Appendix S1

Hydrodynamic model

Three-dimensional sea current velocities were obtained for the period 1961-2099 from the Mediterranean model NEMOMED8 (Sevault *et al.*, 2009; Beuvier *et al.*, 2010), based on the IPCC A2 scenario following the methodology and forcings defined in Somot et al. (2006). NEMOMED8 is a state-of-the-art regional ocean circulation model designed to study the long-term variability of the Mediterranean Sea (Beuvier *et al.*, 2010; Herrmann *et al.*, 2010; Albouy *et al.*, 2012; L'Hévéder *et al.*, 2012). The model accounts for the main drivers of current dynamics: air–sea water, heat and momentum fluxes, river discharges (33 main rivers mouths plus the Black Sea freshwater inflow considered as a river) and water exchanges with the near-Atlantic Ocean. Although widely used for regional scenarios of climate change (Christensen *et al.*, 2002), the A2 scenario is considered a conservative, but not the worst, future prediction of global warming. It assumes a very heterogeneous world that preserves local identities, and which results from a continuously growing human population and atmospheric CO_2 concentrations of ~815ppm by 2099 (IPCC, 2001). The A2 scenario was chosen for NEMOMED8 because it has become the standard for regional climate studies (Christensen *et al.*, 2002). We are aware that using only one simulation (one model, one set of forcings, one socio-economic scenario) did not allow us to take into account the underlying uncertainties in the current climate change impact study. However coordinated multi-model ensemble runs for a given scenario and/or multi-scenario ensemble runs for a given model are on-going efforts for regional oceanography and the outputs were not ready at the start of our study (www.medcordex.eu; Adloff *et al.*, in prep.).

NEMOMED8 has a horizontal resolution of 1/8th degree, corresponding to a 9-12 km horizontal cell width; NEMOMED8 is thus considered as an eddy-permitting model for the Mediterranean area. The model has 43 vertical layers, unevenly spaced from 6 m-thick at the surface to 250 m-

thick at the bottom. It is worth noting that we cut the domain at depth of 150m for the larval dispersal simulations, using only the first 10 layers of the original model grid (level 10 is 20m-thick). This is sufficient because previous studies (Andrello *et al.*, 2013) showed that larvae very rarely descend below 100 m. After a 15-year spin-up to allow the model to reach its own quasi-equilibrium, we performed a historical simulation from 1961 to 2000 (GHG and aerosol concentrations imposed in the atmosphere model are observed) followed by the scenario run (2001-2099), in which GHG and aerosols concentrations came from the IPCC-A2 scenario. This simulation has been already exploited Albouy *et al.* (2012) to explore the possible evolution of the biogeography of coastal Mediterranean fishes.

Larval dispersal simulation

Daily outputs of zonal and meridional velocities from NEMOMED8 were used in this study to simulate larval dispersion using the software Ichthyop 3.1 (Lett *et al.*, 2008). As the tidal signal in the Mediterranean is relatively small, daily currents were considered appropriate inputs to Ichthyop and were obtained by averaging over the time-steps of NEMOMED8. Thus, circulations acting at higher frequencies are not considered. For a single year, there were 10,000 release events per MPA, therefore providing a lower limit of 0.0001 for connection probability. Larvae were released at 20 cm depth, because eggs of *Epinephelus marginatus* were seen ascend to the surface immediately after spawning (Zabala *et al.*, 1997).

The time step of iteration was chosen so as to be lower than the ratio of cell size to maximum current velocity, so that larvae do not cross more than one cell boundary in a single time step. In our case, cell size was ~9-12 km and maximum current velocity was ~0.5 m s^{-1}, giving an 18000-24000 s ratio, so we chose a 3600 s (1 h) time-step of iteration. Current velocities were tri-linearly interpolated to the position of each larva, each iteration, and the positions of larvae were recorded every 24 time steps (24 h). Advection was simulated using a Runge-Kutta numerical scheme. Horizontal diffusion was applied via a random walk for individual larvae to account for sub-grid-

scale hydrodynamics associated with coastal features (reefs, bays, gulfs, etc.) following Peliz et al. (2007). They suggest that floating velocity can be calculated by adding a random component $u_r(x,y)$ to the horizontal velocity vector, with $u_r = \delta\sqrt{2K_h/\Delta t}$. Here, δ is a real uniform random number in the interval $[-1, 1]$, K_h is the lagrangian horizontal diffusion coefficient $K_h = \varepsilon^{1/3}l^{4/3}$, following Monin and Ozmidov (Monin & Ozmidov, 1982), with ε = turbulent dissipation rate (m^2 s^{-3}) and l = length of the grid cell. Monin and Ozmidov suggested $\varepsilon = 10^{-9}$.

In Ichthyop, larvae intercepting the outer limits of the domain were considered lost; larvae reaching the sea surface were sent back into water; larvae floating in the bottom layers did not touch the seabed because the current velocity was zero at the vertical midpoint of the layer. Larvae reaching the interface between sea and land were sent back to the sea (*bouncing* option in Ichthyop).

Calculation of climate change effects on connectivity variables

We described the effects of climate change on connectivity variables using the predicted values from the linear model. We expressed the effect as a percent difference in predicted values between the end and the beginning of the time series: $100 \cdot [\hat{y}_{2099} - \hat{y}_{1970}] / \hat{y}_{1970}$. The map of connections (**Fig. 3**) was plotted using the observed values from the combined scenario averaged over the 1970-1999 and the 2070-2099 periods. We did not compare statistically the results of the two time periods (1970-1999 and 2070-2099) because our linear model showed a significant temporal trend for all connectivity variables, therefore the 30 years of each time period cannot be considered as independent replicates.

Sensitivity analyses

We analysed the sensitivity of model results (connectivity variables) to larval behaviour and settlement length under the "combined" scenario. We estimated the effects of larval behaviour on connectivity simulating daily movements between sea surface and deeper waters (diel vertical migration). Vertical migration was simulated by imposing instantaneous movement for larvae at

sunrise (7am) and sunset (7pm). Larvae descended to 50 m depth at sunrise and ascended to 1 m depth at sunset. The other parameters were as in the combined scenario. The effect of larval behaviour was tested by fitting the linear model:

$$y = \beta_0 + \beta_1 t + \beta_2 b + \beta_3 bt + \varepsilon \qquad (1)$$

Here, y is the response variable (one of dispersal distance, connectance, seeded area and retention), t is the year, ε is the error term and b is a dummy variable defining larval behaviour: $b = 0$ for no vertical migration (combined scenario) and $b = 1$ for vertical migration. The interaction between year and larval behaviour indicates whether vertical migration has an effect on the annual increase in connectivity ($\beta_3 \neq 0$) or not ($\beta_3 = 0$).

The sensitivity to larval settlement length was estimated by increasing L_S by 10% of its value. The effect was tested by fitting a linear model analogous to (2), where b is a dummy variable defining settlement length: $b = 0$ for $L_S = 15$ mm and $b = 1$ for $L_S = 16.5$ mm.

Literature cited

Albouy, C., Guilhaumon, F., Araujo, M.B., Mouillot, D. & Leprieur, F. (2012) Combining projected changes in species richness and composition reveals climate change impacts on coastal Mediterranean fish assemblages. *Global Change Biology*, **18**, 2995-3003.

Andrello, M., Mouillot, D., Beuvier, J., Albouy, C., Thuiller, W. & Manel, S. (2013) Low Connectivity between Mediterranean Marine Protected Areas: a Biophysical Modeling Approach for the Dusky Grouper Epinephelus marginatus. *Plos One*, In Press.

Beuvier, J., Sevault, F., Herrmann, M., Kontoyiannis, H., Ludwig, W., Rixen, M., Stanev, E., Béranger, K. & Somot, S. (2010) Modeling the Mediterranean Sea interannual variability during 1961–2000: Focus on the Eastern Mediterranean Transient. *Journal of Geophysical Research: Oceans*, **115**, C08017.

Christensen, J.H., Carter, T.R. & Giorgi, F. (2002) PRUDENCE employs new methods to assess European climate change. *Eos, Transactions American Geophysical Union*, **83**, 147-147.

Herrmann, M., Sevault, F., Beuvier, J. & Somot, S. (2010) What induced the exceptional 2005 convection event in the northwestern Mediterranean basin? Answers from a modeling study. *Journal of Geophysical Research: Oceans*, **115**, C12051.

IPCC (2001) Climate Change 2001. The scientific basis. Contribution of working group I to the third assessment report of the IPCC. (ed. by Houghton Jt, Ding Y, Griggs Dj, Noguer M, V. Der, Linder Pj, Dai X, Maskell K and J. Ca), p. 881. Cambridge University Press, Cambridge.

L'Hévéder, B., Li, L., Sevault, F. & Somot, S. (2012) Interannual variability of deep convection in the Northwestern Mediterranean simulated with a coupled AORCM. *Climate Dynamics*, 1-24.

Lett, C., Verley, P., Mullon, C., Parada, C., Brochier, T., Penven, P. & Blanke, B. (2008) A Lagrangian tool for modelling ichthyoplankton dynamics. *Environmental Modelling & Software*, **23**, 1210-1214.

Monin, A.S. & Ozmidov, R.V. (1982) *Turbulence in the Ocean*, Reidel, Boston.

Peliz, A., Marchesiello, P., Dubert, J., Marta-Almeida, M., Roy, C. & Queiroga, H. (2007) A study of crab larvae dispersal on the Western Iberian Shelf: Physical processes. *Journal of Marine Systems*, **68**, 215-236.

Sevault, F., Somot, S. & Beuvier, J. (2009) A regional version of the NEMO ocean engine on the Mediterranean Sea: NEMOMED8 user's guide. Technical Note number 107. Groupe de Météorologie de Grande Echelle et Climat. CNRM. In:

Somot, S., Sevault, F. & Deque, M. (2006) Transient climate change scenario simulation of the Mediterranean Sea for the twenty-first century using a high-resolution ocean circulation model. *Climate Dynamics*, **27**, 851-879.

Zabala, M., GarciaRubies, A., Louisy, P. & Sala, E. (1997) Spawning behaviour of the Mediterranean dusky grouper *Epinephelus marginatus* (Lowe, 1834) (Piscea, Serranidae) in the Medes Islands Marine Reserve (NW Mediterranean, Spain). *Scientia Marina*, **61**, 65-77.