USDA

United States
Department of
Agriculture

Forest Service

Pacific Northwest
Research Station

General Technical
Report
PNW-GTR-602
April 2004

Effects of Alternatives to Clearcutting on Invertebrate and Organic Detritus Transport From Headwaters in Southeastern Alaska

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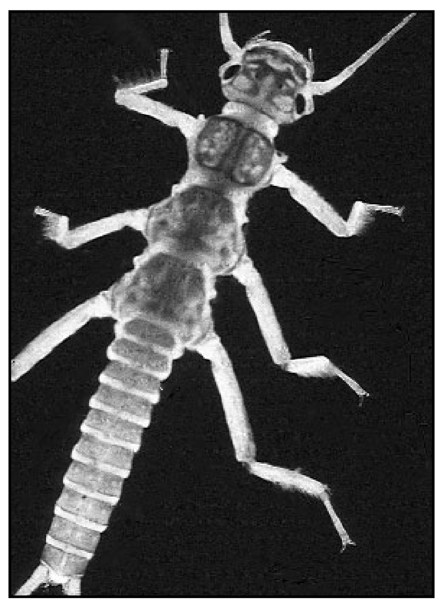

Authors

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Abstract

Musslewhite, Jake; Wipfli, Mark S. 2004. Effects of alternatives to clearcutting on invertebrate and organic detritus transport from headwaters in southeastern Alaska. Gen. Tech. Rep. PNW-GTR-602. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 28 p.

We examined the transport of invertebrates and coarse organic detritus from headwater streams draining timber harvest units in a selective timber harvesting study, alternatives to clearcutting (ATC) in southeastern Alaska. Transport in 17 small streams (mean measured discharge range: 1.2 to 14.6 L/s) was sampled with 250-μm-mesh drift nets in spring, summer, and fall near Hanus Bay at an ATC installation on Catherine and Baranof Islands. Samples were taken before (1996) and after (1999, 2000) nine timber harvesting treatments were applied. Invertebrate and organic detritus drift densities and community composition were used to assess treatment effects. A comparison of drift densities before and after treatment showed year-to-year differences comparable to natural variation at other sites in this study, but no clear relationship to intensity or type of timber harvest treatments. Natural variation in drift densities prevented detection of any potential timber harvesting effects. Coefficients of variation showed transport was most variable among streams, followed by seasons and then days. A trend toward an increase in the proportion of true flies (Diptera) and a decrease in the proportion of mayflies (Ephemeroptera) was seen in more intensive treatments. Although transport rates were extremely variable, a mean of 220 mg invertebrate dry mass and 18 g detritus per stream per day was being transported downstream. The transport of this material suggests that headwaters are potential source areas of aquatic and terrestrial invertebrates and detritus, linking upland ecosystems with habitats (commonly fish bearing) lower in the catchment.

Keywords: Alternatives to clearcutting, headwater streams, invertebrates, organic detritus, riparian.

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Introduction

River continuum theory implies that headwater streams are tightly linked to and dependent upon surrounding terrestrial ecosystems (Vannote et al. 1980). Autotrophic production in these streams is often low, but the streams typically receive large inputs of coarse particulate organic matter in the form of leaves, woody debris, and other organic material (Bilby and Likens 1980, Iverson et al. 1982). Coarse particulate organic material is subject to physical and microbial processing (Hall and Meyer 1998) and macroinvertebrate processing (Cummins et al. 1989), which produce fine particulate organic matter. This processed material can serve as food for macroinvertebrate communities, both within the headwater stream and in downstream habitats (Cummins 1974). The flow of detritus and macroinvertebrates from these headwater production zones may represent a valuable subsidy to downstream fish and associated food webs (Wipfli and Gregovich 2002).

Headwater streams produce a range of benthic invertebrates and much particulate detritus (Stone and Wallace 1998; Wallace et al. 1986, 1997). The high gradient and velocity typical of headwater streams facilitate the movement and drift of this material, especially during freshets (Anderson and Lehmkuhl 1968). Invertebrates are often common in drift (Allan 1995) with aquatic insect densities ranging from fewer than 1 to 116 individuals per cubic meter of water (O'Hop and Wallace 1983, Waringer 1992; see Giller and Malmqvist 1998). Wipfli and Gregovich (2002) reported from pretreatment data that headwater streams draining alternatives-to-clearcutting (ATC) installations were transporting both aquatic and terrestrial invertebrates that originated in upland habitats. These headwater streams were discovered to house a wide range of invertebrate taxa, including mayflies, stoneflies, caddisflies, midges, crane flies, beetles, and mites, as well as many less common taxa.

Southeastern Alaska's steep topography and abundant precipitation produce numerous small headwater streams. Previous studies of the effects of timber harvesting on southeastern Alaska streams have largely focused on higher order, fish-bearing streams, especially those containing salmonids, and have commonly shown that loss of large wood for fish habitat can be a negative consequence of logging (Bryant 1985). Although larger, fish-bearing streams are intensively studied, the structure and function of the region's headwater streams are poorly understood (Wipfli and Gregovich 2002).

The ATC demonstration project was established in the early 1990s with the goal of understanding the ecological consequences of various timber harvesting practices in old-growth forests of southeastern Alaska (McClellan et al. 2000). Major study components included silviculture, avian ecology, hydrology, slope stability, and aquatic ecology. The aquatic ecology component of the ATC project focused on the transport of aquatic and terrestrial invertebrates and organic detritus in headwater streams before and after timber harvesting. Specifically, we wanted to measure the change in (1) invertebrate and organic detritus drift densities and (2) invertebrate taxonomic composition in response to ATC timber harvesting.

Methods

Study Sites

Southeastern Alaska has a maritime climate, moderate temperature, and much precipitation (which can exceed 500 cm/year) (Harris et al. 1974). The mountainous landscape supports a temperate rain forest dominated by Sitka spruce (*Picea sitchensis* (Bong.) Carr) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), mixed with occasional Alaska yellow-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach), western redcedar (*Thuja plicata* Donn ex D. Don), black cottonwood

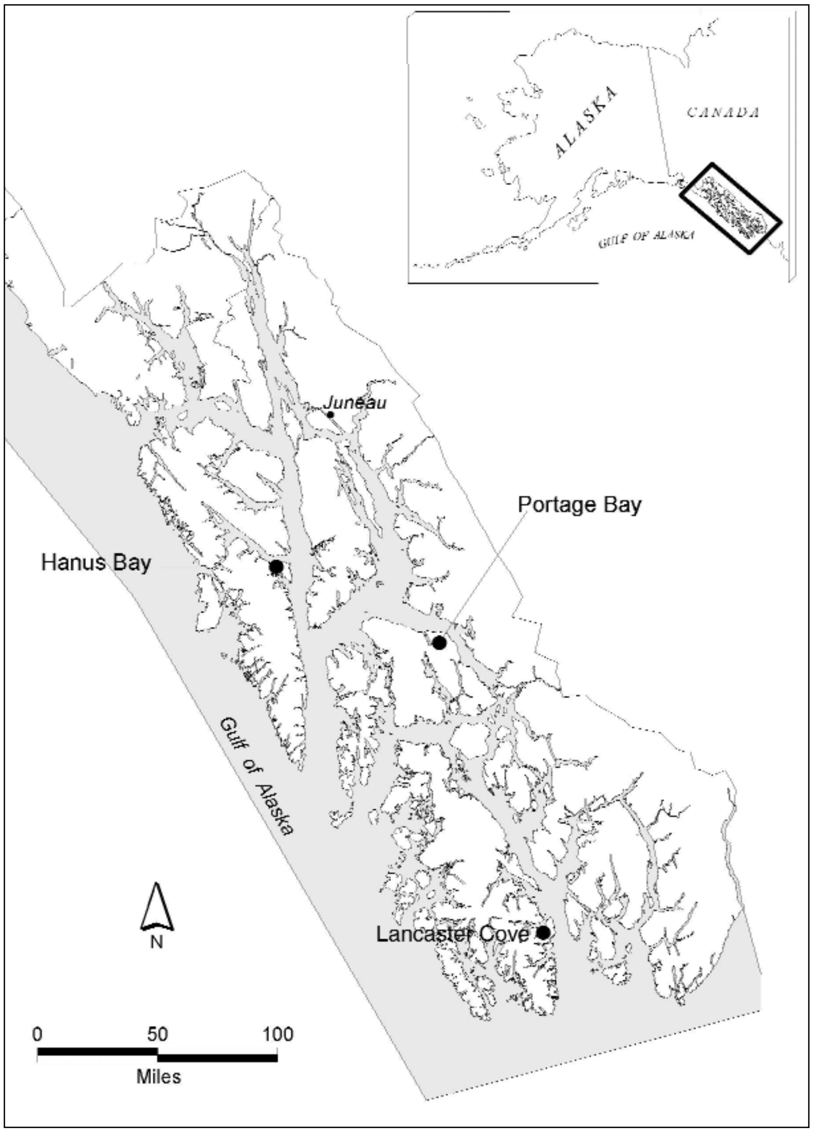


Figure 1—Alternatives-to-clearcutting study sites in southeastern Alaska.

(*Populus trichocarpa* Torr. & Gray), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), red alder (*Alnus rubra* Bong.), and willow (*Salix L.* spp.). The soils range from shallow organic and mineral accumulations over bedrock and glacial till to well-developed spodosols (Harris et al. 1974). A mosaic landscape of forest, peat bogs, and alpine vegetation is drained by numerous small, fishless headwater streams that drain into larger streams containing coho (*Oncorhynchus kisutch*), pink (*O. gorbuscha*), chum (*O. keta*), sockeye (*O. nerka*), and chinook (*O. tshawytscha*) salmon, cutthroat (*O. clarki*) and steelhead trout (*O. mykiss*), Dolly Varden char (*Salvelinus malma*), sculpin (*Cottus* spp.) and stickleback (*Gasterosteus* spp.).

Hanus Bay is one of three ATC installations in southeastern Alaska (fig. 1). We report here on results from the Hanus Bay ATC installation only, because postharvest data have not been collected at the second installation (Portage Bay), and harvesting has not occurred at the third installation (Lancaster Cove) as yet.

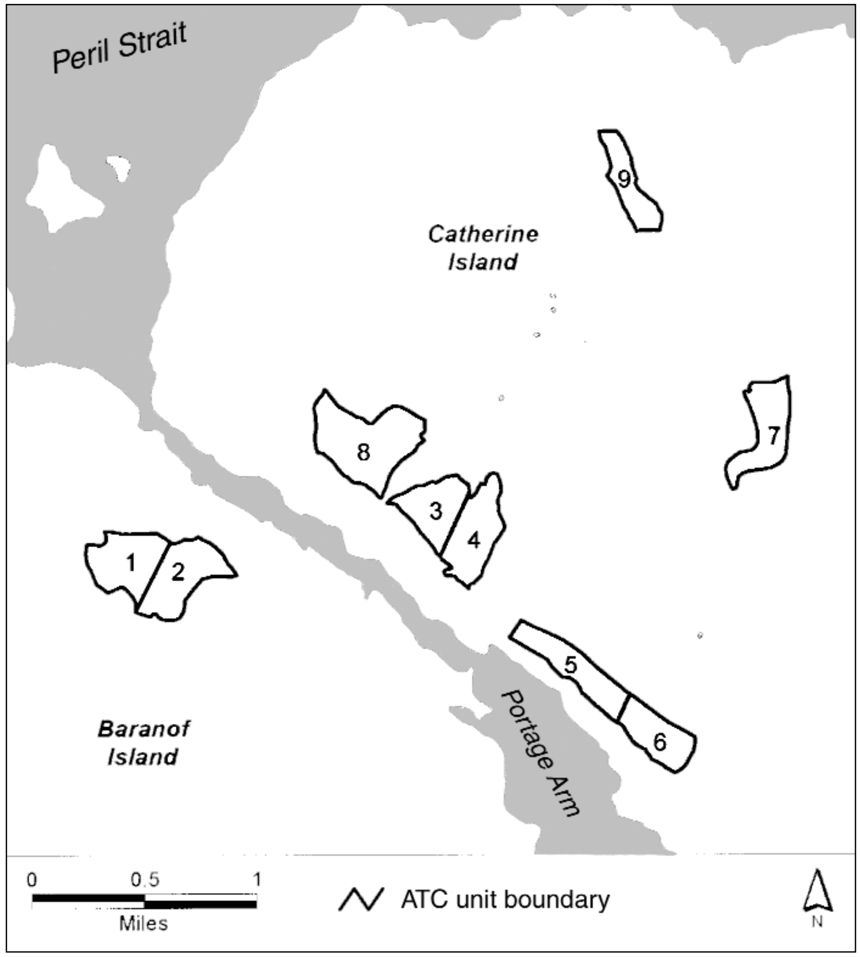


Figure 2—Alternatives-to-clearcutting experimental units in Hanus Bay, Alaska.

The Hanus Bay installation, located on Catherine and Baranof Islands, consists of nine experimental harvest units of approximately 16 ha each that were selected to be representative of productive upland old-growth forest (McClellan et al. 2000) (fig. 2). The units are generally steep (30 to 45 percent slope) and have elevations ranging from 61 to 526 m. Prior to timber harvest, all the units were forested primarily with western hemlock (62 percent by basal area) and Sitka spruce (16 percent), along with yellow-cedar (11 percent) and mountain hemlock (11 percent) (Hennon and McClellan, in press).

Timber harvesting took place during 1997 across the nine units. Each unit received a different timber harvest prescription ranging from an uncut control to conventional clearcutting (McClellan et al. 2000). Intermediate harvest regimes included various spatial arrangements and proportions of unharvested trees (fig. 3). In these intermediate treatments the distribution of retained trees formed gaps, clumps, or was uniform throughout the unit. In units where retention was uniformly distributed, harvested trees were individually selected (ITS, or individual tree selection), and 5, 25, or 75 percent of the original basal area was retained. Units receiving clump or gap treatments retained 25 or 75 percent of the original basal area, and harvested trees were either part of a harvested patch or individually selected from the surrounding matrix.

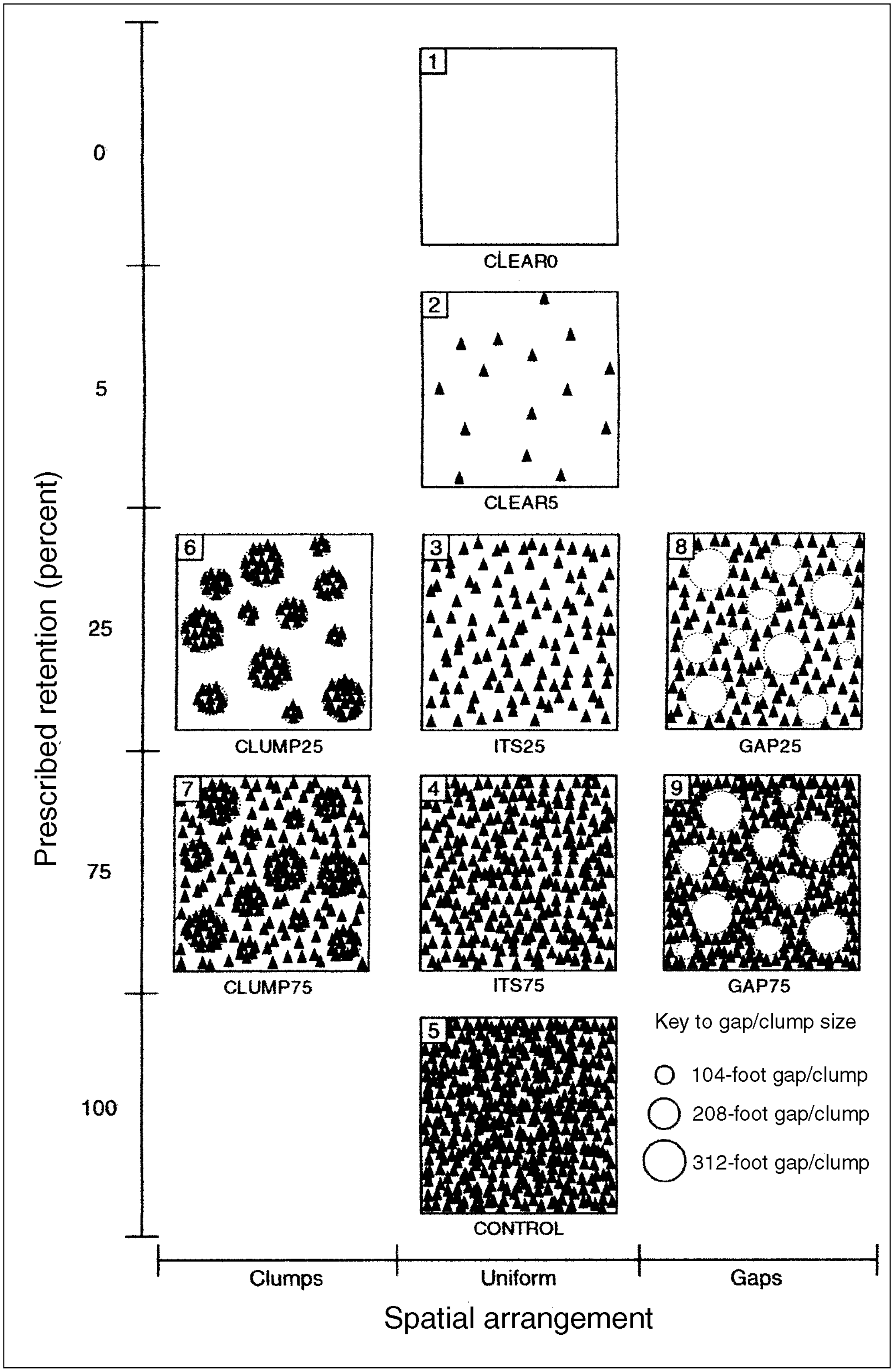


Figure 3—Schematic representation of alternatives-to-clearcutting experimental treatments (from McClellan et al. 2000).

Table 1—Physical characteristics and timber harvest prescriptions of study streams at the Hanus Bay alternatives-to-clearcutting installation, southeastern Alaska

Unit	Stream	Mean (range) estimated discharge	Mean bankfull width	Silvicultural treatment	Basal area retention
		Liters per second	*Meters*		*Percent*
1	1	2.0 (0.07-6.7)	0.90	Gap	25
2	1	3.8 (0.5-12.9)	1.64	Clump	25
	2	5.1 (0.6-14.3)	1.84		
3	1	3.5 (0.3-11.2)	1.98	ITS	75
	2	7.4 (0.5-44.8)	2.83		
4	1	3.4 (0.2-17.6)	2.46	Clump	75
	2	2.0 (0.5-7.5)	1.33		
5	1	9.4 (2.3-17.5)	4.73	Gap	75
	2	9.1 (0.5-29.7)	2.98		
6	1	4.3 (0.2-23.8)	6.03	Wildlife trees	5
	2	14.6 (2.2-48.7)	5.20		
7	1	1.2 (0.04-5.1)	1.47	ITS	25
	2	1.7 (0.2-4.8)	2.62		
8	1	3.8 (0.2-8.8)	1.60	Control	100
	2	3.3 (0.2-8.1)	1.92		
9	1	2.8 (0.2-9.2)	1.97	Clearcut	0
	2	1.7 (0.07-5.5)	1.10		
Mean of all streams		4.7	2.51		

Note: ITS = individual tree selection.

Seventeen headwater streams were selected from within these nine units. Two streams were selected within each unit, except for one unit having only one suitable stream. Study streams were located within 6 km of each other and were spread among three watersheds. These streams were high gradient and small (mean bankfull width 2.5 m) (table 1). The length of stream between its origin and the sampling site was generally less than 0.5 km. All streams contained some surface flow (mean, 4.7 L/s) during all sampling bouts, albeit negligible flow for some streams during dry periods (down to 0.04 L/s).

Sampling Procedures

Permanent sampling stations were established for each stream. The station was located on or close to the lowest elevation along the unit boundary in order to sample the stream after it had flowed through as much of the unit as possible. In many cases, the stream originated within the unit and eventually flowed into fish habitat.

At each sampling station, invertebrates (aquatic and terrestrial) and organic detritus (≥250 μm) were sampled with a 250-μm-mesh net attached to one end of a 75-cm long, 10-cm diameter plastic pipe that rested on the stream bottom. The pipe with attached net was secured in the middle of each stream with sandbags. Facilitated by high stream gradient, the downstream end of each horizontal pipe rested above the stream surface. Discharge through the pipe was determined by recording the time required to fill a container of known volume. Discharge was measured at the beginning and end of each sampling period, and these values were used to estimate the total volume of water that passed through the pipe over the sampling period. The total volume sampled was used to calculate invertebrate and detritus drift densities. Many of the streams were sufficiently small for the entire streamflow to pass through the pipe. If not, the percentage of the total streamflow passing through the pipe was estimated, and this fraction was used to estimate the total discharge of the stream.

Streams were sampled seasonally (spring, summer, fall). One year (1996) of pretreatment sampling was conducted, followed by two years (1999, 2000) of posttreatment sampling. In 1996, each seasonal sampling bout consisted of three samples for each stream, collected over consecutive 24-hour periods. This was modified in posttreatment sampling to two 48-hour sampling periods for each season. Owing to time constraints, only the first of these two 48-hour samples was used for 2000 data. The sampling period for each stream began and ended at approximately the same time of day in order to minimize the effect of diel variation in invertebrate drift. Stream temperature was recorded hourly with temperature loggers placed near the sampling sites. These were placed in the stream during the first sampling of each year and removed following the last sampling of the year.

Sample Processing and Data Analysis

Samples, once collected and returned to the laboratory, were preserved in 70 percent ethanol. A plankton splitter was used to subsample unusually large samples. Invertebrates were sorted from detritus, identified to the lowest reliable taxon, and their body lengths measured to the nearest millimeter. Their dry mass was estimated by using taxon-specific length:dry mass regression equations (Burgherr and Meyer 1997, Meyer 1989, Rogers et al. 1977, Sample et al. 1993, Smock 1980; M. Wipfli, unpublished data). The remainder of the sample (detrital component) was ovendried, weighed, ashed (at 500˚ C for 5 hours), and reweighed to determine ash-free dry mass (AFDM).

Drift densities were calculated for each unit and seasonal sampling bout. Drift density of individuals was calculated as the total of all invertebrates captured in the unit over the seasonal sampling bout divided by the volume of water sampled (number of invertebrates/m^3). Biomass (mg invertebrates/m^3) and organic detritus (g AFDM/m^3) densities were calculated in the same fashion. Mean drift densities for each unit and year were computed from the three corresponding seasonal drift density estimates. These were used to compare pretreatment drift densities to each posttreatment year's drift densities.

The spatial and temporal variation in drift densities was measured with coefficients of variation (CV). Because the intent was to measure the amount of natural variation (i.e., not owing to treatment effects), only pretreatment data were used. For these calculations, drift densities were calculated for individual samples rather than from estimates at the unit level as described above.

Temporal variability was determined from pretreatment data by using both day-to-day and seasonal CVs. Day-to-day CVs measured the daily variation in drift densities seen within a single stream; seasonal CVs measured the seasonal variation within a single stream. The three consecutive 24-hour samples from each stream's seasonal sampling bout were used to calculate each day-to-day CV, which were then averaged across all streams and sampling bouts. Seasonal CVs for each stream were calculated from the mean drift density of the three consecutive samples taken each season. The seasonal CVs from each stream were then averaged across all streams. Spatial variability was measured by using stream-to-stream CVs, which measured the variation in drift densities between all study streams on the same day. A CV was calculated for each sampling day by using the samples for all 17 streams, and then averaging these across all sampling days.

Results

Drift Densities

There did not appear to be a relationship between harvest treatment prescriptions and subsequent changes in mean drift density. Drift densities of both invertebrate individuals and biomass were generally lower in posttreatment years than in the pretreatment year (including in the control treatment), but in a different pattern for each of these two responses (fig. 4). Biomass density differences appeared to be more consistent across treatments and years, whereas density differences for individuals appeared to differ more from treatment to treatment and between years. The only positive changes in drift densities following treatment were seen in the GAP75 and ITS25 treatments in one year only.

As for invertebrate drift densities, mean posttreatment organic detritus drift densities for most harvest units were lower than those seen in pretreatment (including in the control treatment) (fig. 5). However, in 1999 the units with 25 percent retention had densities much higher than before treatment; in 2000 only the ITS25 treatment had mean organic drift densities higher than pretreatment means.

Invertebrate drift density showed a seasonal pattern: mean density was highest in summer (2.85 invertebrates/m^3, 0.90 mg/m^3), lowest in spring (1.31 invertebrates/m^3, 0.38 mg/m^3), and intermediate in fall (1.63 invertebrates/m^3, 0.38 mg/m^3). The mean drift density of individuals across all sampling was 1.95 invertebrates/m^3, with a corresponding biomass density of 0.57 mg/m^3. Organic detritus densities were also seasonal, but the pattern was different than that of invertebrates. The highest mean detritus densities were in fall, at 0.06 g AFDM/m^3; the lowest were in summer (0.03 g/m^3); and spring had intermediate densities at 0.05 g/m^3. Overall, the mean organic detritus density was 0.05 g/m^3.

The transport rate of invertebrates from each stream averaged 830 individuals and 220 mg biomass per day. The largest transport rate occurred in spring, when an average of 1,500 individuals and 400 mg biomass per stream per day were transported by that season's typically larger discharges. In comparison, the low discharges of summer transported a stream average of 520 individuals and 130 mg biomass per day, which translated to substantially higher drift densities than in the higher flows of spring. Mean transport rates per stream in fall were the lowest at 400 individuals and 110 mg biomass per day. Organic detritus transport followed a similar pattern of higher mean stream transport rates in spring (34 g AFDM per day) than in fall (17 g per day) or summer (3 g per day). The overall mean stream transport rate of organic detritus was 18 g per day.

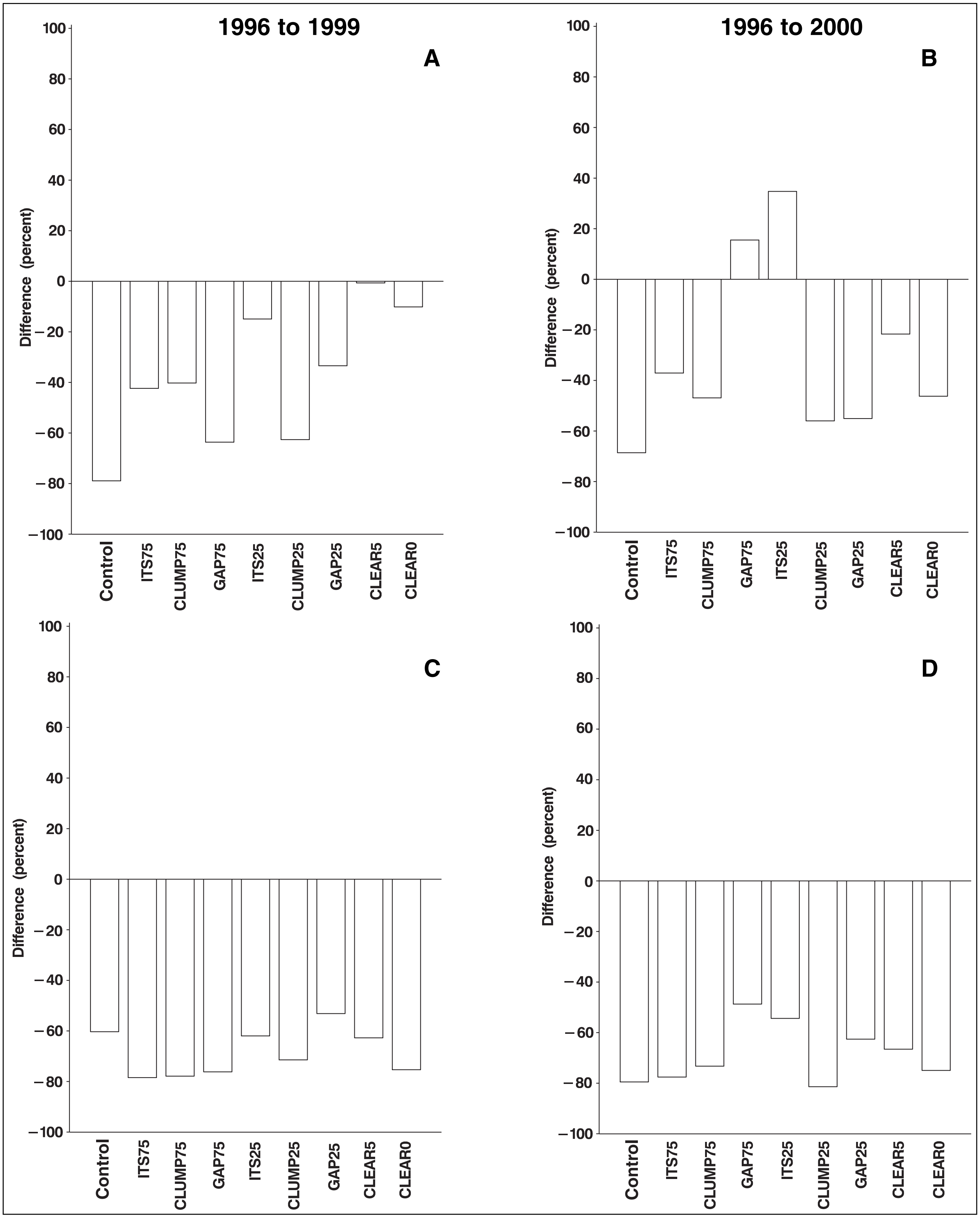


Figure 4—Difference between pretreatment (1996) and posttreatment (1999, 2000) mean invertebrate individual (A,B) and biomass (C,D) drift densities at the Hanus Bay alternatives-to-clearcutting installation, Alaska. Differences are expressed as a percentage of the pretreatment value; a negative value indicates a decrease in density.

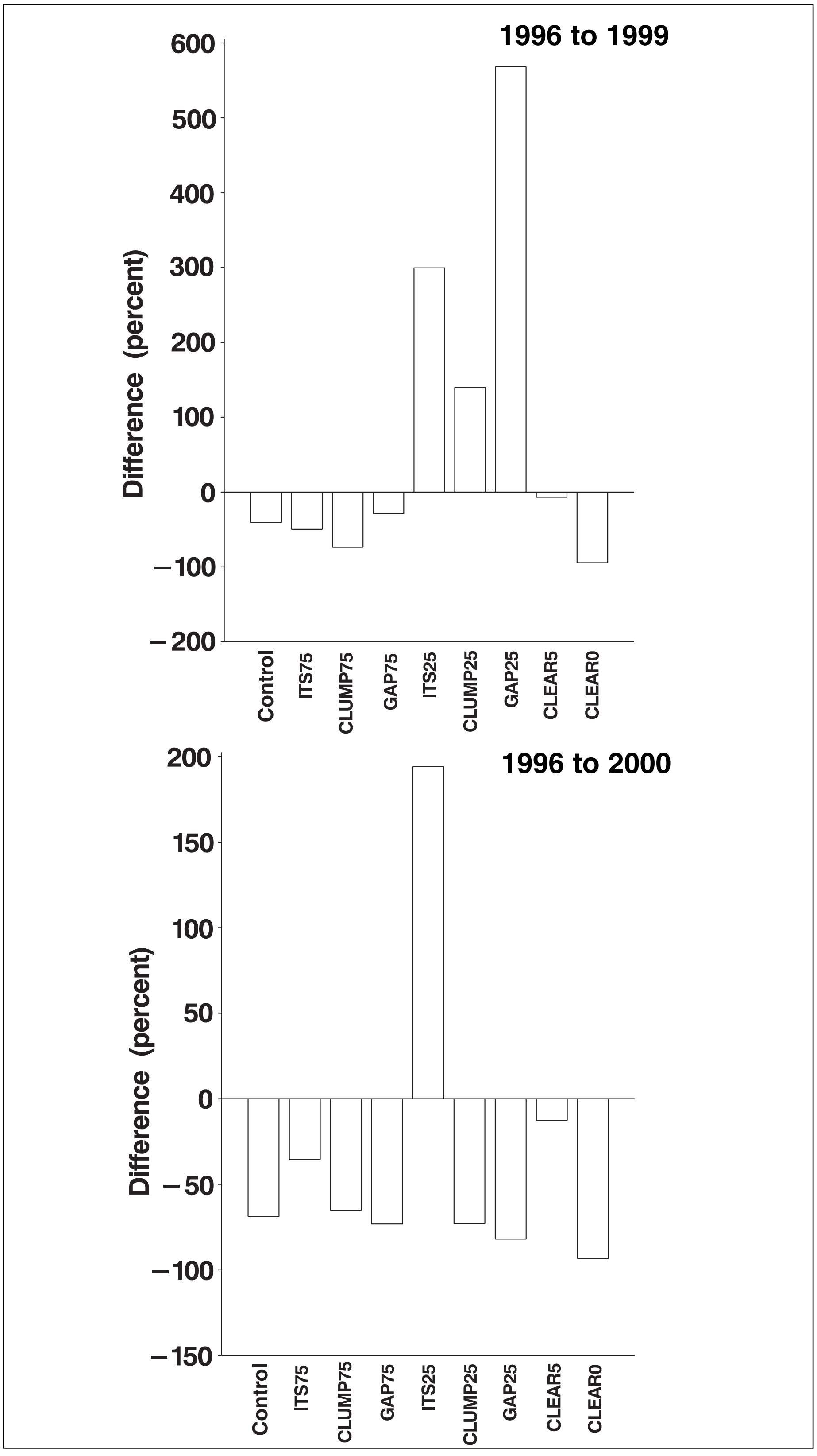


Figure 5—Difference between pretreatment (1996) and posttreatment (1999, 2000) mean organic detritus drift densities at the Hanus Bay alternatives-to-clearcutting installation, Alaska. Differences are expressed as a percentage of the pretreatment value; a negative value indicates a decrease in density. Note differences in scales of vertical axes.

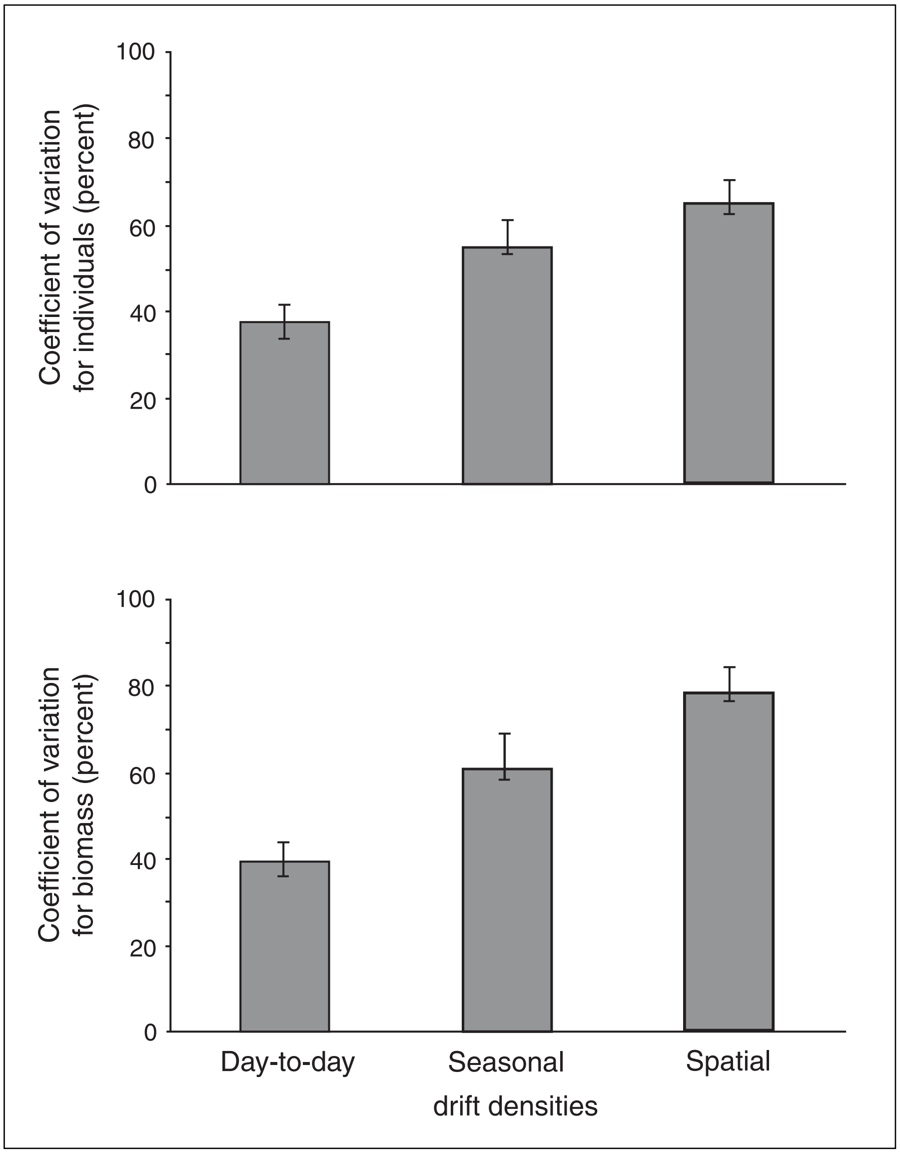


Figure 6—Comparison of pretreatment day-to-day, seasonal, and spatial coefficients of variation (± standard error) for invertebrate individuals (top) and biomass (bottom) drift densities at the Hanus Bay alternatives-to-clearcutting installation, Alaska.

Invertebrate Drift Density Variability

Pretreatment invertebrate drift densities were highly variable both spatially and temporally (fig. 6). Spatial CVs were the highest, followed by seasonal and then day-to-day CVs. This pattern was similar for drift densities of both individuals and biomass. Mean spatial CVs for drift density of individuals were highest in fall (84 percent) and lowest in spring (50 percent), whereas summer was intermediate at 60 percent. For biomass drift density, spatial CVs were highest in summer (90 percent), and spring and fall CVs were similar at 67 and 73 percent, respectively. The largest mean day-to-day CVs for drift densities of both individuals and biomass were seen in the fall (58 and 49 percent). The lowest day-to-day CVs occurred in spring (27 and 24 percent), whereas summer day-to-day CVs were 32 and 45 percent.

Table 2—The most abundant orders of invertebrates collected in headwater stream drift samples at the Hanus Bay alternatives-to-clearcutting installation, southeastern Alaska

Order	Number	Biomass
	Percentage of total (rank)	
Ephemeroptera	38.0 (1)	27.0 (1)
Diptera	25.3 (2)	19.3 (3)
Ostracoda	10.5 (3)	.4
Acarina	7.6 (4)	.3
Plecoptera	7.2 (5)	11.0 (5)
Coleoptera	2.6	24.1 (2)
Trichoptera	1.7	11.3 (4)

Invertebrate Community Composition

Mayflies (Ephemeroptera, primarily *Baetis*) and dipterans (primarily Chironomidae) were the most abundant taxa captured (table 2). Coleopterans (primarily *Amphizoa*, hydrophilids, and dytiscids) were numerically only 2.6 percent of the total, but nearly a quarter of the biomass owing to their larger size. Collembolans, mites, and ostracods composed nearly a quarter of the total invertebrates captured, but together were only 3.3 percent of the biomass. A detailed list of taxa and their relative proportions is given in the appendix.

There is an apparent relationship between treatment intensity (i.e., basal area retention) and the relative proportions of mayflies and dipterans, the two dominant taxa (fig. 7). In the first year (1999) of posttreatment sampling, the proportion of mayflies tended to decrease, and the proportion of dipterans increased. The magnitude of this change seemed to be related to treatment intensity, with little or no change seen in the control unit, and the largest change seen in the CLEAR5 (wildlife trees) treatment. In the following year, these proportions tended to revert to closer to their pretreatment condition. In the CLEAR5 treatment, an exceptionally large number of chironomid larvae captured in the summer of 1999 was primarily responsible for the increase in the proportion of dipterans for that year.

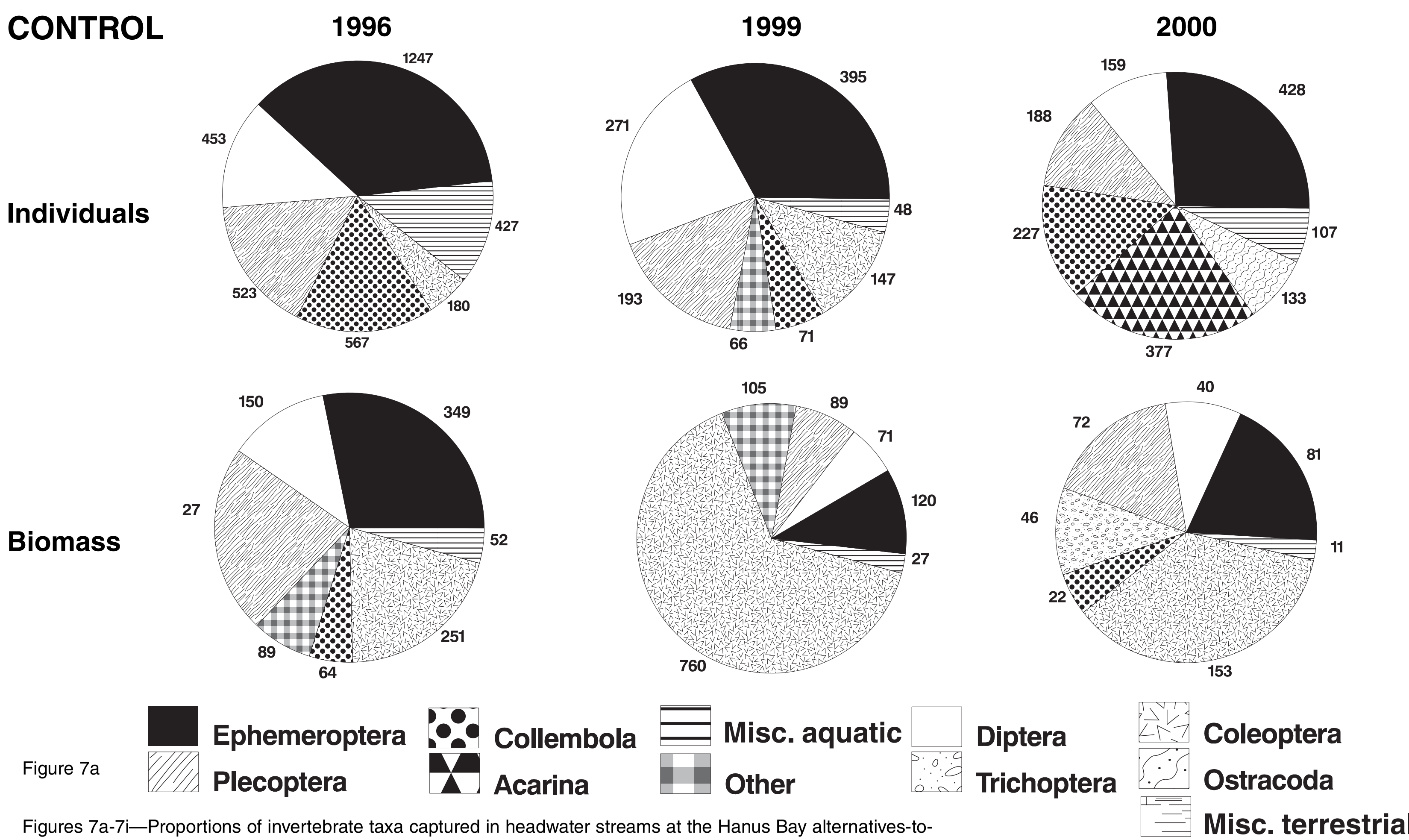


Figure 7a

Figures 7a-7i—Proportions of invertebrate taxa captured in headwater streams at the Hanus Bay alternatives-to-clearcutting installation, Alaska, for each year and treatment. Units are (A) number of individuals and (B) mg dry mass. The “other” category is the aggregate of all taxa composing less than 5 percent of the total.

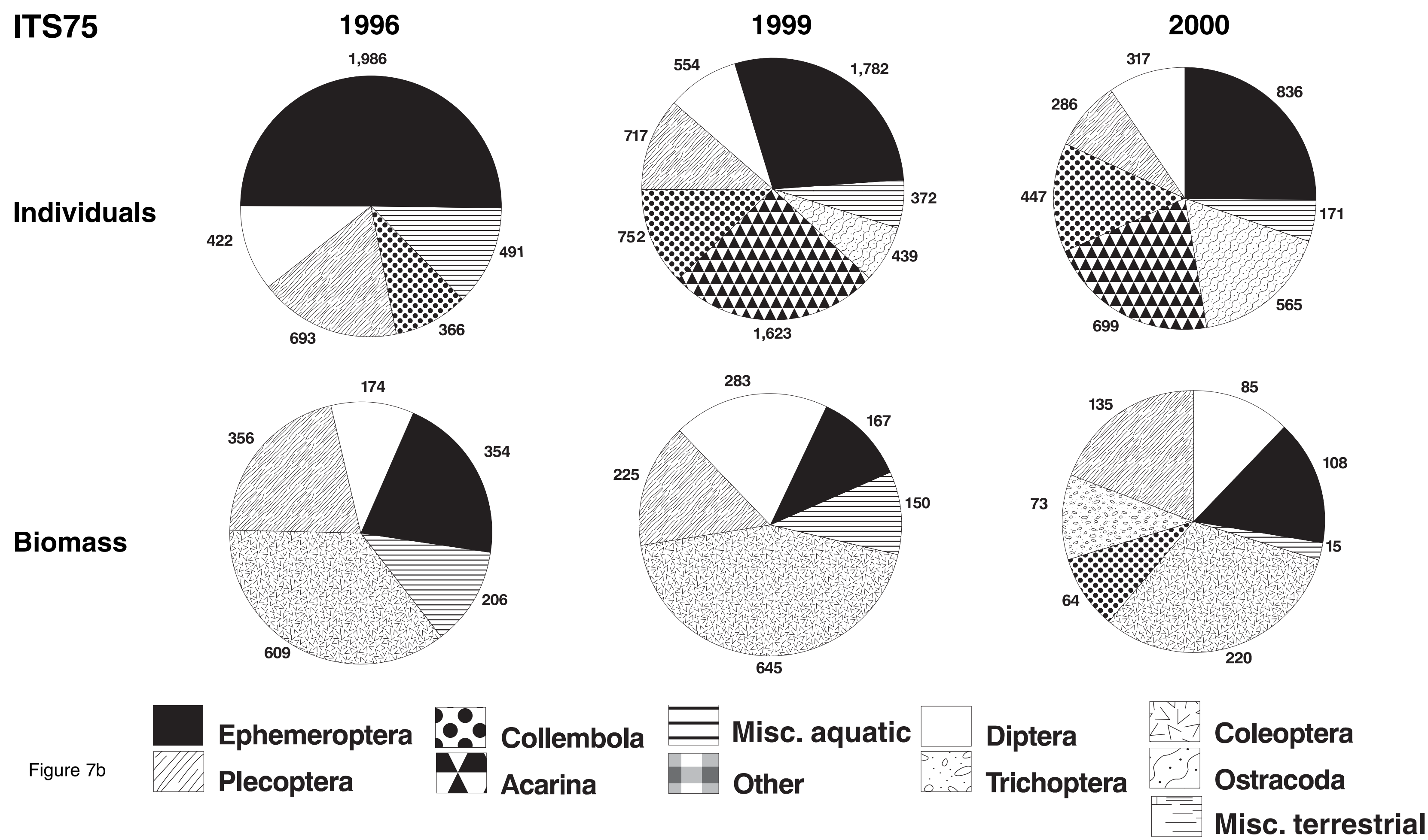

ITS75
1996
1999
2000
Individuals
Biomass
1,986
422
693
366
491
554
1,782
717
372
752
439
1,623
317
836
286
447
171
565
699
174
356
354
206
609
283
167
225
150
645
135
85
108
73
15
64
220
Ephemeroptera
Plecoptera
Collembola
Acarina
Misc. aquatic
Other
Diptera
Trichoptera
Coleoptera
Ostracoda
Misc. terrestrial

Figure 7b

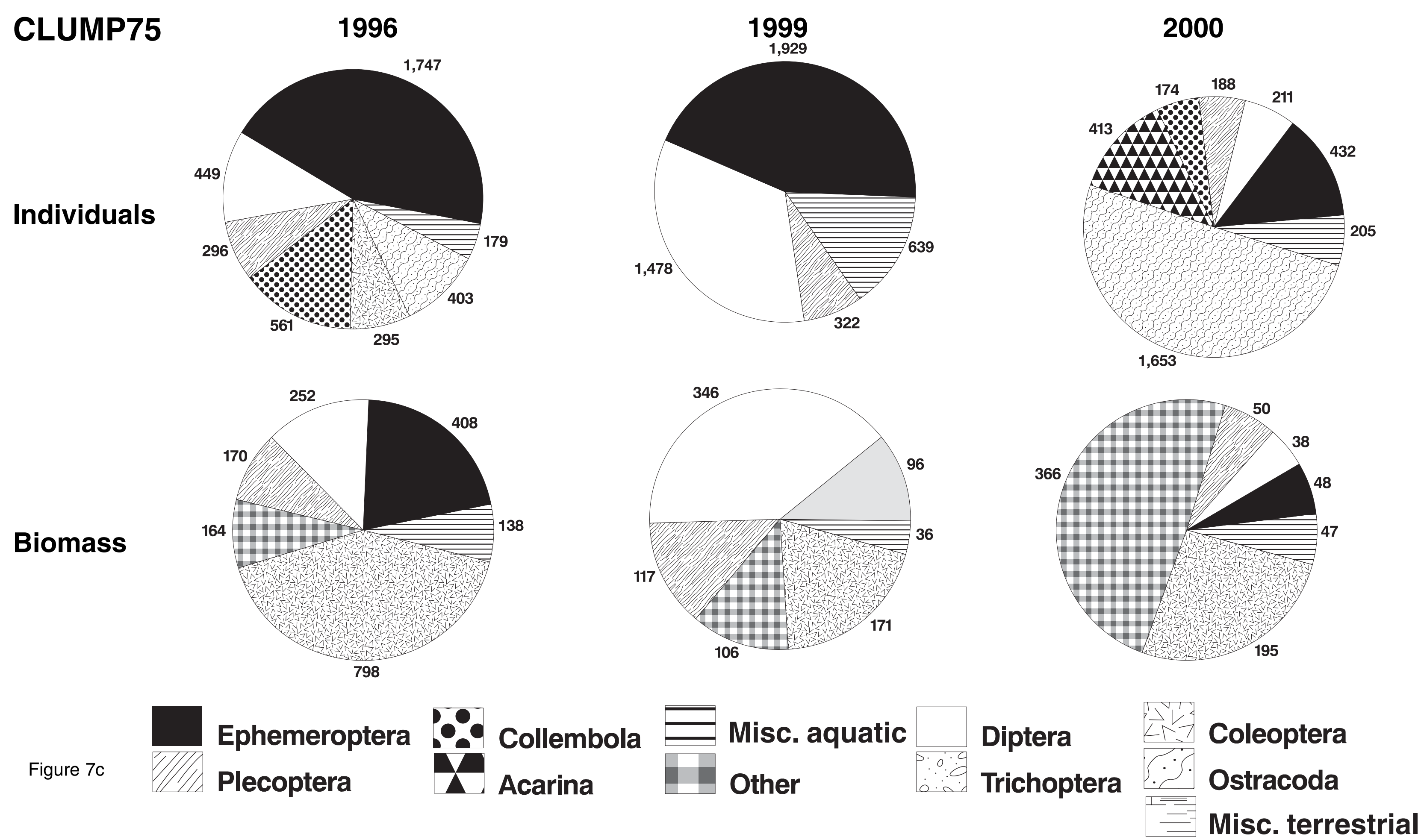

CLUMP75
1996
1999
2000
Individuals
Biomass
1,747
449
296
561
295
403
179
1,929
1,478
322
639
413
174
188
211
432
205
1,653
252
408
170
164
138
798
346
96
36
117
106
171
366
50
38
48
47
195
Ephemeroptera
Plecoptera
Collembola
Acarina
Misc. aquatic
Other
Diptera
Trichoptera
Coleoptera
Ostracoda
Misc. terrestrial

Figure 7c

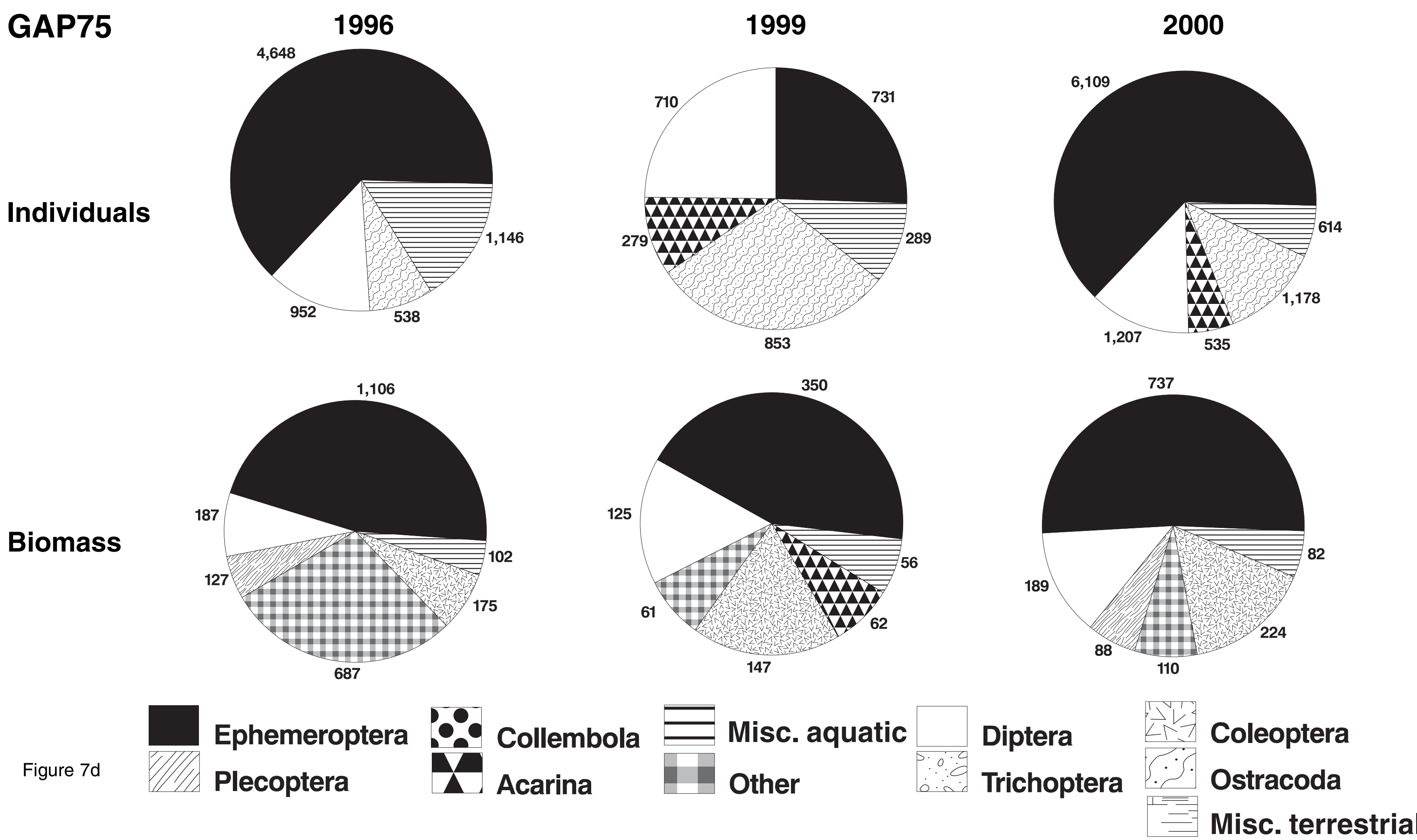

GAP75
1996
1999
2000
Individuals
4,648
952
538
1,146
710
731
279
289
853
6,109
614
1,178
1,207
535
Biomass
1,106
187
127
102
175
687
350
125
56
61
62
147
737
82
189
224
88
110
Ephemeroptera
Plecoptera
Collembola
Acarina
Misc. aquatic
Other
Diptera
Trichoptera
Coleoptera
Ostracoda
Misc. terrestrial

Figure 7d

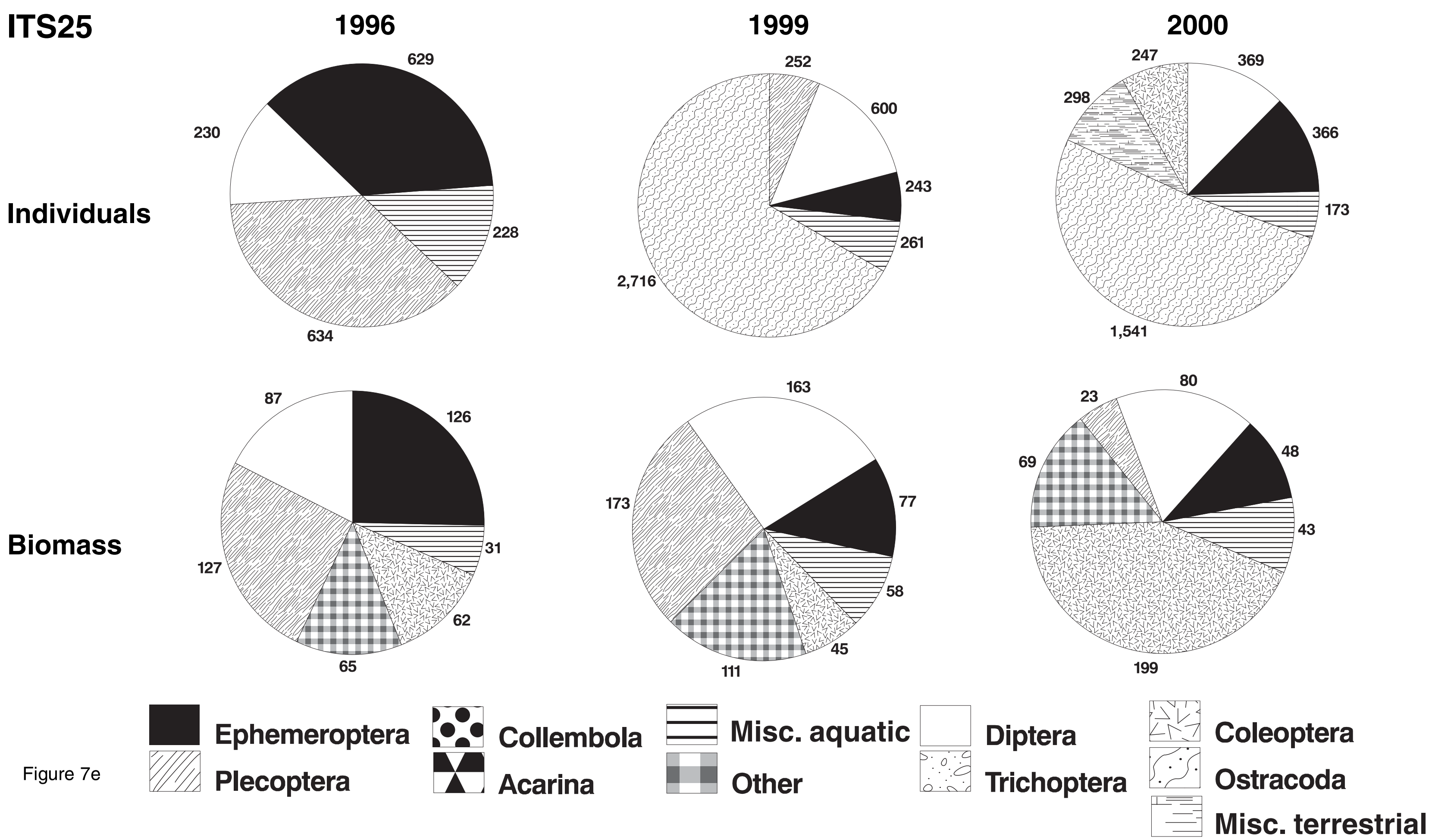
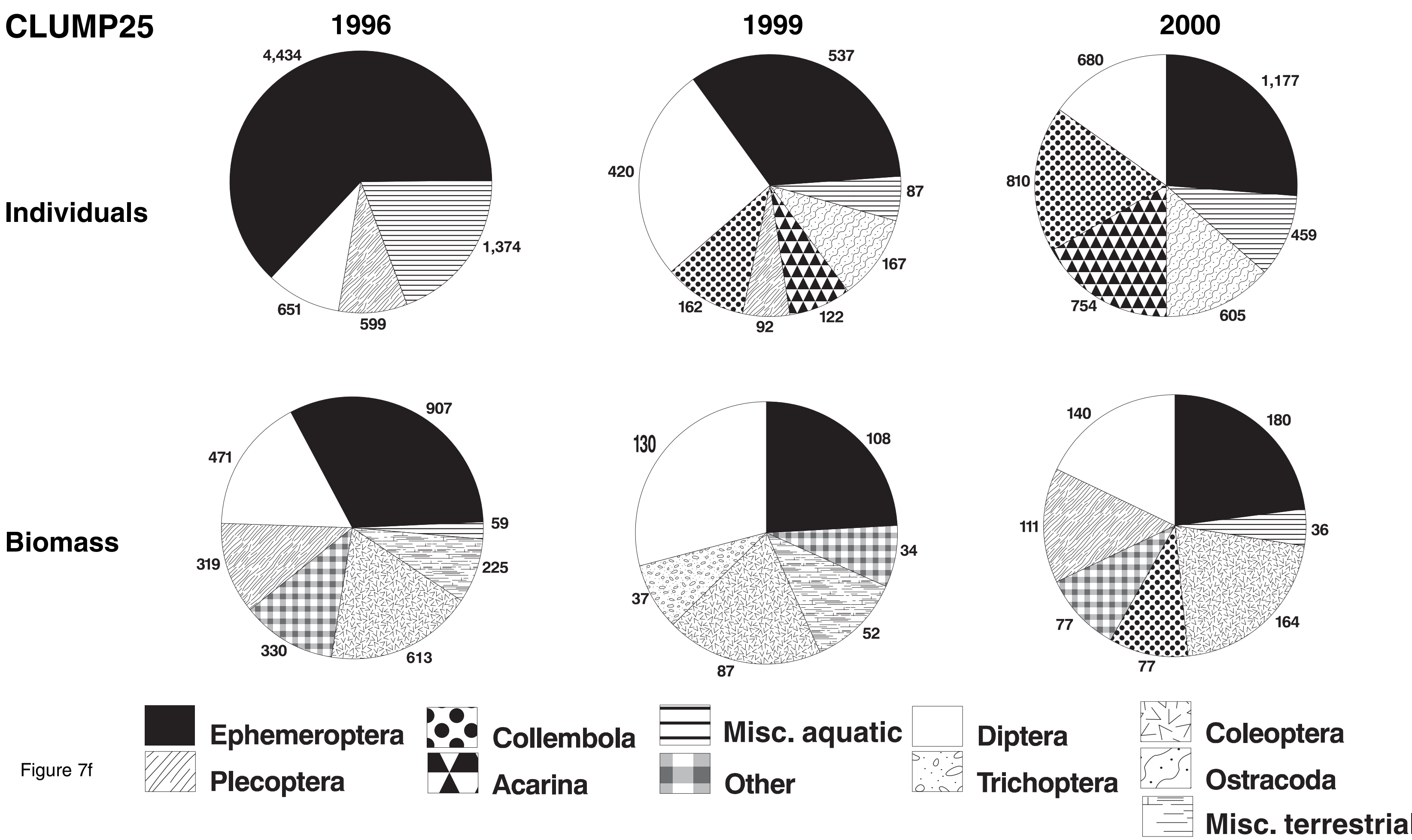
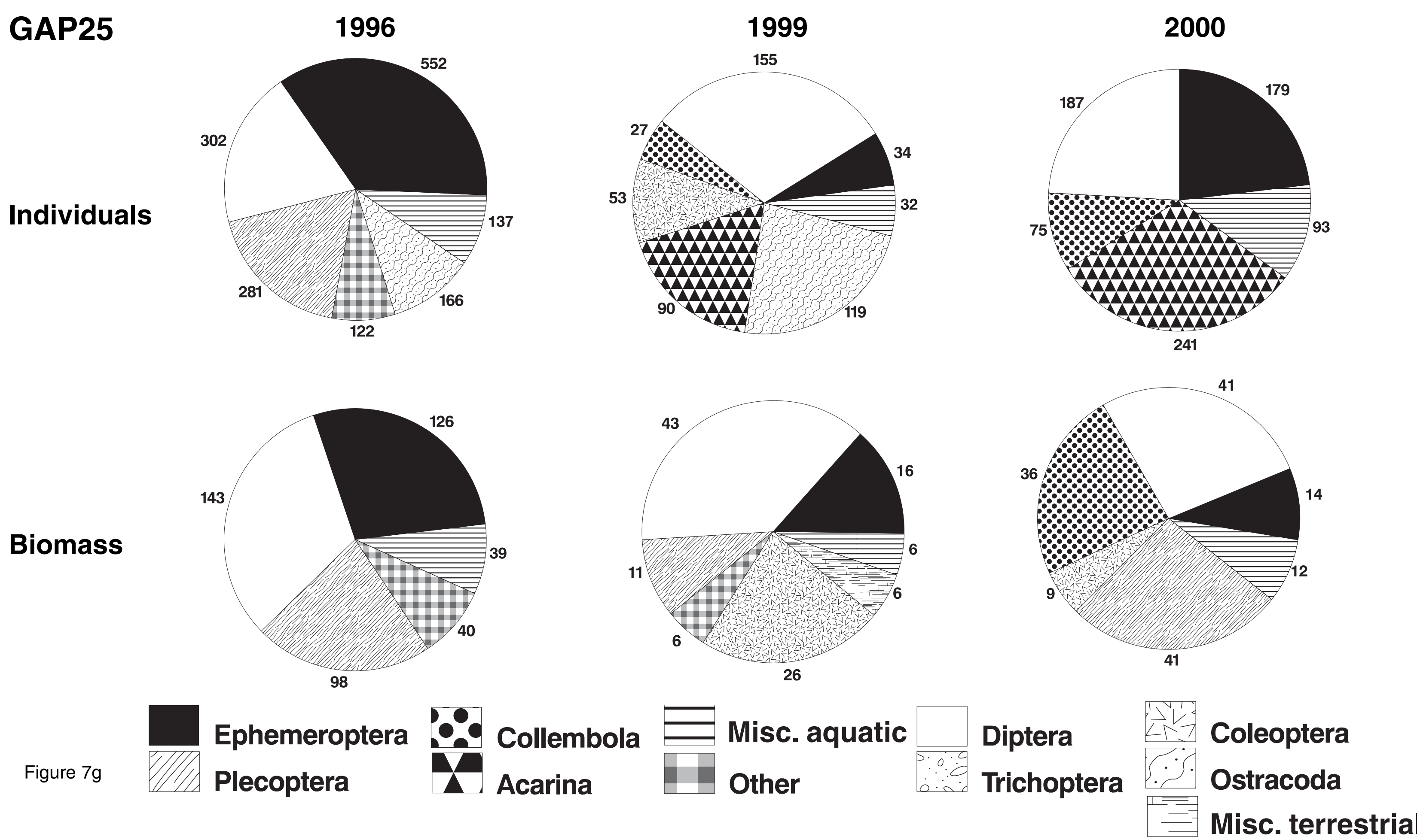

ITS25
1996
1999
2000
Individuals
Biomass
629
230
228
634
252
600
243
261
2,716
247
369
298
366
173
1,541
87
126
31
127
62
65
163
173
77
58
45
111
23
80
69
48
43
199
Ephemeroptera
Plecoptera
Collembola
Acarina
Misc. aquatic
Other
Diptera
Trichoptera
Coleoptera
Ostracoda
Misc. terrestrial

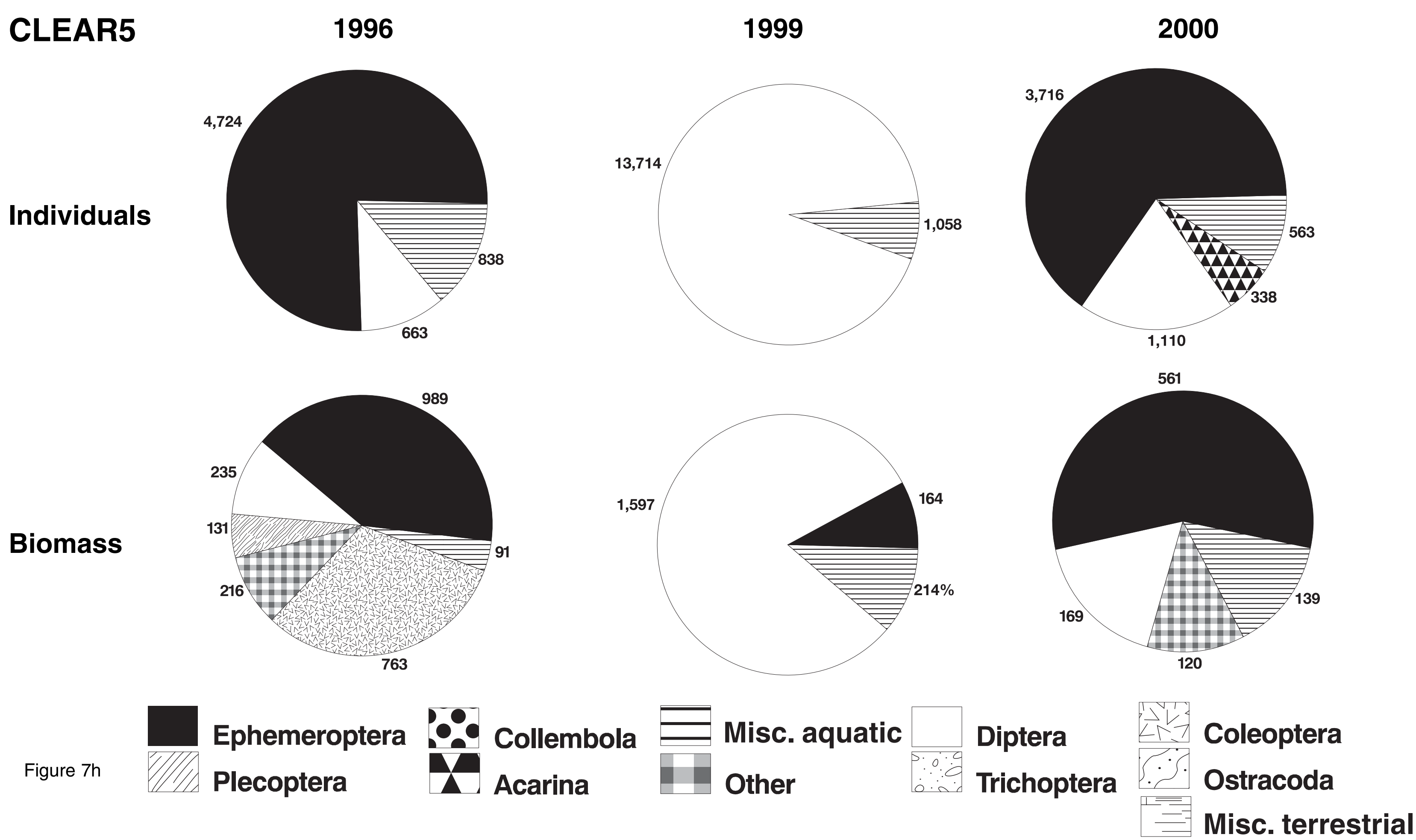
Figure 7e



CLUMP25
1996
1999
2000
Individuals
Biomass
4,434
1,374
651
599
537
420
87
167
162
92
122
680
1,177
810
459
754
605
907
471
59
319
225
330
613
130
108
34
37
52
87
140
180
111
36
77
164
77
Ephemeroptera
Plecoptera
Collembola
Acarina
Misc. aquatic
Other
Diptera
Trichoptera
Coleoptera
Ostracoda
Misc. terrestrial

Figure 7f


GAP25
1996
1999
2000
Individuals
Biomass
552
302
281
122
166
137
155
34
32
119
90
53
27
179
93
241
75
187
126
143
98
40
39
43
16
6
6
26
6
11
41
14
12
41
9
36
Ephemeroptera
Plecoptera
Collembola
Acarina
Misc. aquatic
Other
Diptera
Trichoptera
Coleoptera
Ostracoda
Misc. terrestrial
Figure 7g


CLEAR5
1996
1999
2000
Individuals
Biomass
4,724
838
663
13,714
1,058
3,716
563
338
1,110
989
235
131
216
763
91
1,597
164
214%
561
139
120
169
Ephemeroptera
Plecoptera
Collembola
Acarina
Misc. aquatic
Other
Diptera
Trichoptera
Coleoptera
Ostracoda
Misc. terrestrial
Figure 7h

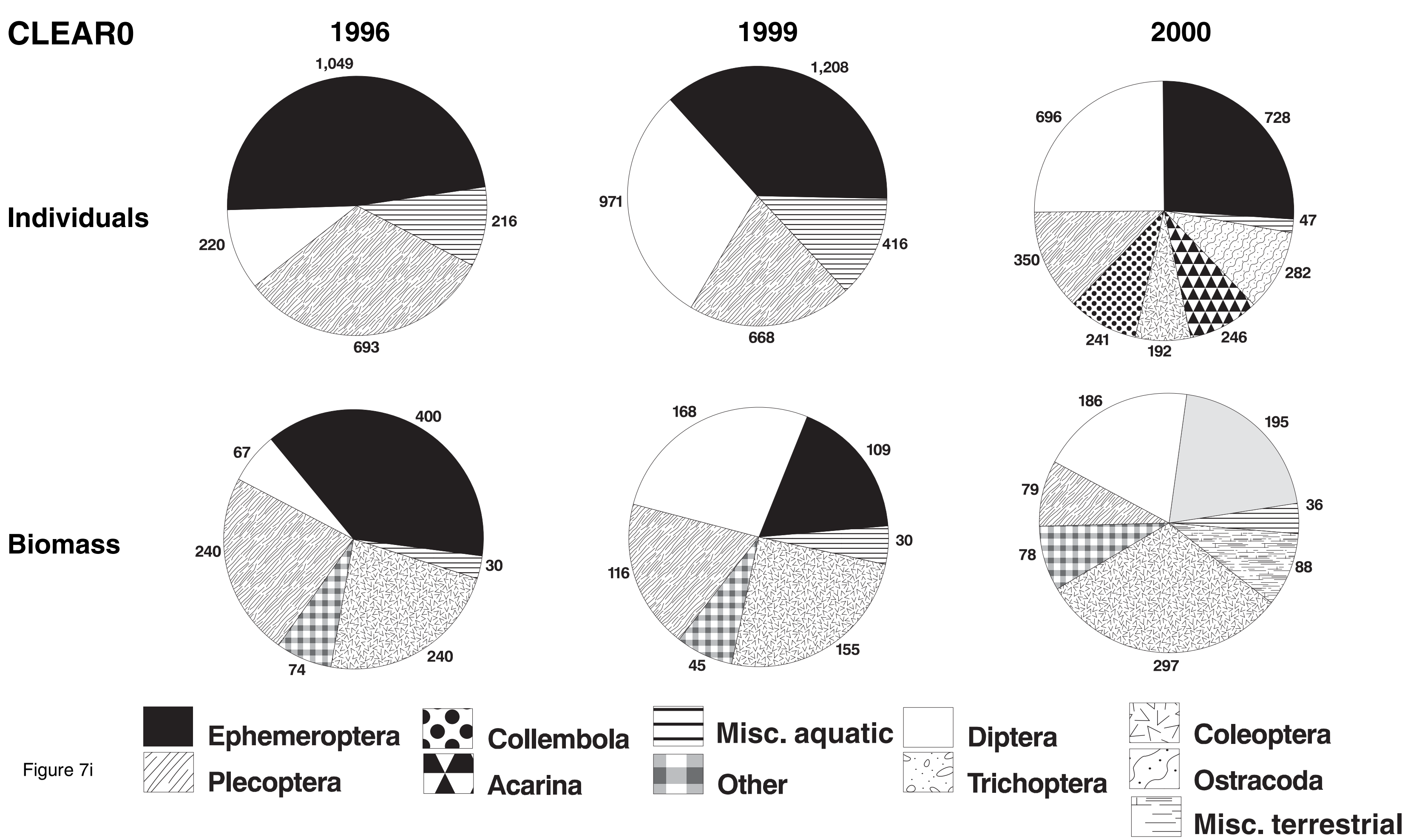

CLEAR0
1996
1999
2000
Individuals
Biomass
1,049
220
693
216
1,208
971
668
416
728
696
350
241
192
246
282
47
400
67
240
74
240
30
168
109
116
45
155
30
186
195
79
78
297
88
36
Ephemeroptera
Plecoptera
Collembola
Acarina
Misc. aquatic
Other
Diptera
Trichoptera
Coleoptera
Ostracoda
Misc. terrestrial

Figure 7i

Table 3—Temperature of headwater streams at the Hanus Bay alternatives-to-clearcutting installation, southeastern Alaska before (1996) and after (1999, 2000) timber harvest

Treatment	Pretreatment mean (range)	Posttreatment mean (range)	Change in mean temperature
	Degrees Celsius		
Control	7.5 (2.5–12.1)	7.8 (2.0–12.4)	0.3
Clump75	7.9 (3.4–11.3)	8.1 (3.6–12.6)	.2
Gap75	5.8 (3.7–8.1)	6.3 (4.4–11.2)	.5
ITS75	8.2 (2.2–15.4)	8.3 (2.3–13.5)	.1
Clump25	8.0 (1.8–12.9)	8.5 (1.8–13.6)	.5
Gap25	7.3 (1.3–10.9)	7.6 (0.8–11.5)	.3
ITS25	6.3 (2.3–10.2)	8.2 (1.8–16.9)	1.9
Wildlife trees	7.4 (2.5–12.9)	8.9 (3.0–15.2)	1.5
Clearcut	7.5 (3.1–10.6)	9.7 (3.9–15.3)	2.2
All treatments	7.4 (1.3–15.4)	8.4 (0.8–16.9)	1.0

Note: Data are from continuous hourly measurements taken from May through September.

Stream Temperature

Mean water temperatures across all treatments rose by about 1 °C after treatment (table 3). More change was seen in more intensive treatments, such as clearcut and wildlife trees; less change was seen in less intensive treatments, such as the control and units with 75 percent retention. Intensive treatments also tended to be associated with a larger change in maximum water temperature.

Discussion

Although there were large differences in mean invertebrate drift density between pretreatment and posttreatment sampling, there was little indication that these differences were due to treatment effects. There was no obvious relationship between the intensity and spatial arrangement of timber harvest and subsequent magnitude of invertebrate drift density change. In fact, the largest differences were often seen in the uncut control unit. Large pretreatment to posttreatment differences also were seen in organic detritus drift densities, but these, too, had little apparent relationship to the applied treatments. Although drift density measurements were an inconclusive measure of the impacts of treatment, the taxonomic composition of the drift did seem to show changes following treatment. Focusing on the two dominant taxa present, we observed an apparent increase in the proportion of dipterans and a decrease in the proportion of mayflies after treatment. This change seemed to be related to the intensity of harvest, although we could not confirm this statistically.

Drift densities in these streams were highly variable both spatially and temporally, which, along with lack of replication, made detection of treatment effects problematic. Any change in drift densities as a result of treatment would have to have been large to be distinguished from natural year-to-year variation. Pretreatment data from two other ATC installations, Portage Bay and Lancaster Cove, were used to assess the natural year-to-year variation in drift densities (Wipfli and Gregovich 2002). Neither of these locations had data spanning 2 complete years, so seasonal comparisons were made, i.e., comparing a unit's summer drift densities of one year to that unit's summer drift densities of the next year. In this comparison, mean invertebrate drift densities differed by an average of 95 percent between years. Some units had drift densities that changed 300 to 800 percent from year to year. This is in excess of the 60 percent average yearly difference seen in Hanus Bay. Year-to-year differences between pretreatment and posttreatment drift densities at Hanus Bay, although large, fit within the range of natural variation seen at other sites when using the same sampling methodology as in this study.

Seasonal variation within a stream was expected as a consequence of seasonal differences in temperature and sunlight, and of the various life histories of drifting organisms. The amount of day-to-day variation seen within a stream, although less than seasonal variation, was considerable. This degree of day-to-day variation appears to be a prominent feature of drift and has been reported by others (Shearer et al. 2002, Williams 1980). Variability across streams on the same sampling date was even larger than seasonal variation, suggesting that localized factors such as gradient, substrate, or aspect may play a large role in productivity and the amount of invertebrate and organic matter transported.

We, like others, have found that considerable sampling effort is necessary to achieve meaningful results (Allan and Russek 1985, Matthaei et al. 1998, Shearer et al. 2002). Drift sample processing is time consuming, so careful consideration of the amount of natural variation and the analytical requirements of any drift sampling project is critical. Drift sampling was used here because of the potential of headwater stream transport to affect downstream, fish-bearing communities. Other measures, such as benthic invertebrate abundance, may be better indicators of changes owing to timber harvest.

Drift density measures were used as a tool to compare the transport of material in streams of different sizes. Drift density measures have typically been used in larger rivers, where it is impossible or impractical to sample the entire drift (Allan and Russek 1985, Brittain and Eikeland 1988). In this study, we were usually able to capture all or most of the stream's surface flow, so obtaining a reasonably accurate estimate of total transport was possible. However, estimates of total transport are of little use when making comparisons between streams whose discharges can differ by an order of magnitude. The use of drift density measures facilitated these comparisons, but we suggest some caution when using this technique. Extremely high and low discharges were associated with a concentration or dilution of the sample so that the drift density seemed to be more related to the volume of water sampled than to the abundance of the invertebrates it carried. Samples obtained during periods of extremely low discharge, or in very small streams, tended to have misleadingly high densities despite containing few invertebrates. For example, the samples with the highest and second-highest drift densities of individuals (19.6 and 12.7 invertebrates/m^3) collected during low flows (0.50 and 0.24 m^3/day) at the Portage Bay ATC installation had only 10 and 3 invertebrates, respectively. Both of these samples were collected at the same stream on consecutive days. Conversely, samples taken in larger streams or in streams at high flows tended to have lower densities. The stream with the highest observed densities in Portage Bay was also the source of the sample with the lowest observed density (0.02 invertebrates/m^3). This sample was collected during a period of higher discharge, estimated at 144 m^3/day, and contained three invertebrates. Clearly, the use of drift density measures does not negate the effect of streamflow differences and must be used carefully by investigators.

Conclusions

The objective of this study was to measure the effects of various timber harvest treatments on the invertebrate and organic detritus transport from headwater streams. These effects were measured by comparing drift densities and community composition before and after timber harvest. Large natural spatial and temporal variability prevented detection of possible treatment effects from timber harvesting in this study. When developing experimental studies and monitoring plans for headwater streams such as these in the future, considerations of low statistical power resulting from high natural variability along with the large amount of time and money needed to achieve suitable replicates and information from drift sampling should be carefully balanced. Nonetheless, these streams have much potential to influence downstream habitats through the energy (food) they deliver to these habitats year round. Understanding these linkages more fully should aid ecosystem management in regions containing upland forests, headwater streams, and critical fish habitat.

Acknowledgments

This report is a contribution from the USDA Forest Service study, Alternatives to Clearcutting in the Old-Growth Forests of Southeast Alaska, a joint effort of the Pacific Northwest Research Station, the Alaska Region, and the Tongass National Forest. Special thanks are given to Dave Gregovich, Alison Cooney, Kim Frangos, John Hudson, Maria Lang, Shuly Millstein, and the USDA Forest Service personnel at the Sitka Ranger District. Thanks to Tim Max and John Caouette for statistical advice. We thank Adelaide Johnson, Jack Piccolo, John Hudson, and Brenda Wright for helping improve earlier versions of this paper. Thanks also to Bob Wisseman for taxonomic assistance and to Frances Biles for preparation of the study sites maps.

English Equivalents

When you know:	Multiply by:	To find:
Millimeters (mm)	0.0394	Inches
Centimeters (cm)	.394	Inches
Meters (m)	3.28	Feet
Kilometers (km)	.6215	Miles
Cubic meters (m^3)	35.3	Cubic feet
Micrometers (μm)	.0000394	Inches
Hectares (ha)	2.47	Acres
Grams (g)	.0352	Ounces
Milligrams (mg)	.0000352	Ounces
Liters (L)	1.057	Quarts
Liters per second (L/s)	.265	Gallons per second
Celsius degrees (°C)	1.8C+32	Fahrenheit degrees

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Appendix 1

Macroinvertebrate taxa collected from headwater streams at the Hanus Bay alternatives-to-clearcutting installation, southeastern Alaska

Taxon[a]	Number	Biomass
	Percentage of total	
Annelida		
Oligochaeta	0.4	0.9
Arthropoda		
Chelicerata		
Arachnida		
Acari	7.6	.3
Araneae	.3	1.5
Pseudoscorpiones	<.1	<.1
Crustacea		
Isopoda	<.1	<.1
Ostracoda	10.5	.4
Uniramia		
Diplopoda	<.1	.3
Chilopoda	<.1	.2
Insecta		
Collembola	5.8	2.6
Ephemeroptera	.2	.3
Ameletidae		
Ameletus	.7	.5
Baetidae	31.9	14.1
Ephemerellidae	<.1	<.1
Caudatella	.1	.3
Drunella	.3	2.2
Heptegeniidae	.2	.3
Cinygma	.1	.8
Cinygmula	.9	1.4
Epeorus	.7	2.0
Rhithrogena	.1	.7
Leptophlebiidae		
Paraleptophlebia	2.8	4.3
Plecoptera	.3	.2
Capniidae	.8	.2
Chloroperlidae	.2	.2
Kathroperla	<.1	<.1
Sweltsa	1.7	5.4
Leuctridae	1.2	2.2
Nemouridae	.9	.7
Podmosta	1.1	.7
Zapada	.8	1.0
Visoka	.4	.4
Perlidae	<.1	<.1
Perlodidae	<.1	<.1
Hemiptera	<.1	<.1
Aphididae	<.1	<.1

Taxon[a]	Number	Biomass
	Percentage of total	
Homoptera	<.1	<.1
Trichoptera	.1	.2
Brachycentridae	<.1	<.1
Micrasema	.2	.2
Glossosomatidae	<.1	.2
Hydropsychidae	<.1	.5
Limnephilidae	.1	.4
Chyranda	.2	1.1
Cryptochia	<.1	.2
Ecclisocosmoecus	<.1	.3
Homophylax	<.1	<.1
Imania	<.1	<.1
Neophylax	<.1	<.1
Psychoglypha	<.1	<.1
Philopotamidae	.2	.7
Polycentropodidae	<.1	<.1
Rhyacophilidae	.7	7.6
Lepidoptera	<.1	.2
Coleoptera	.4	1.1
Misc. terrestrial	.2	3.7
Amphizoidae	.2	12.8
Curculionidae	<.1	.2
Dytiscidae	1.0	1.9
Elmidae	<.1	<.1
Hydrophilidae	.1	1.2
Ametor	<.1	.5
Hydrovatus	.6	1.4
Staphylinidae	.2	1.3
Diptera	4.7	4.2
Ceratopogonidae	<.1	<.1
Chaoboridae	<.1	<.1
Chironomidae	19.0	9.7
Culicidae	<.1	<.1
Dixidae	.4	.2
Empididae	<.1	.1
Ephydridae	<.1	<.1
Mycetophilidae	<.1	<.1
Psychodidae	<.1	<.1
Sciaridae	.3	.5
Simuliidae	.2	.2
Tipulidae	.1	1.4
Dicranota	.3	.1
Pedicia	<.1	.5
Tipula	<.1	2.0
Hymenoptera	.2	.2
Formicidae	<.1	<.1
Orthoptera	<.1	<.1

Taxon[a]	Number	Biomass
	Percentage of total	
Psocoptera	<.1	<.1
Thysanoptera	.1	<.1
Mollusca		
Gastropoda	<.1	.4
Nematomorpha	<.1	<.1
Platyhelminthes		
Turbellaria	<.1	.2

[a] Macroinvertebrates were identified to the lowest reliable taxon (i.e., individuals that could not be positively identified to a certain taxonomic level were assigned to the next higher category), so percentage of relative abundance by count or biomass of a higher taxon (i.e., family) does not include those from the taxon or taxa below them (i.e., genus).

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