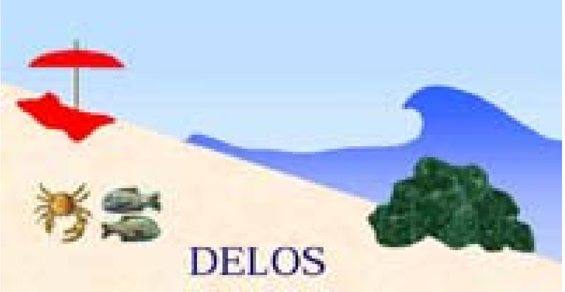
EU Fifth Framework Programme 1998-2002
Energy, Environment and Sustainable development

# Environmental Design of Low Crested Coastal Defence Structures (DELOS)



## Draft report

## Deliverable 50
## WP 3.5

Report on the development and implications of metapopulation structure of low crested structures as habitat patches for rocky shore organisms

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## Introduction

The construction of artificial reefs in a sandy beach environment creates virgin habitat for rocky shore organisms. Earlier isolated patches of natural habitat may become connected via a chain of "stepping-stones" such that gene flow is permitted and also the dynamics of some or all species is shifted from the original situation.

Such a situation may promote the invasion of introduced or alien species. Depending on the actual positions of new artificial substrate the dispersal speeds, i.e., km/generation or similar, may differ. In W.P 3.5 we are assessing the large-scale effects of breakwaters on the distribution and abundance of species. For Deliverable 50 we have used *Patella caerulea* as a model organism. *P. caerulea* is a long lived prosobranch gastropod living in the intertidal (Della Santina et al. 1993). This marine snail grazes on the rock surface consuming the microfilm as well as recruits of barnacles and macroalgae. It has the potential of structuring its environment.

Spatial ecology and spatial population dynamics are wide fields of research. However, it is still unknown what the general effect on originally isolated natural communities is when gene flow is established. Deliverable 50 tries to answer some questions about the effect of the positioning of LCS's on the regional population dynamics of *P. caerulea* in the Ravenna region.

## Principles of metapopulations

A metapopulation is a population of populations. In effect this means that there exist several local populations that interact, via migration or dispersal. This interaction causes regional dynamics. Many people have helped in developing metapopulation models, and models exist for several different organisms, environments etc (for review see Hanski & Gilpin 1997).

Metapopulation models are used to calculate extinction risks for endangered species in fragmented landscapes, the design of nature reserves etc. We have constructed a metapopulation model that encompasses local dynamics. This is important for long-lived organisms such as *P. caerulea*.

## Effects of specific placement of LCS's

Dispersal models in marine environments using diffusion models have not been very successful in explaining dispersal speeds and distances presumably due to between year variations in current speeds and directions (Grosholz 1996; Hastings 1996). For that reason we here used a model of a Lagrangean form driven by current data collected in the field. This type of model treats larvae as passive particles being moved by water currents. This has the advantage that we are using actual current speeds and directions. However we do not get around the problem of between year variations due to a limited data set.

Demographic data on *P. caerulea*, sizes (mm) and growth of individuals, have been collected over a wide geographical range in the study area. This work has been conducted every 6 months. From the demographic data transition matrices were constructed to predict the dynamics of *P. caerulea* on each LCS.

The connectivities of the different LCS's were calculated using MatLab. All LCS's had been mapped with GPS and put into MatLab. From each LCS a large number of virtual larvae were released and tracked to establish the probability of settling and metamorphosing on other LCS's. All pair wise combinations were tested.

The transition matrices, describing the local dynamics, and the connectivity matrix, describing dispersal make up the metapopulation of *P. caerulea* populations in the Ravenna region.

The duration of larval stages is one factor that can explain how far larvae are dispersed. Larvae of marine invertebrates have widely varying larval stages concerning swimming activity, feeding, duration etc. These different behaviours lead to very different dispersal distances. Hence it is not possible to develop a general model of dispersal of marine invertebrates. The modelling framework we have developed is useful for many different organisms but the actual dispersal kernel needs to be developed for the specific biology of the studied organism.

## Effects of behaviour of larvae

There are examples of larvae changing position in the water column depending on tidal cycle such that the individual larva maximises its chance of reaching a suitable habitat to settle and metamorphose in. Because of these behavioural differences leading to very different dispersal patterns we have modelled different scenarios. Either larvae are distributed by the surface current or by the water current along the bottom (Case 3). In surface water we tested different maturation times, i.e., if the larvae are ready to settle and metamorphose after 1.5 (Case 2) or 4 days (Case 1).

## Distribution of dispersal

We have calculated potential spread of larvae as well as the maximal distance for different scenarios of behaviour. The distributions of dispersal distances of *P. caerulea* larvae vary greatly depending on the depth at which they travel. The polar diagrams below show the position at which a larva dies after being released. No larva is allowed to travel for more than 12 days. 12 days is assumed the maximum life span of a *P. caerulea* larva.

Case 1:
Larvae travel in surface water and settle after 4 days.

Case 2:
Larvae travel in surface water and settle after 1.5 days.

Case 3
Larvae travel in bottom water (app. 3 meters depth) and settle after 1.5 days.

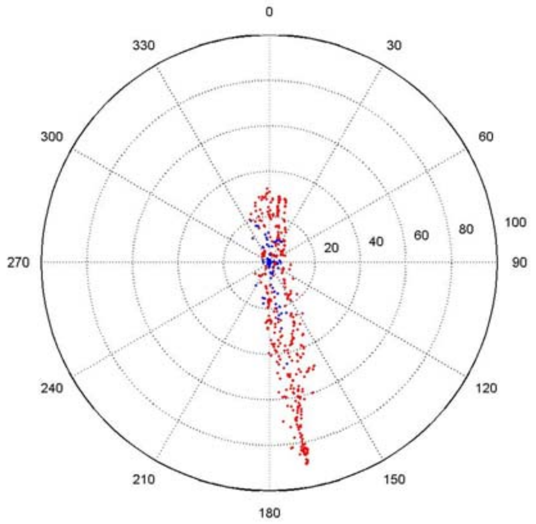

**Figure 1**. Dispersal distances for larvae travelling at the surface. Distance (km) and bearing recorded when larvae die. Blue dots indicate larvae that died before maturing into competent.

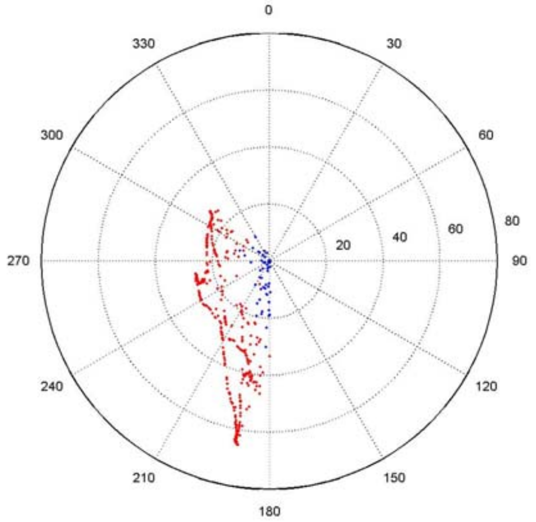

**Figure 2**. Dispersal distances for larvae travelling in the middle of the water column. Distance and bearing recorded when larvae die. Blue dots indicate larvae that died before maturing into competent.

The maximum dispersal distance of a larva travelling in surface water in the region along the Ravenna shore is 89 km. However, this is unlikely to happen since *P. caerulea* larvae have an inactive phase early in the larval stage when they most likely are fairly sedentary. The maximum dispersal distance for a larva spending its entire larval stage close to the bottom is 47 km. This is a theoretical example of dispersal in an environment with no limits, such as shoreline. For the given current regime and the bathymetry of the Ravenna coast all of the competent larvae in Figure 3 will end up on the beach. The maximal distance correcting for the shoreline (assuming that larvae die and are unable to settle if they reach the beach) becomes 60 km for the case in Figure 1, 20 km for the Figure 2 case and 10 km for the Figure 3 case. Also, extremely few competent larvae will disperse successfully to suitable habitat (i.e., LCS's).

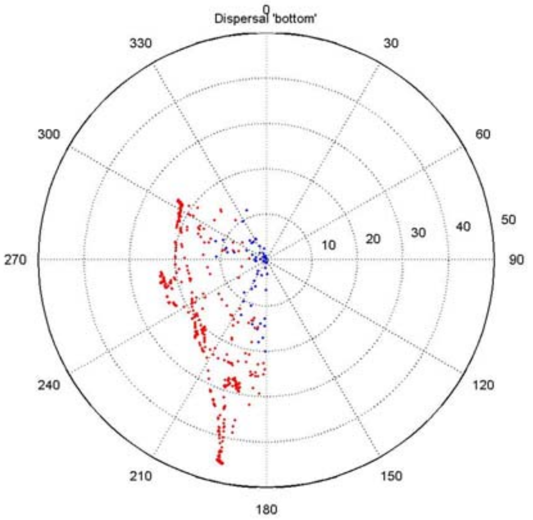

**Figure 3**. Dispersal distances for larvae travelling along the bottom. Distance and bearing recorded when larvae die. Blue dots indicate larvae that died before maturing into competent.

## Validation of model

The developed model contains a large number of variables and is constructed from a large set of data. To validate its function we use the large-scale distribution patterns from the pilot study (Deliverable 3).

The distribution patterns given from the dispersal kernel shows that the Cesenatico LCS are receiver populations and hence should be high density populations. Also there is a cluster of LCS's in the centre of the study area that are receiver populations as well. This cluster of populations corresponds to the Lido Di Classe LCS's. This corresponds well to the patterns found in the pilot study (Deliverable 3).

In the null-models, i.e., the metapopulation models where no structures are removed the fraction occupied patches is 0.53, 0.91 and 0.29 for Case 1, Case 2 and Case 3 respectively. These figures should be compared to the following simulations of random removals of structures ((C) in Figures 4-6).

## Removal of LCS

Removing habitat patches increases the risk of regional extinction as the extinction probability is correlated to the size of the populations and the connectivity among the remaining populations will decrease. The regional extinction of *P. caerulea* may have positive effects on the natural populations of *P. caerulea*. Local adaptation may, for example, be suppressed by gene flow (dispersal) between natural populations. This gene flow is off course mediated by the presence of LCS's.

The predicted effect of removing a random LCS is that the fraction of populations containing adult individuals will decrease due to decreased production of larvae and decreased dispersal of larvae. However, the magnitude of the effect will depend on the physical and biological environment of the particular LCS. There will be an enormous difference between removing a low-density population contributing nothing in terms of larvae to other populations, or removing a high-density population contributing substantial amounts of larvae to other populations on the effect of the population dynamics.

Figures 4-6 show three different simulations of random removals of LCS's in the Ravenna region. Of the 77 LCS's in the study first 1 then 2, 3 … 76 were removed. Every set of removals was repeated randomly 150 times to see the effect of different positions on the resulting dynamics of *P. caerulea* in the area. The three different simulations correspond to the Cases stated above. following flow regimes and larval biology:

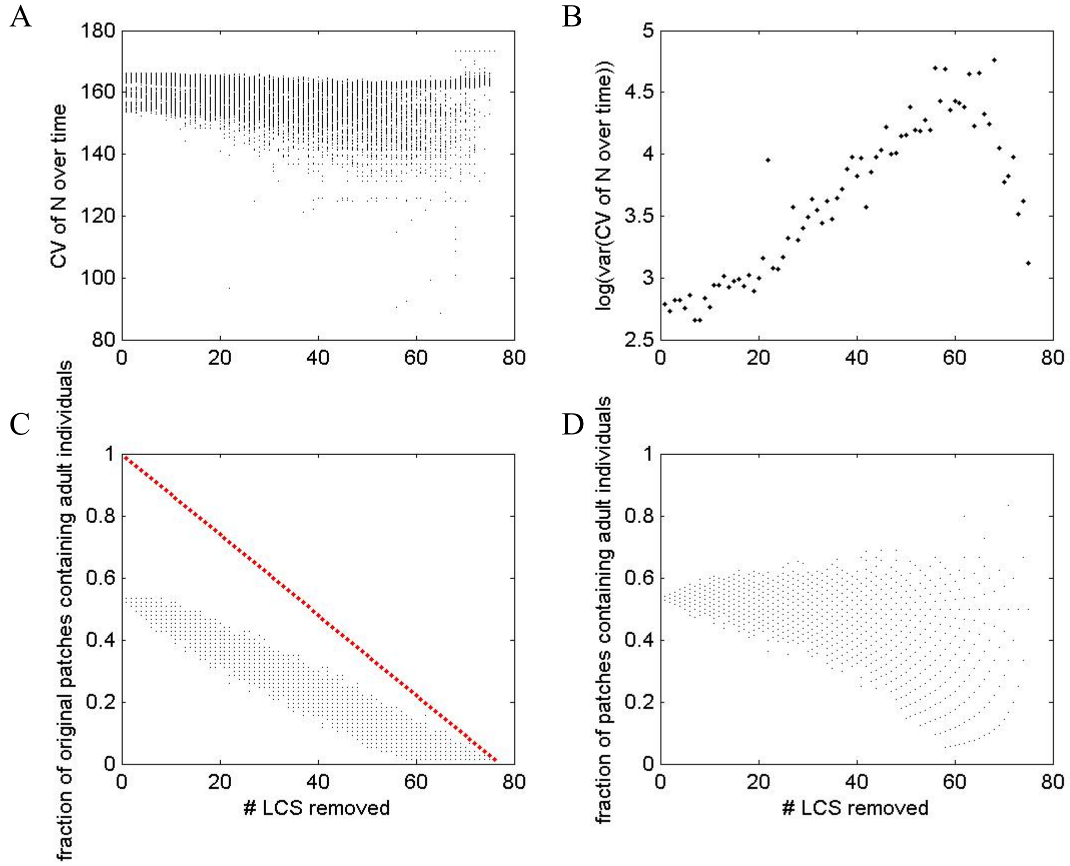

**Figure 4**. Simulation 1. 4 different types of dynamics of *Patella caerulea* are depicted. Each simulated removal was repeated randomly 150 times. (**A**) Coefficient of variation (CV) of the population sizes in the whole region. (**B**) The logarithm of the variance of the CV of the population sizes of the different sites, i.e., a measure of the variation in regional population dynamics. (**C**) Proportion occupied structures (out of 77). The dashed line is the maximum possible fraction. (**D**) Same data as in (C) but scaled to the maximum possible fraction.

The dispersal matrix for Simulation 1 shows a general transportation of larvae from North to South. However, a fair amount of the populations (LCS's) are not connected to any other populations. Hence the fraction of populations containing adult individuals is fairly low (Figure 4C). Interesting to note is that The variability in population size (Figure 4A and 4B) increases as the number of removed LCS's increase but after a maximum level it drops off. The number of remaining LCS's is small and the number of different combinations is rather small, hence the small variation in population size.

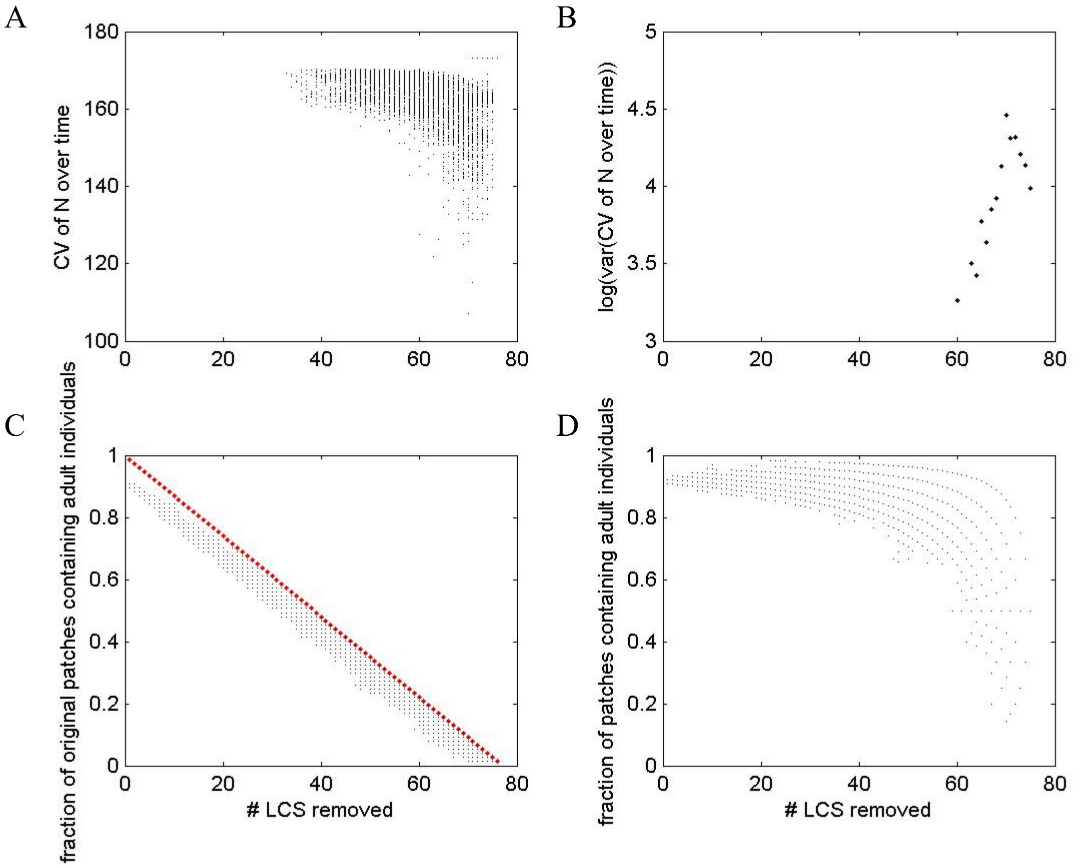

**Figure 5**. Simulation 2. 4 different types of dynamics of *Patella caerulea* are depicted. Each simulated removal was repeated randomly 150 times. (**A**) Coefficient of variation (CV) of the population sizes in the whole region. (**B**) The logarithm of the variance of the CV of the population sizes of the different sites, i.e., a measure of the variation in regional population dynamics. (**C**) Proportion occupied structures (out of 77). The dashed line is the maximum possible fraction. (**D**) Same data as in (C) but scaled to the maximum possible fraction.

In Simulation 2 the dispersal matrix still shows transportation of larvae from North to South, but in this case more populations are connected. This connectivity leads to large fluctuations in population size (Figure 5A). These fluctuations are so large for removals fewer than 60 that MatLab calls them Inf and cannot calculate proper variances (Figure 5B). The high connectivity causes a higher proportion of the populations to contain adult individuals (Figure 5C and 5D) compared to Simulation 1. However, there is a drastic decline in proportion occupied patches (Figure 5D) for a high number of removed LCS’s.

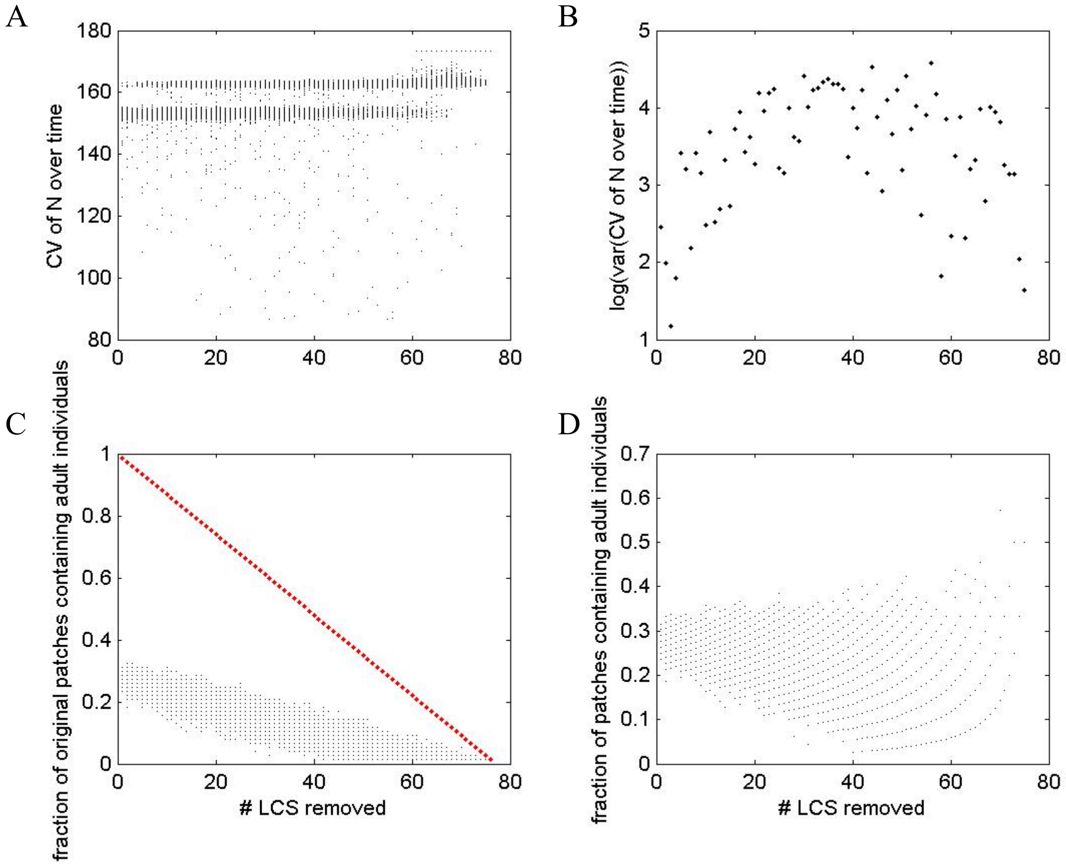

**Figure 6**. Simulation 3. 4 different types of dynamics of *Patella caerulea* are depicted. Each simulated removal was repeated randomly 150 times. (**A**) Coefficient of variation (CV) of the population sizes in the whole region. (**B**) The logarithm of the variance of the CV of the population sizes of the different sites, i.e., a measure of the variation in regional population dynamics. (**C**) Proportion occupied structures (out of 77). The dashed line is the maximum possible fraction. (**D**) Same data as in (C) but scaled to the maximum possible fraction.

The results from Simulation 3 are similar to those from Simulation 1. However, one great difference exists. The dispersal matrix for dispersal along the bottom has a flux of larvae from South to North. The quantitative results are similar to Simulation 1, but the actual LCS's causing the dynamics may be different.

Understanding the variation in effect depending on LCS position is essential in accuiring the aspired result of a removal of a LCS. A well-designed field campaign and a reasonable dispersal model are useful tools in assessing spatial dynamics of any system.

**Table 1**. Numbering of structures in the simulations.

| Location of structures | Number of structures |
|---|---|
| Lido Adriano | 1-16 |
| Lido Di Dante | 17-18 |
| Lido Di Classe | 19-28 |
| Lido Di Savio | 29-43 |
| Cesenatico | 44-77 |

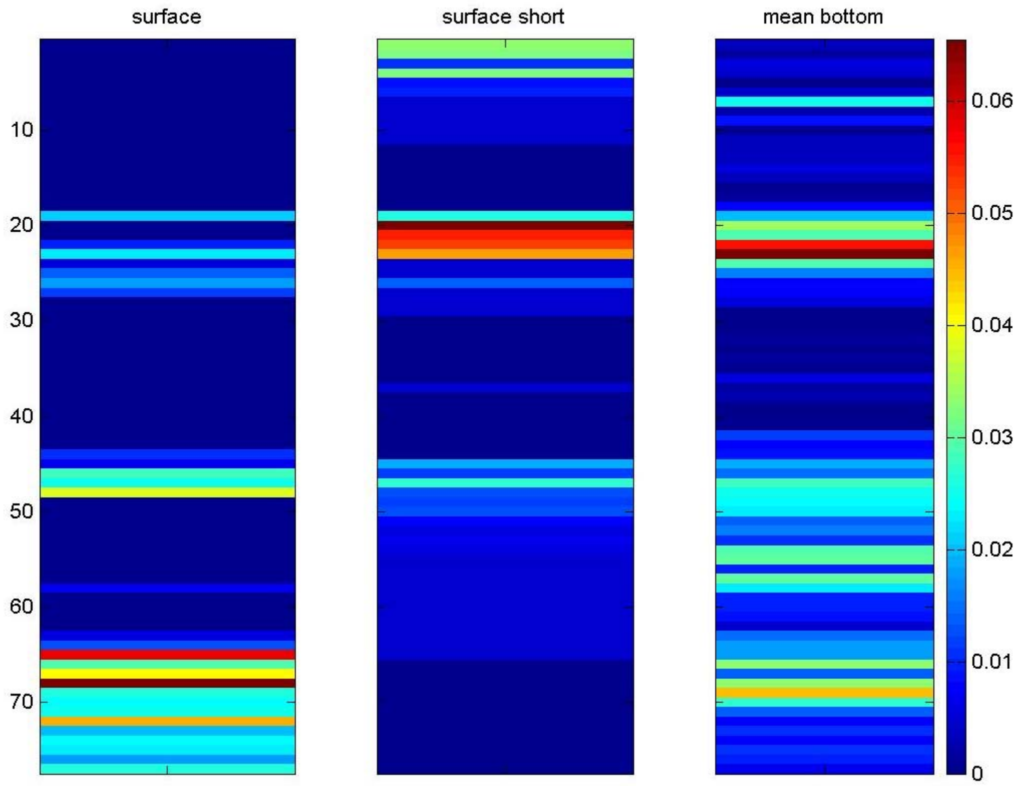

**Figure 7**. Stable structures of the metapopulation models given three different flow regimes. The sites corresponding to LCS number are given in Table 1. The colour shows every populations size in percentage of the total region. Structures # 19-27 (Lido Di Classe) and 44-49 (Northern part of Cesenatico) are key structures for the persistence of *P. caerulea* in this system.

To see which LCS's are important to the population dynamics of the system we calculated the stable structures for the dispersal matrices of the three cases. The numbering of cells in Figure 7 correspond to the sites given in Table 1. From Figure 7 one can see that in Simulation 1 ("surface") the Southern populations (Cesenatico) are persistent in the system as well as some populations in the middle and Northern part of the study area. For Simulation 2 ("surface short") the persistent populations are all over the area. If the dispersal takes place mainly in the lower part of the water column the persistent populations are mainly in the northern part of the study area ("mean bottom"). Some persistent populations coincide in all simulations. These populations can be interpreted to be the most important to the population dynamics of this system. LCS #19-27 are situated at Lido Di Classe and LCS # 44-49 correspond to the Northern part of Cesenatico. These LCS's are the ones determining a major part of the dynamics of *P. caerulea* around the Ravenna shoreline.

## Addition of new LCS's

It is not hard to realize that the addition of new LCS's will have more or less the opposite effect of removals. We see possibilities in managing the populations of *P. caerulera*. The positioning of new LCS's from a metapopulation dynamics point of view will be a question of how one wants the populations of *P. caerulea* to develop. Two scenarios are considered.

First, is *P. caerulea* wanted as a grazer on the structures for example to remove macroalgae and one wants to facilitate dispersal? In this case one should add LCS's where they benefit the dispersal as much as possible. In Figure 7 these sites are given for the different flow regimes. To minimize an increase in gene flow this may be the best solution.

Second, if *P. caerulea* is not wanted on the structures new LCS's should be constructed in the regions in Figure 7 coloured in blue, the sites that are not long term persistent. However, this may be harmful in a gene flow sense, increasing large-scale dispersal.

## Conclusions

We have modelled the maximum distance of dispersal to 89 km. However, depending on variations in flow and behaviour of larvae dispersal may range between 10 and 89 km. This means that the probability of gene flow between the natural rocky reefs in the area was extremely low before the construction of breakwaters and harbours began. There are no longer any stretches of beaches without structures of 89 km or longer. We conclude that although we cannot at present quantify the probability of gene flow, or migrants per generation, between the natural rocky reefs in the studied area, there exists a substantial transport of larvae along the Ravenna shoreline. Through the action of the structures as "stepping-stones" the natural reefs will undoubtedly experience gene flow.

The position of a LCS' has a great effect on the population dynamics following removal.

Also, the removal of LCS's will have different effects depending on flow regime.

We have identified a number of key structures that with a high probability contribute to a substantial part of the regional population dynamics.

Additions of LCS's have different effects depending on the position. C.f. removal of LCS's.

## References

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