

Appendix S1. R-script for simulation scenarios 1 and 2.

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##  
##Tomas J Bird and Amanda E Bates, June 2014  
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library(plyr)  
  
#####  
# Create function for sampling range edges: SCENARIO 1  
#####  
  
## Function parameters (occ, eff, reps, sims) are defined below  
## where sampling in stratified, fixed design  
  
## This function simulates sampling across a species' range given  
## values of occupancy, effort, replicates and number of simulations  
Range_Samp=function(occ, eff, reps, sims){  
  Ssites=round(seq(1,100,(100)/(eff)),digits=0)  
  CH=matrix(0,sims,length(Ssites))  
  Starts=rep(0,sims)  
  Ends=rep(0,sims)  
  Mids=rep(0,sims)  
  
  for(k in 1:sims){  
    Captures=rbinom(length(Ssites),reps, occ[Ssites])  
    CH[k,]=Captures  
    Starts[k]=Ssites[min(which(Captures>=1))]  
    Ends[k]=Ssites[max(which(Captures>=1))]  
    Mids[k]=median(Ssites[(which(Captures>=1))], na.rm=T)  
  }  
  return(list(CH, Starts, Mids, Ends))  
}  
  
#####  
# Estimate ranges shifts with stratified sampling and even effort: SCENARIO 1  
#####  
  
#Define Parameters  
# Simulate a gradient with 100 evenly spaced points;  
# for illustration, we interpret 100 units as being equivalent to 20 degrees of latitude  
# The mid-point is thus 50, which is equivalent in our latitudinal illustration to 10  
Grad= seq(1:100)  
St=50  
  
# Set species abundance parameters  
# Note we were comparing simulated data to data which represented mean abundance  
A=seq(1, 500, length=4991)  
sd=rep(10, length(A))
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# Set the units shifted (example here is +0 units along the spatial gradient
# of 1 to 100 that is equivalent in our illustration to 20 degrees of latitude)
# Change this value to simulate a range shift
Rshift = 0

# Simulate geographic range distributions: returns shift estimate for trailing, middle and
leading range edges
St_Abund=matrix(unlist(lapply(1:length(A), FUN=function(x){
  dnorm(Grad, mean=St, sd=sd[x])*A[x])/max(dnorm(Grad, mean=St+Rshift,
sd=sd[x])))),length(Grad),length(A))
# Allows manipulating of the edge curvature
Edge=qnorm(c(0.025,0.975), St, sd[1])
Edgers=qnorm(c(0.025,0.975), St+Rshift, sd[1])
St_Abund[which(St_Abund>0 & St_Abund<0.05)]=0.05
A_out=which(Grad<Edge[1] | Grad>Edge[2])
A_outrs=which(Grad<Edgers[1] | Grad>Edgers[2])
St_Abund[A_out,]=0;St_Abund=St_Abund/50;St_Abund[St_Abund>1]=1

## Ending abundance - no shift
End_Abund=matrix(unlist(lapply(1:length(A), FUN=function(x){dnorm(Grad, mean=St+Rshift,
sd=sd[x])*A[x])/max(dnorm(Grad, mean=St+Rshift, sd=sd[x])))),length(Grad),length(A))
End_Abund[which(End_Abund>0 & End_Abund<0.05)]=0.05
End_Abund[A_out,]=0;End_Abund=End_Abund/50;End_Abund[End_Abund>1]=1

# Code for assumption that the geographic range distribution has a uniform shape for
comparison to results obtained when the geographic range is modelled as a normal
distribuiton
# For uniform distribution, end of the distribution needs to be defined, such as End=70
###St_Abund=matrix(unlist(lapply(1:length(A), FUN=function(x){dunif(Grad, min=St,
max=End)*A[x]})),length(Grad),length(A))
###End_Abund=matrix(unlist(lapply(1:length(A), FUN=function(x){dunif(Grad, min=St+Rshift,
max=End+Rshift)*A[x]})),length(Grad),length(A))

# Plot Occupancy Distributions - here no shift has occurred
plot(Grad, St_Abund[,1], type="l", ylim=c(0, max(St_Abund, na.rm=T)))
for(i in 2:length(A)){
  points(Grad, St_Abund[,i], type="l")}

plot(Grad, End_Abund[,1], type="l", ylim=c(0, max(End_Abund, na.rm=T)),col="red")
for(i in 2:length(A)){
  points(Grad, End_Abund[,i], type="l",col="red")}

# Prepare data for abundance-related simulations
Nsims=1000
nreps=1
Starts<-Ends<-Mids<-shift<-n_shift_obs<-matrix(0,Nsims,length(A))
Effort=50

# Simulate sampling of the pre- and post-sampling distributions 'Nsims' times
for(j in 1:length(A)){
  pre=Range_Samp(occ=St_Abund[,j], eff=Effort, reps=nreps, sims=Nsims)
  post=Range_Samp(occ=End_Abund[,j], eff=Effort, reps=nreps, sims=Nsims)
  # This is a vector of the observed range difference for each simulation
  # in this case we have modelled a range extension

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#####returns value for leading range edge
shift[,j]=pre[[3]]-post[[3]]
}
# note that NA values are returned when the simulated range edge
# for one time interval does fall within the simulated sampling area

logA=log10(A)
obs_shift=matrix(0,length(A)*Nsims, 2)
obs_shift[,1]=rep(logA, each=Nsim)
obs_shift[,2]=shift;obs_shift=data.frame(obs_shift)
colnames(obs_shift)=c("log.abundance", "Diff")

#####
# Estimate range shifts with variable effort: SCENARIO 2
#####

Nsims=1000

# Keep abundance and distribution parameters same, but change Range Shift parameter
Rshift = 5

# Simulate geographic range distributions with peak abundance equal to A
St_Abund=matrix(unlist(lapply(1:length(A), FUN=function(x){
  dnorm(Grad, mean=St, sd=sd[x])*A[x])/max(dnorm(Grad, mean=St+Rshift,
sd=sd[x])))),length(Grad),length(A))
# Allows manipulating of the edge curvature
Edge=qnorm(c(0.025,0.975), St, sd[1])
Edgers=qnorm(c(0.025,0.975), St+Rshift, sd[1])

# Produces probability of observing a presence
St_Abund[which(St_Abund>0 & St_Abund<0.05)]=0.05
A_out=which(Grad<Edge[1] | Grad>Edge[2])
A_outs=which(Grad<Edgers[1] | Grad>Edgers[2])
St_Abund[A_out,]=0;St_Abund=St_Abund/50;St_Abund[St_Abund>1]=1

## Ending abundance - shift of 5 units, which we equate to 1 degree of latitude
End_Abund.rs=matrix(unlist(lapply(1:length(A), FUN=function(x){dnorm(Grad,
mean=(St+Rshift), sd=sd[x])*A[x])/max(dnorm(Grad, mean=St+Rshift,
sd=sd[x])))),length(Grad),length(A))
End_Abund.rs[which(End_Abund.rs>0 & End_Abund.rs<0.05)]=0.05
End_Abund.rs[A_outs,]=0;End_Abund.rs=End_Abund.rs/50;End_Abund.rs[End_Abund.rs>
1]=1

plot(Grad, St_Abund[,1], type="l", ylim=c(0, max(St_Abund, na.rm=T)))
for(i in 2:length(A)){
  points(Grad, St_Abund[,i], type="l")}

plot(Grad, End_Abund.rs[,1], type="l", ylim=c(0, max(End_Abund.rs, na.rm=T)),col="red")
for(i in 2:length(A)){
  points(Grad, End_Abund.rs[,i], type="l",col="red")}

# function for simulating sampling across species range with variable effort
Range_Samp_R.eff=function(occ, eff, reps, sims){
  Ssites=round(seq(1,100,(100)/(eff)))
  CH=matrix(0,sims,length(Ssites))

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Starts=rep(0,sims)
Ends=rep(0,sims)
Mids=rep(0,sims)

for(k in 1:sims){
  ### varies sampling effort between simulations
  neg.eff=sample(Effort,sample(0:10,1))
  ones=rep(1,length(occ))
  ones[Ssites[neg.eff]]=NA
  Captures=rbinom(length(Ssites),reps, occ[Ssites]*ones[Ssites])
  CH[k,]=Captures
  Starts[k]=Ssites[min(which(Captures>=1))]
  Ends[k]=Ssites[max(which(Captures>=1))]
  Mids[k]=median(Ssites[(which(Captures>=1))], na.rm=T)
}
return(list(CH, Starts, Mids, Ends))
}

# Prepare data matrices for abundance-related simulations
Starts<- Ends<- Mids<- shift2<- n_shift_obs<- matrix(0,Nsims,length(A))
Effort=50

for(j in 1:length(A)){
  ### Simulate sampling of the pre- and post-sampling distributions 'Nsims' times
  ### Creates a historical bias in sampling effort which is similar to what was observed in
  Wernberg et al. 2011
  pre=Range_Samp_R.eff(occ=St_Abund[,j], eff=(Effort+(sample(-1:3,1))), reps=nreps,
sims=Nsims)
  post=Range_Samp_R.eff(occ=End_Abund.rs[,j], eff=(Effort+(sample(-3:1,1))),
reps=nreps,sims=Nsims)
  ### This is a vector of the observed range differences for each simulation and in this case
  we have extracted values returned for a range extension at the trailing range edge
  shift2[,j]=pre[[2]]-post[[2]]
}

logA=log10(A)
obs_shift2=matrix(0,length(A)*Nsims, 2)
obs_shift2[,1]=rep(logA, each=Nsims)
obs_shift2[,2]=shift2;
obs_shift2=data.frame(obs_shift2)
colnames(obs_shift2)=c("log.abundance", "Diff")

#####
# Example Plots
#####

par(mfrow=c(1,2))
par(mar=c(6,6,2,6))

# figure 1 panel a
# SCENARIO1
# convert 100 units to latitude by dividing by 5
plot((obs_shift[,2]/5)~obs_shift[,1],pch=16,xlab="log10(Abundance)",
ylab="Simulated Change in Latitude", cex=1,cex.axis=1.5, cex.lab=1.5,
ylim=c(-4,4),xlim=c(0,2.699),col="white")

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#####plots 95th quantile of the data distribution
for(i in 1:length(A)){
  par(new=T)
  segments(logA[i],data.frame(quantile(shift[,i]/5,0.95,na.rm=T))[1,1],
    logA[i],data.frame(quantile(shift[,i]/5,0.05,na.rm=T))[1,1],
    col="orange",lwd=2)
}
arrows(0,0.45,2.7,0.45,lty=2,length = 0,col="black",lwd=2)
arrows(0,-0.45,2.7,-0.45,lty=2,length = 0,col="black",lwd=2)
par(new=T)

prop.detected.high=ddply(obs_shift,c("log.abundance"),summarize,
prophigh=(sum(subset(Diff,!is.na(Diff))< -2.275 |
subset(Diff,!is.na(Diff))>2.275)/(length(subset(Diff,!is.na(Diff))))))

plot(lowess(prop.detected.high[,1],prop.detected.high[,2],f=1/20),
  col="red",type="l",xaxt="n",yaxt="n",ylab="",xlab="",yaxt="n",
  lwd=2,cex=1,cex.axis=1.5, cex.lab=1.5)
axis(4,cex=1,cex.axis=1.5, cex.lab=1.5)
mtext("Proportion False Shifts Detected", side=4, line=3)

# figure 2 panel a
# range shift
plot(obs_shift2[,1], (obs_shift2[,2]/5), pch=16,
  xlab="log(Abundance)", ylab="Simulated Change in Latitude",
  cex.axis=1.5, cex.lab=1.5, ylim=c(-6.5,4.5),xlim=c(0,2.699),col="white")
#####plots standard deviation
for(i in 1:length(A)){
  par(new=T)
  segments(logA[i],data.frame(quantile((shift2[,i]/5),0.95,na.rm=T))[1,1],
    logA[i],data.frame(quantile((shift2[,i]/5),0.05,na.rm=T))[1,1],
    col="orange",lwd=2)
}
arrows(0,(0.45),2.7,(0.45),lty=2,length = 0,col="black",lwd=2)
arrows(0,(-0.45),2.7,(-0.45),lty=2,length = 0,col="black",lwd=2)
arrows(0,(-1),2.7,(-1),lty=1,length = 0,col="gray",lwd=4)

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Appendix S2. Qualitative abundance of the macroalgal species estimated by experts^{1,2,3} on a qualitative scale of 1 to 5 where 1 = rare, 2 = infrequent, 3 = common but low abundance, 4 = moderately abundant, 5 = highly abundant (the three experts scored algae within 2 units in all instances). Effort ratio is the number of museum records in 1950 divided by the number of samples in 1990. Total sample size and change in latitude are reported in Wernberg *et al.* (2011): see main text methods.

Species	Qualitative Abundance index	Total sample size	Change in latitude
<i>Bornetia binderiana</i>	3	21	-0.5
<i>Callophycus oppositifolius</i>	3	32	-0.6
<i>Carpopeltis elata</i>	3.7	20	-3.2
<i>Carpopeltis phyllophora</i>	3	14	-0.7
<i>Caulerpa flexilis</i>	4	25	-1.6
<i>Caulerpa obscura</i>	4	26	0.3
<i>Caulerpa sedoides</i>	3	16	-2.5
<i>Caulerpa simpliciuscula</i>	3.7	25	0.3
<i>Caulocystis uvifera</i>	2.5	29	0.7
<i>Ceramium puberulum</i>	2.5	12	0.9
<i>Cladurus elatus</i>	3	21	0.1
<i>Clavicolonium ovatum</i>	1.7	28	0
<i>Craspedocarpus blepharicarpus</i>	3.5	18	-1
<i>Cystophora brownii</i>	3.3	16	-4.8
<i>Dasyclonium incisum</i>	2.3	28	-0.7
<i>Dicranema revolutum</i>	2	12	0.4
<i>Dictyomenia sonderi</i>	3.7	28	0.4
<i>Dictyomenia tridens</i>	2.5	15	-0.5
<i>Dictyopteris muelleri</i>	3.5	28	0.1
<i>Dictyota fastigiata</i>	2	12	-0.1
<i>Erythroclonium muelleri</i>	3.5	13	-1.8
<i>Euptilota articulata</i>	3	26	-1
<i>Gigartina disticha</i>	1.7	26	-1
<i>Glossophora nigricans</i>	2.7	16	0.9
<i>Griffithsia teges</i>	3	12	-3.1
<i>Heterodoxia denticulata</i>	3	37	0.3
<i>Hypnea ramentacea</i>	4.3	38	0.4

<i>Kuetzingia canaliculata</i>	3.5	26	-0.5
<i>Laurencia elata</i>	4	19	-1.3
<i>Metagoniolithon chara</i>	3.5	18	-0.7
<i>Metagoniolithon stelliferum</i>	4	18	0.4
<i>Metamastophora flabellata</i>	4	29	0.4
<i>Myriodesma quercifolium</i>	3.7	33	0
<i>Nizymenia conferta</i>	2.7	17	0.4
<i>Osmundaria prolifera</i>	2.5	33	0
<i>Pachydictyon paniculatum</i>	2.7	18	0.3
<i>Platythalia angustifolia</i>	2.3	17	0
<i>Plocamium preissianum</i>	3.7	18	-2.8
<i>Pollexfenia lobata</i>	3	22	-0.5
<i>Pterocladia lucida</i>	3.5	49	-1.2
<i>Scaberia agardhii</i>	3.5	24	0.4
<i>Scytothalia doryocarpa</i>	4.3	14	-1.6
<i>Thuretia quercifolia</i>	3	17	-1.4
<i>Vidalia spiralis</i>	3	20	0.1
<i>Zonaria turneriana</i>	3.5	27	1.6

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