the steelhead prematurely which could result the obstruction of spawning or other significant life stages (Perry 2007).

Major lagoon invertebrates within the Carmel Lagoon are a key factor in influencing the fecundity of steelhead (Covich 1999). In August of 1984, Fields found a sufficient amount of major lagoon invertebrates within the stomach contents of resident steelhead. Fields' study found that seven species of major lagoon invertebrates, six of which being benthic invertebrates, were consumed by steelhead where one of the most commonly found invertebrate within steelhead's stomach contents was an amphipod, *Corophium spinicorne* (Fields,1984).

Both terrestrial vegetation and reed beds play a significant role in nuturient input into higher trophic levels in the form of detritus (dead and decomposing organic matter) (Nelson & Scott 1962; Min-shall 1967; Kaushik & Hynes 1971; Peterson & Cummins 1974; Bell et al.

1978; Minshall et al. 1983, 1985; Stewart & Davies 1990). As terrestrial vegetation is input into the aquatic system, it is referred to as Coarse Particulate Organic Matter (CPOM) where it is broken down by bacteria, invertebrate shredders and detritovores such as Stoneflies (*Plecoptera*) and Nematodes respectively (Bilby & Likens, 1980).

Watson (2007) tried to understand the temporal dynamics of major lagoon invertebrates within the Carmel Lagoon. In an attempt to elucidate the temporal dynamics of *C. spinicorne*, Watson (2007) found that the spatial patterns of habitat types had a greater affect on invertebrate abundance than temporal patterns. In her conclusion, she stated that efficient management of the lagoon would require a more thorough understanding of spatial patterns of major lagoon invertebrates. It is at this point where this research paper picks up in an attempt to determine the spatial patterns of major lagoon invertebrates within the Carmel Lagoon.

Knowing the spatial habitat requirements of major lagoon invertebrates would allow managers to focus restoration on their preferred habitat type, and would allow monitoring programs to stratify long-term monitoring according to spatial habitat types, and avoid temporal sampling being obfuscated by fine-scale spatial variations.

Research Question

The question addressed by this study is: What is the spatial pattern of variation in abundance of the major lagoon invertebrates in relation to substrate type?

In general, I postulate that each lagoon invertebrate taxon is associated with different habitats to different degrees. A specific hypothesis consistent with this general postulate is (stemming from Watson's work (2007)):

Corophium abundance is higher over sandy substrates than over grassy substrates.

Methods

Methodological approach

The overall methodological approach used to examine the above postulate began by collecting data on species abundance at a number of sites spanning a range of habitat types. With assistance from F. Watson (Assistant Professor, CSUMB, pers. comm.), regression models were then fit, predicting abundance from habitat type. These models were compared to ‘null’ models where abundance was assumed to be constant, and the existence of habitat associations was inferred from whether or not the habitat models were superior to the null models in terms of Akaike’s Information Criterion (Burnham & Anderson, 2002).

Study Site

The Carmel River Lagoon is a water body that retains brackish water and remains salinity-stratified throughout the year. During periods of stormy weather, the Carmel River feeds water into the lagoon until waters reach a high enough level to break the sand bar that separates the lagoon and river from the ocean. As periods of stormy weather reside, the sand bar is created from the force of waves on the beach, thus holding the remaining water into the lagoon with only freshwater inputs from the Carmel River and the adjacent shallow aquifer (Figure 1).

Figure 1. Photo of the Carmel Lagoon. (Photo courtesy of Ifland Survey 2010).

Sampling Design

To begin finding spatial scales of major lagoon invertebrates among the different substrate types, the different substrate types first needed to be identified, and then they each needed to be located along the entire lagoon. A thorough walk-through of the lagoon proved to be the simplest strategy for categorizing the different substrate types. After identifying the different substrate types and locating them respectively within the Carmel lagoon, every location for each specified substrate type was given a number to use for simple random sampling method where one location was randomly selected for each substrate type (Table 1). Within each randomly selected location for each substrate type, a transect tape was extended for the full length of the specified substrate type zone, where ten locations along the transect tape were randomly selected to preserve the randomly selected assumption to later perform an appropriate statistical analysis. To preserve the assumption of independent sampling, each randomly selected location along the transect line was only sampled once.

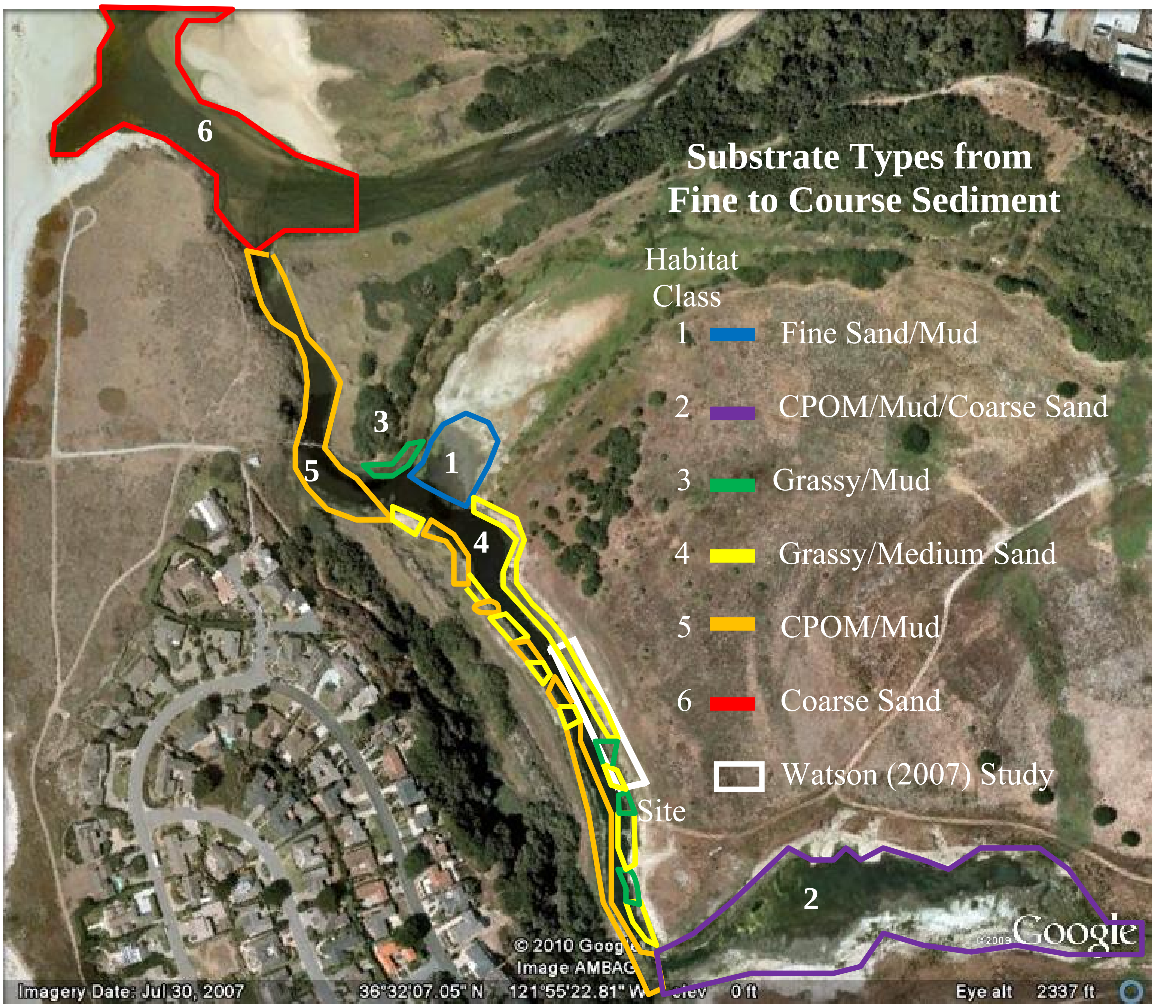

Figure 2. Photo Illustrating the different Substrate Types within the Carmel Lagoon. (Photo courtesy of Google Maps. 2010.)

Figure 2 shows both, the approximate locations of each of the six substrate types within the Carmel Lagoon and each of the six sample locations within each of the six different substrate types. The study site of Watson (2007) is also shown among the Grassy/Medium Sandy Substrate.

Sampling the Carmel Lagoon occurred over a two week time scale during the first two weeks of March, 2010. The weather during the time of sampling was mixed, both sunny and cloudy following stormy weather. Prior to arriving on site, ten random locations were already selected for purpose of time efficiency. Upon locating each randomly selected location along the transect tape, a D-net was used at waste height with a 1.5 meter pole extension and a mesh size of 500 μm to sample for major lagoon invertebrates. The same technique employed by Larson et al. (2005, 2006) and Perry et al. (2007) was used to sample for major lagoon invertebrates. The steps in their techniques involved quickly yet gently dragged the D-net across the lagoon floor ten times in a 180 degree motion. All substrates were sampled when the lagoon stage was between 2.8 and 3.4 meters in depth, leading to typical depths of water at sampling locations of between .28 and .36 meters. Immediately following each sampling, the major lagoon invertebrates were emptied into collection containers for later observations. For purposes of time and light efficiency, each sample was not sorted through at the site, but instead, each sample was later sorted in a lab. Upon sorting in the lab, each sample was emptied into a sorting tray with additional water where each species was carefully counted. Larger specimens were collected with forceps and smaller specimens were collected with a plastic pipette. Following the separation of each sample with respect to habitat type, each major lagoon invertebrate was carefully identified and then recorded into an excel worksheet for further statistical analysis.

Substrate Types

The Odello Extension was observed as being layered, with a sandy substrate at the bottom, finer sediments above the sand (silts/clays), and above the finer sediments was a slimy layer presumed to be Fine Particulate Organic Matter (FPOM). Upon sorting in the lab, the sediment also appeared to contain tule reed fibers which made sorting increasingly difficult (Table 1) (Appendix B:c).

At the turn from the lake to the Odello Arm, substrate type drastically changed, from finer sediments into course sand with true grasses (Table 1) (Appendix B:a & b). The grass present in both sandy and muddy substrates were unknown terrestrial true grasses that are capable of inhabiting saturated soils (Appendix B). The entire Odello Arm was a long and complex zone to categorize in terms of substrate type locations because there are some zones within the Odello Arm that have a significant amount of erosional deposition occurring, resulting in sandier substrate. As the zone of erosion ends, a small ~four meter zone of Mud with Coarse Particulate Organic Matter occurs and then returns back to Sandy Substrate with Grass at the next zone of erosional deposition. The zones of Mud with Coarse Particulate Organic Matter appear to have reed beds immediately at the banks of the Odello Arm while the Sandy Substrate with Grass has reed beds that are further away or absent from the bank.

As the Odello Arm continues, it meets the South Arm which consists of a muddy substrate with a very fine sediment size (silts/clays), categorized as Fine Sand/Mud (Table 1). This zone spanned fifty meters from east to west and consisted of reed bed growth on both sides of the fifty meter zone.

Just as the Fine Sand/Mud zone ends, and the lagoon begins to wrap around to the north, a small grassy mud zone is present. This zone could only be sampled following stormy weather because the grassy muddy zone was higher up the bank in comparison to all the other substrate types, therefore higher water levels were required for invertebrates to be present (Table 1).

After the grassy muddy zone came the Coarse Particulate Organic Matter with Mud Zone which extended the full length from the Wastewater Pipe all the way to where the lagoon meets the Carmel River, a full length of a ~160 meters. This substrate type consisted of sharp banks that quickly dropped to depths greater than waste height, and contained reed bed growth on both sides of the extension (Table 1).

As the brackish waters of the lagoon meet the freshwater input of the Carmel River, the substrate type drastically changes from Coarse Particulate Organic Matter with mud to Course

Sandy Substrate with a fast flowing current that flows directly through the open sand bar and into the ocean (Table 1).

Table 1. Table illustrating the Six Different Observed Substrate Types from Fine to Course Substrate (1-6).

Habitat Class	Substrate Type	Descriptive Observations
1)	Fine_Sand_Mud	Thick mud that is difficult to walk in. Very fine sediment with little to none organic particles.
2)	CPOM_Mud_Course Sand (Odello Extension)	Thick layered mud throughout with coarse sand below, finer sand above the coarse sand, silts/clays above the fine sand, and a thin layer of tule reed fibers within the top layer
3)	Grass_Mud	Only accessible during periods of high water levels. Characterized by coarse sand within the base layer, an organic-muddy substrate above the coarse sand with grass growing out of the organic-muddy substrate.
4)	Grass_Sand	Mats of *C. spinicorne* sand tubes compose the entire bank with grass growing at ~.3-.4m. in depth.
5)	CPOM_Mud	Thick mud with steep banks. The benthos is carpeted with coarse particles from both terrestrial and tule reed vegetation.
6)	Coarse_Sand (Open_Sand_Bar)	Very coarse sand with fast flowing water due to the open sand-bar.

Results

Figures 3 through 6 show the mean abundance of the four invertebrate taxon identified by Fields 1984 among the six different substrate types.

Figures of Mean Abundance of *C. spinicorne, Eogammarus, Neomysis, and Gnorimosphaeroma* Among each Substrate Type

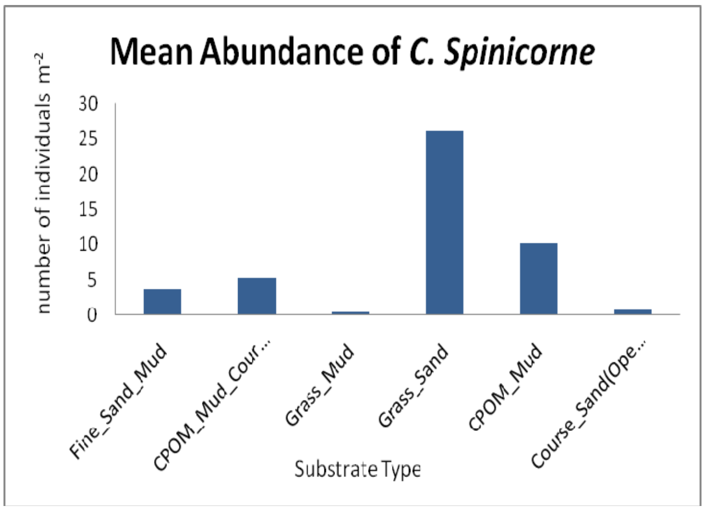

Figure 3. Average Abundance of *Corophium Spinicorne.*

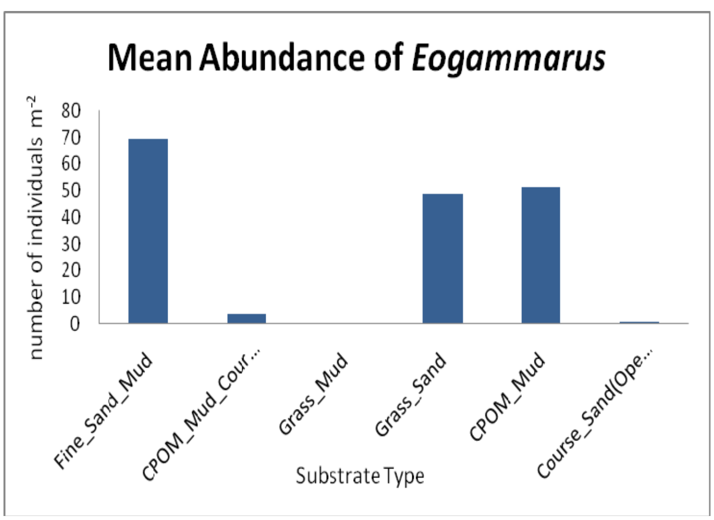

Figure 4. Average Abundance of *Eogammarus.*

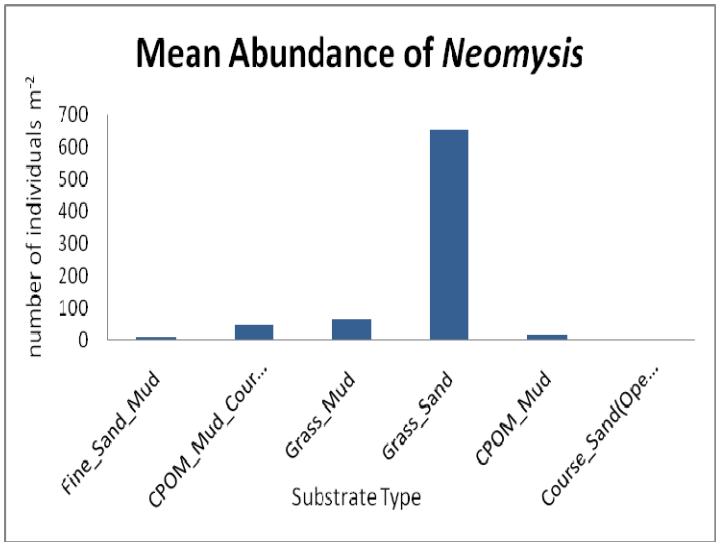

Figure 5. Average Abundance of *Neomysis.*

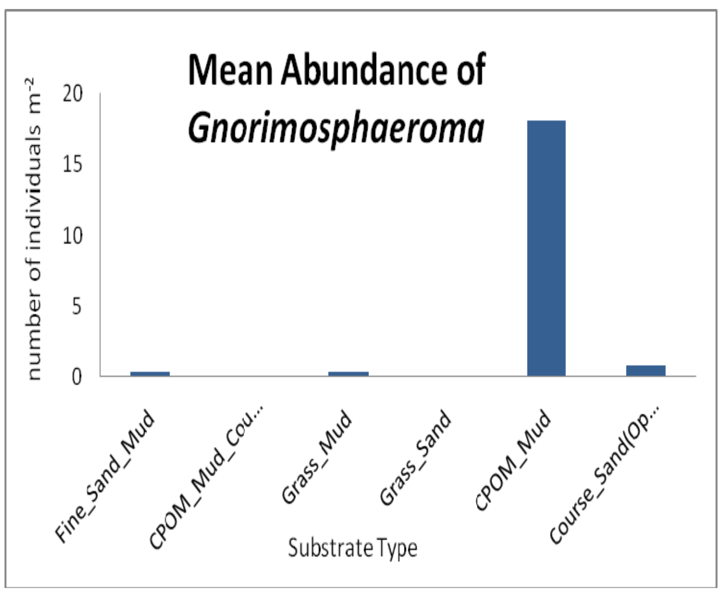

Figure 5. Average Abundance of *Gnorimosphaeroma*

The mean abundance of *C. spinicorne* among the six substrate types is most prevalent among the sandy substrate with true grass (Figure 3) (Appendix B:b). The mean abundance of

Eogammarus among the six substrate types is most prevalent among Fine-Sand/Mud, CPOM/Mud, and Sand/ True Grass (Figure 4) (Appendix B:a). The mean abundance of *Neomysis* among the six substrate types is most prevalent among the sandy substrate with true grass (Figure 5) (Appendix B:b).

The total numbers of each individual per taxon from each epibenthic sample were summed and then divided by the total area of the D-net (4.39 m^2) (Table 2).

Table 2. Taxa Abundance for each of the Twelve Major Lagoon Invertebrates. (number of individuals m^{-2})

	Corophium	Eogamarus	Acari	Neomysis	Nematoda	Isopoda	Gastropoda	Corixidae	Stickleback	Coleoptera 1	Coleoptera 2	Chironomi	trichoptera	Juv.	Plecoptera
Sum	438	1737	53	7948	1965	383	54	3	2	3	5	1	2	1	2
Taxa Abundance	99.8	396	12.07	1810	448	87.2	12	0.7	0.5	0.7	1.1	0	0	0	0.5

Table 3. Raw data of Major Lagoon Invertebrates among each Substrate Type (number of individuals m^{-2})

Substrate	Corophium	Eogamarus	Acari	Neomysis	Nematoda	Isopoda	Gastropoda	Corixidae	Stickleback	Coleoptera	Coleoptera	Chironomi	trichoptera	juv. sculpin	Plecoptera
Fine_Sand_Mud	0	5	0	20	7	0	0	0	0	0	0	0	0	0	0
Fine_Sand_Mud	0	8	0	7	0	0	0	0	0	0	0	0	0	0	0
Fine_Sand_Mud	6	221	0	28	11	0	0	0	0	0	0	0	0	0	0
Fine_Sand_Mud	4	123	0	19	2	0	0	0	0	0	0	0	0	0	0
Fine_Sand_Mud	1	25	0	27	0	0	0	0	0	0	0	0	0	0	0
Fine_Sand_Mud	7	20	0	0	39	2	0	0	0	0	0	0	0	0	0
Fine_Sand_Mud	3	73	0	2	16	0	0	1	0	0	0	0	0	0	0

Fine_Sand_Mud	2	65	1	3	106	1	0	0	0	0	0	0	0	0	0
Fine_Sand_Mud	9	96	0	1	71	1	0	0	0	0	0	0	0	0	0
Fine_Sand_Mud	5	57	0	14	38	0	0	0	0	0	0	0	0	0	0
CPOM_Mud_Course Sand (Lake)	5	4	10	80	156	0	0	0	0	0	0	0	0	0	0
CPOM_Mud_Course Sand (Lake)	1	3	4	66	79	0	0	0	0	0	0	0	0	0	0
CPOM_Mud_Course Sand (Lake)	4	6	1	91	137	0	0	0	0	0	0	0	0	0	0
CPOM_Mud_Course Sand (Lake)	4	1	0	5	270	0	0	0	0	0	0	0	0	0	0
CPOM_Mud_Course Sand (Lake)	6	6	1	102	173	0	1	0	0	0	0	0	0	0	0
CPOM_Mud_Course Sand (Lake)	6	4	2	20	396	0	1	0	0	0	0	0	0	0	0
CPOM_Mud_Course Sand (Lake)	3	4	0	37	127	0	0	0	0	0	0	0	0	0	0
CPOM_Mud_Course Sand (Lake)	5	2	0	26	1	0	0	0	0	0	0	0	0	0	0
CPOM_Mud_Course Sand (Lake)	14	1	3	23	230	0	0	0	0	0	0	0	0	0	0
CPOM_Mud_Course Sand (Lake)	5	5	0	6	95	0	3	0	0	0	0	1	1	0	0
Grass_Mud	4	3	2	18	1	3	1	0	2	0	0	0	0	1	0
Grass_Mud	0	0	0	300	1	0	0	2	0	0	1	0	0	0	0
Grass_Mud	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0
Grass_Mud	0	0	0	21	0	0	0	0	0	3	1	0	0	0	0
Grass_Mud	0	0	6	38	0	0	0	0	0	0	0	0	0	0	0
Grass_Mud	0	0	4	32	0	0	0	0	0	0	1	0	0	0	0
Grass_Mud	0	0	3	91	0	0	0	0	0	0	0	0	0	0	0
Grass_Mud	0	0	1	47	0	0	0	0	0	0	0	0	0	0	0
Grass_Mud	0	0	4	54	0	0	0	0	0	0	0	0	0	0	0
Grass_Mud	0	0	2	67	0	0	0	0	0	0	0	0	0	0	0
Grass_Sand	0	0	2	65	0	0	0	0	0	0	0	0	0	0	0
Grass_Sand	4	24	0	1132	0	53	0	0	0	0	0	0	0	0	0
Grass_Sand	101	81	0	497	0	13	0	0	0	0	0	0	0	0	0
Grass_Sand	21	53	0	830	0	63	0	0	0	0	0	0	0	0	0
Grass_Sand	69	46	0	273	0	10	0	0	0	0	0	0	0	0	0
Grass_Sand	14	30	0	940	0	8	0	0	0	0	0	0	0	0	0
Grass_Sand	6	78	0	348	0	6	0	0	0	0	0	0	0	0	0
Grass_Sand	5	39	1	930	0	22	0	0	0	0	0	0	0	0	0
Grass_Sand	9	76	0	972	0	7	0	0	0	0	0	0	0	0	0
Grass_Sand	6	62	0	523	0	5	0	0	0	0	0	0	0	0	0
CPOM_Mud	58	91	0	8	0	20	0	0	0	0	0	0	0	0	0
CPOM_Mud	3	16	0	1	0	17	0	0	0	0	1	0	1	0	0
CPOM_Mud	17	58	0	0	0	10	17	0	0	0	0	0	0	0	0
CPOM_Mud	1	65	2	6	0	18	0	0	0	0	0	0	0	0	0
CPOM_Mud	7	24	2	58	0	18	0	0	0	0	0	0	0	0	0
CPOM_Mud	13	88	0	110	3	10	4	0	0	0	0	0	0	0	0
CPOM_Mud	0	5	0	0	0	21	0	0	0	0	0	0	0	0	0
CPOM_Mud	2	65	0	1	3	22	4	0	0	0	0	0	0	0	0
CPOM_Mud	1	70	0	0	0	18	15	0	0	0	0	0	0	0	0

Course_Sand(Open_Sand_Bar)	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
Course_Sand(Open_Sand_Bar)	2	0	0	2	0	1	0	0	0	0	0	0	0	0	0
Course_Sand(Open_Sand_Bar)	1	1	0	2	0	0	0	0	0	0	0	0	0	0	0
Course_Sand(Open_Sand_Bar)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Course_Sand(Open_Sand_Bar)	2	0	0	1	0	3	0	0	0	0	0	0	0	0	0
Course_Sand(Open_Sand_Bar)	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Course_Sand(Open_Sand_Bar)	1	0	0	3	0	0	0	0	0	0	0	0	0	0	0
Course_Sand(Open_Sand_Bar)	1	1	0	1	0	2	0	0	0	0	0	0	0	0	0
Course_Sand(Open_Sand_Bar)	0	1	0	0	0	2	0	0	0	0	0	0	0	0	1
Course_Sand(Open_Sand_Bar)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4. Evidence that habitat has an effect on the abundance of each taxon

Taxon	Evidence Ratio between habitat-associated and null model	Evidence for habitat association
C. spinicorne	344	Decisive
Eogammarus	3.8×10^{7}	Decisive
Neomysis	1.2×10^{16}	Decisive
Nematoda	6.0×10^{12}	Decisive
Gnorimosphaeroma	1.3×10^{8}	Decisive
Gastropoda	2.1×10^{4}	Decisive
Acari	5.1×10^{3}	Decisive
Corixidae	1.0	Minimal
Coleoptera 1	2.0	Substantial
Coleoptera 2	3.5×10^{3}	Decisive
Chironomidae	2.0	Minimal
Tricoptera	1.0	Minimal
Plecoptera nymph	55	Strong
Juvenile Sculpin	2.0	Minimal
Stickleback	2.0	Minimal

All the collected data of the abundance of each species in relation to substrate type was entered into an excel spreadsheet where it was then given to Dr. Fred Watson for the purpose of conducting a statistical analysis through the use of the statistical program "R." Evidence ratios were computed as the ratio between the AIC weights of the habitat and null models respectively.

Evidence ratios greater than 100 were interpreted as 'decisive' (*sensu* Jeffreys, 1960), and so on for 'strong', 'substantial', and 'minimal' at evidence ratios above 10, above 3.16 (the square root of 10), and between 1.00 and 3.16. Table 4 thus shows how strong the evidence is that habitat type does have an effect on the abundance for each species.

Discussion

Upon the completion of the analysis, twelve invertebrate taxa and two vertebrate taxa were observed and counted. The twelve invertebrate taxa that were identified within this study were also identified by the taxonomic key of Larson *et al.* (2006), Perry *et al.* (2007), and Fields (1984): *Eogammarus*, *C. spinicorne*, *Neomysis*, *Acari*, *Gnorimosphaeroma*, *Coleoptera* (1&2), Gastropods, Polychaetes, *Chironomidae,* Nematodes, , *Corixidae*, *Plecoptera* nymphs, *Trichoptera* Larvae, and (Appendix A). The two presumed vertebrate species of fish that were sampled were Sticklebacks and a Juvenile Sculpin.

Eogammarus are side-swimming scuds that are commonly found resting among large pieces of vegetation and other forms of debris on top of the soft benthic substrate (McCafferty, 1981). This habitat preference agrees with the results of this study, *Eogammarus* were more abundant among substrate types that contained large pieces of lagoon vegetation, i.e. tuly reed fragments (Appendix A:b).

C. spinicorne are commonly found catching drifting food particles from self-made tubes among sandy sediments (Smith. 2001). The results of this study agree with Smith (2001), *C. spinicorne* was more abundant among sandy-substrates that consisted of self-made tubes that matted the sandy-shoreline (Appendix A:a).

Neomysis, also known as opossum shrimp, are commonly known as omnivores that feed on detritus and algae (Gooderham J. & Tsyrlin, E. 2002). The results of this study are supported by the descriptions made by Gooderham J. & Tsyrlin, E. (2002) since *Neomysis* were most abundant in sandy substrates with grass.

Acari are mites that are commonly found among many different substrate types (Gooderham J. & Tsyrlin, E. 2002). The observed *Acari* within the Carmel Lagoon were free-swimming and were found in five of the six substrate types. The results of this study are consistent with the descriptions of Gooderham J. & Tsyrlin, E. 2002 (Appendix A:e).

Gnorimosphaeroma are Isopods that were found in almost every substrate type that contained coarse and fine particles of vegetation (Gooderham J. & Tsyrlin, E. 2002). Therefore, the results of this study agree with Gooderham J. & Tsyrlin, E. (2002) with respect to habitat preference of *Gnorimosphaeroma* (Appendix A:d).

Two species of aquatic beetles, also known as Order: *Coleoptera* are known to be more abundant among habitats with high amounts of algae and other forms of vegetation (Smith, 2001). The finding of Smith, (2001) are consistent with this study because *Coleoptera* were observed swimming in the substrate type CPOM with mud (Appendix A:h,j).

Both Aquatic Snails, also known as Gastropods and Polychaetes are very tolerant of very axonic water conditions and are therefore able to maintain their abundance as water quality deteriorates (Smith, 2001), Therefore, results of this study agree with Smith (2001), both gastropods and Polychaetes were more abundant among muddy substrates that were exposed to anoxic water conditions (Appendix A: m;g respectively).

Chironomids and nematodes prefer to inhabit substrates that are muddy with anoxic conditions (Gooderham & Tsyrlin, 2002) and Smith (2001). Therefore, this study agrees with Gooderham & Tsyrlin 2002 because both nematodes and one chironomid were observed within the muddy substrate of the Odello Arm of the Carmel Lagoon (Site 2) (Table 1).

Corixidae, commonly referred to as Water Boatman are known to be abundant in many types of water qualities both good (aerobic) and bad (anaerobic) (Gooderham J. & Tsyrlin, E. 2002). The findings of this study do not agree with Gooderham J. & Tsyrlin, E. (2002); *Corixidae* was not found within each of the six different substrate types for unknown reasons. They were instead only found among Fine Sand Mud and Grass Mud Substrates. (Appendix A:i) (Table 1).

Plecoptera, also known as Stoneflies are a species that are sensitive to water quality and are commonly found in freshwater habitats (Peckarsky et al. 1990). Although *Plecoptera* are not commonly found within brackish waters, one individual species was counted while sampling the Course Sand (Open Sand Bar) substrate type. . Therefore, likely due to accidental-drift, the high velocity of the flowing Carmel River resulted in *Plecoptera* getting caught and flowing through the open sand-bar and out into the ocean (Appendix A:n).

Trichoptera, more commonly known as Caddisflies are also known to be sensitive to water quality (Gooderham & Tsyrlin 2002). *Trichoptera* was only found in one substrate type (CPOM and muddy substrate). Therefore, the findings of this study don't completely agree with Gooderham & Tsyrlin (2002) because high water quality is not commonly found among muddy substrates, however further testing of water conditions at Site 5 may result differently (Appendix A:l).

Studies conducted by Larson (2005-2006) and Perry (2007) looked at the abundance of major lagoon invertebrates over a time period of several years and laid the ground work for this study. Although their studies did not observe the spatial patterns of major lagoon invertebrates in relation to substrate type, these studies do however provide a sense of variation of species abundance over time within a newly created Odello Extension of the Carmel Lagoon.

All the provided evidence suggests that there is a strong association between substrate type and the abundance of invertebrate taxa. This evidence supports the original postulate of there being habitat associations for the invertebrate taxa of the lagoon, but they do not support the specific hypothesis that *C. spinicorne* specifically prefer ‘sandy’ habitats. Based on the evidence provided above, the abundance of major lagoon invertebrates is higher among substrates that contains grass, algae, and other forms of both aquatic and terrestrial vegetation.

Originally the hypothesis was made that *C. spinicorne* would avoid substrates that contained a significant amount of fine sediments (silts/clays), however the opposite was true. The study site of Watson (2007) was located along the northern-side of the Odello Arm, which according to Table 1 is made up of saturated sandy substrate with the growth of true grasses (Appendix B:b). The raw data of Watson (2007) shows that *C. spinicorne* within saturated sandy substrate with grass was more abundant in comparison to the abundance of *C. spinicorne* at the same location within this study. Seasonal variation may be a possible explanation for the difference in abundance between Watson (2007) and this study.

While sampling in the field, spatial patterns of *Corophium* and *Eogammarus* were not immediately obvious. However, while sampling in the field, observations of *Neomysis* were immediately evident among muddy substrates with grass and sandy substrates with grass. It wasn’t until the invertebrates within the samples of each substrate type were counted, when the actual spatial patterns were attained, as described above. Also upon walking within Coarse Particulate Organic Matter with mud substrates, algae was accidentally removed from a terrestrial branch, when *Neomysis* were immediately observed feeding on the floating algae. It was upon these observations when it became obvious that *Neomysis* is more commonly found among substrate types that are high in aquatic and terrestrial vegetation because they are nutrient rich. Observations of the study site suggest that the tule reeds that grow along the banks of the lagoon play a significant role in nutrient input.

Since substrate type evidently does play a strong role in the abundance of major lagoon invertebrates, more efficient restoration of California coastal lagoon habitats can be implemented.

Although a significant amount of information has been learned about the effects that substrate type has on the abundance of major lagoon invertebrates, more research is still needed to further understand the complex ecosystem dynamics that occur temporally. A more thorough analysis of substrate type would also be recommended to become more precise in each substrate type's description and exact locations. Further research would also be recommended to investigate the nutrient input of the tule reeds into the Carmel Lagoon (Appendix B:c).

Conclusion

In conclusion, eight taxa were found to have generally strong habitat associations among the six substrate types. The most prevalent taxa among all six sites were *C. spinicorne, Neomysis,* and *Eogammarus*. Both *C. spinicorne* and *Neomysis* were most abundant amoung sandy substrate with true grasses, while Eogammarus preferred Fine_Sand_Mud, sandy substrate with true grass, and Coarse Particulate Organic Matter with mud. From a more broad aspect, the greatest abundances of steelhead-prey taxa were found in sandy substrates with true grass, Fine Sand Mud, and CPOM with mud habitats. More specifically, *C.spinicorne, Neomysis,* and *Eogammarus* (the three out of the four primary food sources of steelhead, as indicated by Fields (1984)) collectively, were most commonly found in sandy substrates with grass. Therefore, it is recommended that sandy substrate with grass habitats should be well protected to influence a greater abundance of the primary food source for steelhead. It is also recommended that more sandy substrate with grass habitats be created. If the primary food source of steelhead can increase, then the populations of steelhead may also increase.

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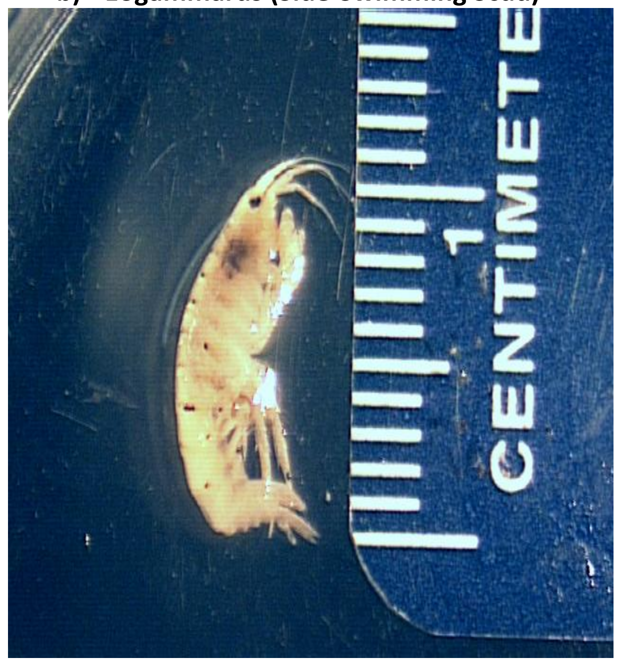
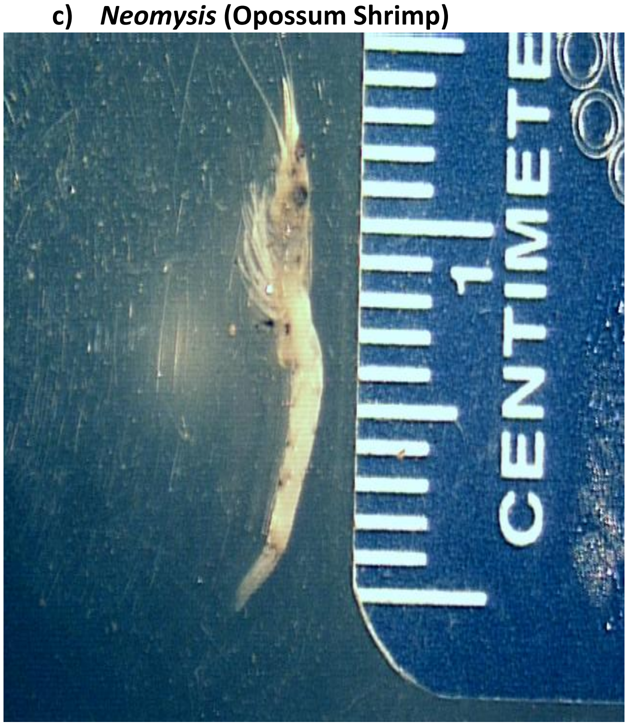
Appendix A

a) *Corophium spinicorne*

b) Eogammarus (Side-Swimming Scud)



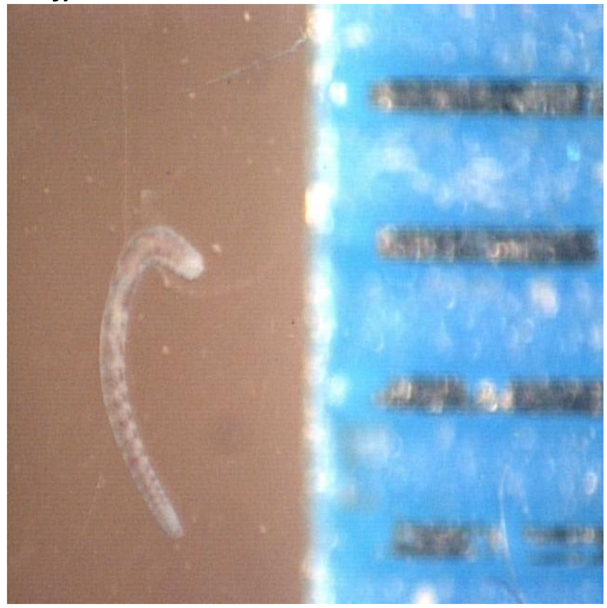
c) *Neomysis* (Opossum Shrimp)



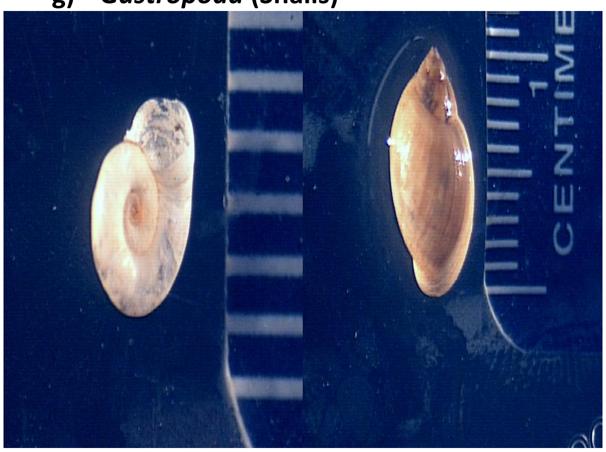
d) *Gnorimosphaeroma (*Isopod)

e) *Acari* (Mite)

f) *Nematoda*

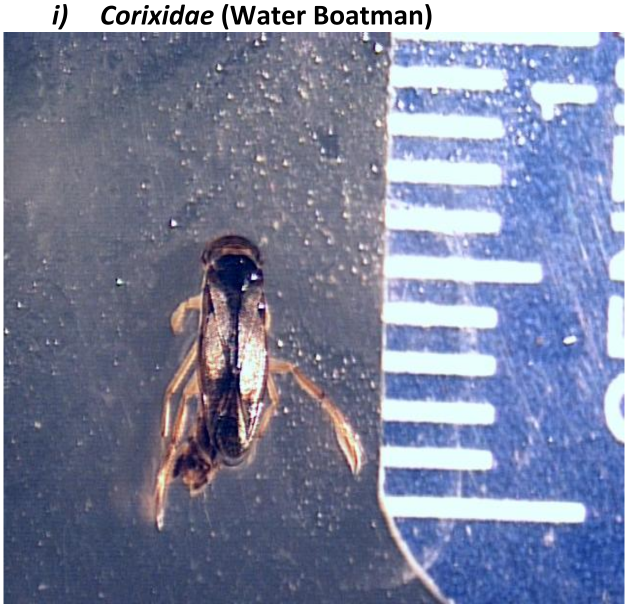


g) *Gastropoda* (Snails)

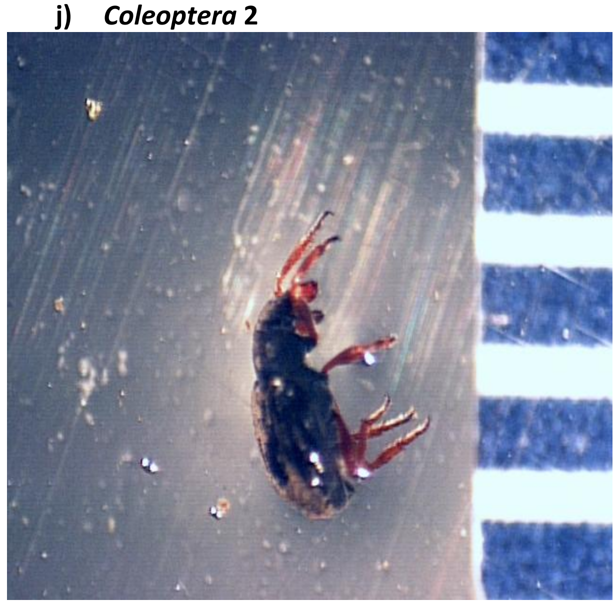


h) *Coleoptera* 1

i) *Corixidae* (Water Boatman)



j) *Coleoptera* 2



k) ***Chironomidae***

l) ***Tricoptera* (Caddisfly Larvae)**

m) Oligochaeta* (Segmented Worm*)

n) ***Plectoptera* (Stonefly Nymph)**

Appendix B

a)True Grass in Saturated Muddy Substrate

b)True Grass in Saturated Sandy Substrate

c) Tule Reed Flower