Tandem Catalysis: The Sequential Mediation of Olefin Metathesis, Hydrogenation, and Hydrogen Transfer Using Single Component Ru Complexes

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Supporting Information

General information. All manipulations were performed in a N₂ filled drybox or using standard Schlenk techniques. Allyl benzene, methyl vinyl ketone, p-chlorostyrene, methyl methacrylate, diethyl diallylmalonate (3), and 1,6-heptadien-4-ol (6) were purchased from Aldrich and used without further purification. cis-4-Cyclopentene-1,3-diol and (+)-citronellal were purchased from Fluka and used without further purification. cis-2-Butene-1,4-diol diacetate and 5-acetoxy-1-hexene were purchased from TCI America and used without further purification. Complexes (PCy₃)₂Cl₂Ru=CHPh (1), (H₂IMes)(PCy₃)Cl₂Ru=CHPh (2), and substrates 1,6-heptadien-4-one (6), 1,8-nonadien-5-one (12), 1-allyl-2-(2-methyl-allyl)-malonic acid diethyl ester (15), 1,4-bis-allyloxy-but-2-ylene (21), 2-methyl-acrylic acid but-3-ynyl ester (24), N-allyl-N-isopropyl-acrylamide (27), and undec-10-enoic acid but-3-ynyl ester (30) were prepared as previously reported. Substrates 4,4-dicarbethoxy-cyclopentene (4), cyclopent-3-enone (7), cyclopent-3-enol (10), cyclohept-4-enone (13), 4,4-dicarbethoxy-1-methylcyclopentene (16), 2,5,2',5'-tetrahydro-[3,3']bifuranyl (22), 3-methyl-5,6-dihydro-pyran-2-one (25), 1-isopropyl-1,5-dihydro-pyrrol-2-one (28), oxacyclotetradec-11-en-2-one (31), acetic acid 4-phenyl-but-2-ynyl ester (33), acetic acid 7-oxo-oct-5-ynyl ester (35), 4-phenyl-but-3-en-2-one (37), and 3-(4-chloro-phenyl)-acrylic acid methyl ester (39) are known metathesis products. ¹H (300 MHz) and ¹³C NMR (75 MHz) spectra were recorded on a GE-300 NMR, referenced to residual protiated solvent (resonances downfield to the standard are reported as positive), and are reported in parts per million (ppm).
Multiplicities are abbreviated as follows: singlet (s), doublet (d), triplet (t), and multiplet (m). Low-resolution mass spectra were obtained on a Hewlett Packard 5890 series II gas chromatograph interfaced with a Hewlett Packard 5989A mass spectrometer. IR spectra were recorded on a Perkin-Elmer Paragon 1000 FT-IR spectrometer. Specific rotations $\alpha_D$ were determined on a Jasco Model P-1010 polarimeter in methanol and are given in $10^1\deg\text{cm}^2\text{g}^{-1}$. Elemental analyses were performed at Midwest Microlab LLC., Indianapolis, IN. High-resolution mass spectra (HR-MS) (EI and FAB) were provided by the UCR Mass Spectrometry Facility (University of California, Riverside).

**General Tandem Metathesis – Hydrogenation Procedure.** Olefin substrate(s) (~0.5 mmol), mesitylene or 1,3,5- trimethoxybenzene (~0.2 mmol, internal standard), and $(\text{PCy}_3)_2\text{Cl}_2\text{Ru}=\text{CHPh} (1)$ or $(\text{H}_2\text{IMes})(\text{PCy}_3)\text{Cl}_2\text{Ru}=\text{CHPh} (2)$ (15 - 45 $\mu$mol) were dissolved in dichloromethane or 1,2-dichloroethane in a screw top vial. The vial was sealed with a cap containing a PTFE septum, removed from the drybox, and placed under an atmosphere of Ar. The reaction mixture was heated to 40 $^\circ$C for 1 h (or until complete consumption of starting material was observed by GC). Then, either a balloon of H$_2$ was attached via a syringe needle or the reaction mixture was transferred to a Fisher-Porter bottle (H$_2$ pressures ~100 psi) or a Parr bomb (H$_2$ pressures >100 psi) and the desired amount of hydrogen was introduced to the reaction. After heating the vessel at 70 $^\circ$C for 8-24 h, the reaction mixture was cooled to ambient temperature, reduced in volume to ~0.5 mL (via a rotary evaporator) and purified directly on a silica gel column (hexanes/ethyl acetate as eluent).

**Cyclopentane-1,1-dicarboxylic acid diethyl ester (5, Table 1, entry 1a).** Using the general procedure with diethyl diallyl malonate (3, 125 $\mu$L, 0.52 mmol), mesitylene (25 $\mu$L, 0.18 mmol), $(\text{PCy}_3)_2\text{Cl}_2\text{Ru}=\text{CHPh} (1)$ (25 mg, 31 $\mu$mol), and 5 mL of 1,2-dichloroethane afforded 106 mg (95%) cyclopentane-1,1-dicarboxylic acid diethyl ester as a colorless oil. $^1$H NMR (300 MHz, CDCl$_3$, ppm): $\delta$ 4.17 (q, $J=7.1$ Hz, 4 H), 2.18 (t, $J=6.0$ Hz, 4H), 1.68 (quint, $J=4.1$ Hz, 4H), 1.24 (t, $J=7.1$ Hz, 6H); $^{13}$C {$^1$H} NMR (75 MHz, CDCl$_3$, ppm): $\delta$ 172.9, 61.4, 60.5, 34.7, 25.7, 14.3; IR (neat): 2981 (s), 2875 (m), 1731 (vs, C=O), 1447 (s), 1390 (m), 1367 (s), 1324 (m), 1260 (vs), 1176 (vs), 1098 (s), 1078 (s), 1028 (s), 953 (w), 908 (w), 862 (m), 754 (w), 705 (w).
Cyclopentanone (8, Table 1, entry 1b). Using the general procedure with hepta-1,6-dien-4-one (6, 50 mg, 0.45 mmol), mesitylene (35 µL, 0.25 mmol), (PCy$_3$)$_2$Cl$_2$Ru=CHPh (1) (12 mg, 15 µmol), and 5 mL of 1,2-dichloroethane quantitatively afforded cyclopentanone (determined by GC/GC-MS analysis).

Cyclopentanol (11, Table 1, entry 1c). Using the general procedure with hepta-1,6-dien-4-ol (9, 53 mg, 0.47 mmol), mesitylene (35 µL, 0.25 mmol), (H$_2$IMes)(PCy$_3$)Cl$_2$Ru=CHPh (1) (15 mg, 18 µmol), and 5 mL of 1,2-dichloroethane quantitatively afforded cyclopentanol (determined by GC/GC-MS analysis).

Cycloheptanone (14, Table 1, entry 2). Using the general procedure with 1,8-nonadien-5-one (12, 60 mg, 0.43 mmol), mesitylene (15 µL, 0.11 mmol), (H$_2$IMes)(PCy$_3$)Cl$_2$Ru=CHPh (2, 10 mg, 12 µmol), and 25 mL of 1,2-dichloroethane afforded 39 mg (81%, 86% by conversion of 12) of cycloheptanone as a colorless oil. All spectra were identical to an authentic sample purchased from Aldrich.

3-Methyl-cyclopentane-1,1-dicarboxylic acid diethyl ester (17, Table 1, entry 3). Using the general procedure with 2-allyl-2-(2-methyl-allyl)-malonic acid diethyl ester (15, 100 mg, 0.39 mmol), mesitylene (25 µL, 0.18 mmol), (PCy$_3$)$_2$Cl$_2$Ru=CHPh (1) (10 mg, 12 µmol), and 5 mL of 1,2-dichloroethane afforded a 70% conversion to product 17 (determined by GC/GC-MS analysis).

3- Allyloxy-5-(2-methallyloxy)-cyclopentene (18). This compound was prepared using a modified procedure of 3,5-cyclopentenediol bis(allyl) ether (see ref. 9). A 20 mL round bottom flask was charged with 391 mg (3.91 mmol) of cis-4-cyclopentene-1,3-diol and dissolved in 15 mL of dry DMF. After cooling the resulting solution to 0 ºC, the slow addition of 94 mg (3.92 mmol) of NaH resulted in the immediate bubbling of H$_2$. After stirring at 0 ºC for 30 min, 0.43 mL (4.26 mmol) of 3-bromo-2-methyl-propene (methallyl bromide) was added via syringe to the suspension and the reaction mixture was allowed to warm to room temperature. After 8 h at room temperature, the resulting yellow solution was diluted with water (30 mL) and extracted with Et$_2$O (5 x 20 mL). After concentrating the organic layer to a yellow oil, purification via column chromatography (silica gel, hexanes/ethyl acetate as...
eluent) afforded 452 mg (75% yield) of 4-(2-methyl-allyloxy)-cyclopent-2-enol as a clear, colorless oil. \(^1\)H NMR (300 MHz, CDCl\(_3\), ppm): \(\delta\) 6.01 (s, 2H), 4.96 (t, \(J=0.8\) Hz, 1H), 4.88 (d, \(J=0.8\) Hz, 1H), 4.64-4.56 (bdd, \(J=6.3\) Hz and 4.4 Hz, 1H), 4.38-4.32 (m, 1H), 3.91 (t, \(J=1.4\)Hz, 2H), 2.70-2.56 (m, 1H), 2.08 (bs, 1H), 1.74 (s, 3H), 1.64-1.54 (dt, \(J=14\) Hz and 5 Hz, 1H); \(^{13}\)C \({^1}\)H NMR (75 MHz, CDCl\(_3\), ppm): \(\delta\) 142.2, 137.0, 134.0, 112.2, 81.2, 74.9, 72.9, 40.9, 19.7; IR (neat): 3425 (br, vs), 2974 (m), 2939 (s), 1655 (s), 1451 (m), 1358 (m), 1257 (w), 1180 (w), 1077 (vs), 899 (m), 764 (m); HR-MS calcd for C\(_9\)H\(_{14}\)O\(_2\) (M\(^+\)): 154.0994, found 154.0992; Anal. calcd for C\(_9\)H\(_{14}\)O\(_2\): C, 70.10; H, 9.15, found: C, 70.15; H, 8.90.

Note: the major byproduct of the above reaction was determined to be 3,5-bis-(2-methallyloxy)-cyclopentene (163 mg). \(^1\)H NMR (300 MHz, CDCl\(_3\), ppm): \(\delta\) 6.02 (s, 2H), 4.97 (t, \(J=1.1\) Hz, 2H), 4.87 (dd, \(J=1.4\) Hz and 0.8 Hz, 2H), 4.38 (dd, \(J=6.3\) Hz and 4.4 Hz, 2H), 3.90 (s, 4H), 2.68-2.56 (m, 1H), 1.75 (s, 6H), 1.70-1.60 (dt, \(J=14\) Hz and 5 Hz, 1H); \(^{13}\)C \({^1}\)H NMR (75 MHz, CDCl\(_3\), ppm): \(\delta\) 142.4, 134.4, 111.9, 81.0, 72.4, 37.7, 19.7; IR (neat): 2975 (s), 2857 (m), 1655 (s), 1451 (m), 1370 (m), 1321 (w), 1257 (w), 1086 (m), 897 (m), 765 (w); HR-MS calcd for C\(_{13}\)H\(_{20}\)O\(_2\) (M\(^+\)): 208.1463, found 208.1465; Anal. calcd for C\(_{13}\)H\(_{20}\)O\(_2\): C, 74.96; H, 9.68, found: C, 75.13; H, 9.94.

A 20 mL round bottom flask was charged with 167 mg (1.08 mmol) of 4-(2-methyl-allyloxy)-cyclopent-2-enol and dissolved in 5.2 mL of dry DMF. After cooling the resulting solution to 0 \(^{\circ}\)C, the slow addition of 125 mg (5.21 mmol) of NaH resulted in the immediate bubbling of H\(_2\). After stirring at 0 \(^{\circ}\)C for 30 min, 0.60 mL (6.93 mmol) of allyl bromide was added via syringe to the suspension and the reaction mixture was allowed to warm to room temperature. After 8 h at room temperature, the resulting yellow solution was diluted with water (15 mL) and extracted with Et\(_2\)O (3 x 10 mL). After concentrating the organic layer to a yellow oil, purification via column chromatography (silica gel, hexanes/ethyl acetate as eluent) afforded 3-allyloxy-5-(2-methallyloxy)-cyclopentene (18) in 83% yield (175 mg) as a clear, colorless oil. \(^1\)H NMR (300 MHz, CDCl\(_3\), ppm): \(\delta\) 6.03 (s, 2H), 6.02-5.88 (m, 1H), 5.27 (m, 1H), 5.15 (m, 1H), 4.97 (m, 1H), 4.87 (m, 1H), 4.40-4.33 (m, 2H), 4.00 (dt, \(J=5.5\) Hz and 1.1 Hz, 2H), 3.90 (s, 2H), 2.69-2.57 (m, 1H), 1.73 (s, 3H), 1.71-1.60 (m, 1H); \(^{13}\)C \({^1}\)H NMR (75 MHz, CDCl\(_3\), ppm): \(\delta\) 142.4, 135.0, 134.5, 134.2, 116.7, 111.9, 81.1, 81.0, 72.5, 69.5, 37.7, 19.7; IR (neat): 3076 (m), 2975 (m),
2-(2,5-dihydro-furan-2-ylmethyl)-4-methyl-2,5-dihydrofuran (19) Using the general metathesis procedure (no hydrogenation) with compound 18 (55 mg, 0.29 mmol), (H₂IMes)(PCy₃)Cl₂Ru=CHPh (2, 8 mg, 9 µmol), mesitylene (25 µL, 0.18 mmol), and 6 mL of 1,2-dichloroethane afforded 43 mg (91%) of compound 19 as a colorless oil. \(^1\)H NMR (300 MHz, CDCl₃, ppm): δ 5.91 (m, 2H), 5.45 (d, J=1.4 Hz, 1H), 4.96-4.91 (m, 2H), 4.71-4.43 (m, 4H), 1.93-1.77 (m, 2H), 1.75 (m, 3H); \(^{13}\)C \(^1\)H NMR (75 MHz, CDCl₃, ppm): δ 136.3, 130.2, 126.4, 124.0, 84.2, 83.7, 77.9, 75.1, 42.4, 12.5; IR (neat): 2926 (m), 2857 (m), 1755 (s), 1644 (m), 1506 (w), 1445 (m), 1382 (w), 1341 (w), 1145 (vs), 993 (w), 899 (s), 763 (m); HR-MS calcd for C₁₀H₁₄O₂ (M⁺): 166.0994, found 166.0996; Anal. calcd for C₁₀H₁₄O₂: C, 72.26; H, 9.59, found: C, 72.40; H, 9.60.

4-Methyl-2-(tetrahydro-furan-2-ylmethyl)-2,5-dihydro-furan (20, Table 1, entry 4). Using the general procedure with compound 18 (55 mg, 0.29 mmol), mesitylene (10 µL, 0.07 mmol), (H₂IMes)(PCy₃)Cl₂Ru=CHPh (2, 8 mg, 9 µmol), and 6 mL of 1,2-dichloroethane afforded 43 mg (90%) of compound 20 as a colorless oil. \(^1\)H NMR (300 MHz, CDCl₃, ppm): δ 5.45 (t, J=1.5 Hz, 1H), 4.91 (pseudo octet, J=1.9 Hz, 1H), 4.56-4.42 (m, 3H), 3.95-3.84 (m, 2H), 3.74-3.67 (m, 2H), 2.07-1.46 (m, 7H); \(^{13}\)C \(^1\)H NMR (75 MHz, CDCl₃, ppm): δ 136.3, 123.9, 84.8, 77.8, 77.0, 67.8, 42.1, 31.8, 25.8, 12.5; IR (neat): 2931 (vs), 2890 (s), 1756 (vs), 1446 (m), 1381 (m), 1062 (vs), 764 (w), 613 (w); HR-MS calcd. for C₁₀H₁₆O₂ (M⁺): 168.1150, found 168.1151. Anal. calcd for C₁₀H₁₆O₂: C, 71.39; H, 9.59, found: C, 71.50; H, 9.60.

Octahydro-[3,3']bifuranyl (23, Table 1, entry 5).\(^{15}\) Using the general procedure with compound 21 (250 mg, 1.5 mmol), mesitylene (40 µL, 0.29 mmol), (PCy₃)₂Cl₂Ru=CHPh (1, 38 mg, 46 µmol), and 10 mL of dichloromethane afforded (an inseparable diastereomeric mixture) of compound 23 (198 mg, 93%) as a colorless oil. \(^1\)H NMR (300 MHz, CDCl₃, ppm): δ 3.95-3.80 (m, 4H), 3.79-3.69 (m, 2H), 3.47-
3.40 (m, 1H), 3.39-3.33 (m, 1H), 2.20-1.93 (m, 4H), 1.70-1.47 (m, 2H); 13C 1H NMR (75 MHz, CDCl3, ppm): δ 72.2, 72.0, 68.0, 67.8, 42.8, 42.7, 31.4, 31.3; IR (neat): 2963 (s), 2931 (s) 2863 (s), 1474 (w), 1452 (m), 1367 (w), 1210 (w), 1079 (s), 1041 (m), 963 (w), 909 (s), 689 (m), 668 (w); HR-MS calcd. for C8H14O2 (M+): 142.0994, found 142.0996; Anal. calcd for C8H14O2: C, 67.57; H, 9.92; found: C, 67.71; H, 9.71.

3-Methyl-tetrahydro-pyran-2-one (26, Table 1, entry 6).16 Using the general procedure with compound 24 (160 mg, 1.14 mmol), mesitylene (25 µL, 0.18 mmol), (H2IMes)(PCy3)2Cl2Ru=CHPh (2, 37 mg, 44 µmol), and 5 mL of 1,2-dichloroethane afforded 100 mg (77%, 85% by conversion of 24) of compound 26 as a colorless oil. 1H NMR (300 MHz, CDCl3, ppm): δ 4.06 (t, J=6.6. Hz, 2H), 2.53 (dt, J1=7.14 Hz, J2=6.9 Hz, 1H), 1.69-1.59 (m, 2H), 1.41-1.36 (m, 2H), 1.16 (d, J=6.9 Hz, 3H); 13C 1H NMR (75 MHz, CDCl3, ppm): δ 177.2, 64.4, 34.3, 28.9, 25.9, 19.4; IR (neat): 2973 (vs), 2876 (s), 1732 (vs, C=O), 1471 (s), 1391 (s), 1366 (w), 1344 (m), 1261 (s), 1193 (s), 1157 (s), 1078 (s), 1029 (w), 984 (m), 930 (w), 907 (w), 843 (w), 753 (m), 700 (w).

1-Isopropyl-pyrrolidin-2-one (29, Table 1, entry 7).17 Using the general procedure with compound 27 (97 mg, 0.63 mmol), mesitylene (25 µL, 0.18 mmol), (H2IMes)(PCy3)2Cl2Ru=CHPh (2, 20 mg, 24 µmol), and 5 mL of 1,2-dichloroethane afforded 68 mg (84%, 94% by conversion of 27) of compound 29 as a colorless oil. 1H NMR (300 MHz, CDCl3, ppm): δ 4.37 (sept, J=6.9 Hz, 1H), 3.33 (t, J=6.9 Hz, 2H), 2.38 (t, J=7.7 Hz, 2H), 1.99 (quint, J=7.7 Hz, 2H), 1.13 (d, J=6.6 Hz, 3H); 13C 1H NMR (75 MHz, CDCl3, ppm): δ 174.4, 42.5, 41.9, 31.8, 20.0, 18.2; IR (neat): 2970 (s), 2927 (s), 1938 (w), 1676 (vs, C=O), 1493 (w), 1462 (m), 1424 (m), 1367 (m), 1312 (w), 1288 (s), 1241 (s), 1169 (w), 1128 (m), 1066 (m), 1012 (w), 932 (w), 878 (w), 842 (w), 736 (w), 651 (m).

Oxa-cyclotetradecan-2-one (32, Table 1, entry 8).18 Using the general procedure with undec-10-enoic acid but-3-enyl ester 30 (120 mg, 0.50 mmol), 1,3,5-trimethoxybenzene (68 mg, 0.40 mmol), (PCy3)2Cl2Ru=CHPh (1, 17 mg, 21 µmol), and 150 mL of 1,2-dichloroethane afforded 98 mg (84%, 93% by conversion of 30) of
compound 32 as a colorless oil. $^1$H NMR (300 MHz, CDCl$_3$, ppm): $\delta$ 4.15 (t, $J$=5.5 Hz, 2H), 2.38 (t, $J$=6.3 Hz, 2H), 1.68-1.62 (m, 4H), 1.37-1.27 (m, 16H); $^{13}$C {$^1$H} NMR (75 MHz, CDCl$_3$, ppm): $\delta$ 174.2, 63.5, 34.6, 27.9, 26.4, 26.3, 26.1, 25.9, 24.9, 24.8, 24.2, 23.9, 22.9; IR (neat): 2928 (vs), 2859 (s), 1736 (vs, C=O), 1461 (s), 1384 (w), 1348 (w), 1243 (m), 1169 (m), 1143 (m), 1106 (w), 1055 (w), 998 (w), 950 (w), 905 (w), 808 (w), 718 (w).

Acetic acid 4-phenyl-butyl ester (34, Table 2, entry 1). Using the general procedure allyl benzene (100 mg, 0.85 mmol), cis-2-butene-1,4-diol diacetate (300 mg, 1.7 mmol), mesitylene (30 µL, 0.22 mmol), (H$_2$IMes)(PCy$_3$)Cl$_2$Ru=CHPh (2, 20 mg, 25 µmol), and 5 mL of 1,2-dichloroethane afforded 135 mg (83%, 91% by conversion of allyl benzene) of compound 34 as a colorless oil. $^1$H NMR (300 MHz, CDCl$_3$, ppm): $\delta$ 7.34-7.19 (m, 5H), 4.10 (t, $J$=6.3 Hz, 2H), 2.67 (t, $J$=7.1 Hz, 2H), 2.08 (s, 3H), 1.73-1.68 (m, 4H); $^{13}$C {$^1$H} NMR (75 MHz, CDCl$_3$, ppm): $\delta$ 171.4, 142.2, 128.6, 128.5, 126.0, 64.6, 35.7, 28.4, 27.9, 21.2; IR (neat): 3086 (w), 3063 (m), 3027 (s), 2940 (vs), 2861 (s), 1947 (w), 1873 (w), 1739 (vs, C=O), 1604 (m), 1584 (w), 1496 (m), 1454 (s), 1387 (m), 1366 (s), 1241 (vs), 1043 (vs), 970 (w), 951 (w), 909 (w), 848 (w), 789 (w), 749 (s), 700 (s), 635 (w), 607 (m), 572 (w).

Acetic acid 6-oxo-octyl ester (36, Table 2, entry 2). Using the general procedure methyl vinyl ketone (200 µL, 2.4 mmol), 5-acetoxy-1-hexene (200 µL, 1.2 mmol), mesitylene (45 µL, 0.32 mmol), (H$_2$IMes)(PCy$_3$)Cl$_2$Ru=CHPh (2, 33 mg, 35 µmol), and 5 mL of 1,2-dichloroethane afforded 172 mg (77%, 91% by conversion of 5-acetoxy-1-hexene) of compound 36 as a colorless oil. $^1$H NMR (300 MHz, CDCl$_3$, ppm): $\delta$ 4.04 (t, $J$=6.9 Hz, 2H), 2.43 (t, $J$=7.7 Hz, 2H), 2.13 (s, 3H), 2.04 (s, 3H), 1.64-1.55 (m, 4H), 1.36-1.30 (m, 4H); $^{13}$C {$^1$H} NMR (75 MHz, CDCl$_3$, ppm): $\delta$ 209.3, 171.4, 64.6, 43.8, 30.1, 28.9, 25.9, 23.8, 21.2; IR (neat): 2938 (vs), 2860 (s), 1736 (vs, C=O), 1464 (m), 1434 (w), 1387 (w), 1366 (s), 1243 (vs), 1163 (m), 1039 (s), 954 (w), 721 (w), 634 (w), 607 (w).

4-Phenyl-butan-2-one (38, Table 2, entry 3). Using the general procedure with methyl vinyl ketone (75 µL, 0.9 mmol), styrene (200 µL, 1.75 mmol), mesitylene (30 µL, 0.22 mmol), (H$_2$IMes)(PCy$_3$)Cl$_2$Ru=CHPh (2, 38 mg, 45 µmol), and 5 mL of 1,2-
dichloroethane afforded 106 mg (80%, 94% by conversion of methyl vinyl ketone) of compound 38 as a colorless oil. All spectra were identical to an authentic sample purchased from Aldrich. \(^1\)H NMR (300 MHz, CDCl\(_3\), ppm): \(\delta 7.33-7.19\) (m, 5H), 2.92 (t, \(J=7.3\) Hz, 2H), 2.78 (t, \(J=7.3\) Hz, 2H), 2.16 (s, 3H); \(^{13}\)C \({}^1\)H NMR (75 MHz, CDCl\(_3\), ppm): \(\delta 208.2, 141.2, 128.7, 128.5, 126.3, 45.4, 30.3, 29.9\); IR (neat): 3086 (m), 3062 (m), 3028 (m), 2926 (s), 1716 (vs, C=O), 1603 (m), 1497 (m), 1454 (m), 1409 (w), 1359 (s), 1242 (w), 1162 (s), 1080 (w), 1031 (w), 964 (w), 750 (s), 700 (s).

3-(4-Chloro-phenyl)-propionic acid methyl ester (40, Table 2, entry 4). Using the general procedure, methyl acrylate (210 \(\mu\)L, 2.3 mmol), \(p\)-chlorostyrene (140 \(\mu\)L, 1.2 mmol), mesitylene (45 \(\mu\)L, 0.32 mmol), (H\(_2\)IMes)(PCy\(_3\))Cl\(_2\)Ru=CHPh (2, 33 mg, 35 \(\mu\)mol), and 5 mL of 1,2-dichloroethane afforded 160 mg (69%, 75% by conversion of \(p\)-chlorostyrene) of compound 40 as a colorless oil. \(^1\)H NMR (300 MHz, CDCl\(_3\), ppm): \(\delta 7.26\) (d, \(J=8.5\) Hz, 2H), 7.14 (d, \(J=8.5\) Hz, 2H), 3.67 (s, 3H), 2.93 (t, \(J=7.4\) Hz, 2H), 2.62 (t, \(J=7.4\) Hz, 2H); \(^{13}\)C \({}^1\)H NMR (75 MHz, CDCl\(_3\), ppm): \(\delta 173.2, 139.1, 132.2, 129.9, 128.8, 51.9, 35.7, 30.4\); IR (neat): 3028 (m), 2996 (m), 2952 (s), 2846 (m), 1898 (w), 1732 (vs, C=O), 1598 (w), 1577 (w), 1494 (s), 1436 (s), 1409 (m), 1365 (s), 1295 (m), 1197 (vs), 1093 (s), 1016 (s), 988 (m), 952 (w), 901 (w), 820 (s), 782 (w), 727 (w), 716 (w), 638 (m), 516 (m).

4-Phenyl-but-3-en-2-ol (41). Methyl vinyl ketone (75 \(\mu\)L, 0.9 mmol), styrene (200 \(\mu\)L, 1.75 mmol), mesitylene (30 \(\mu\)L, 0.22 mmol), and (H\(_2\)IMes)(PCy\(_3\))Cl\(_2\)Ru=CHPh (2, 38 mg, 45 \(\mu\)mol) were dissolved in 5 mL of 1,2-dichloroethane in a screw top vial. The vial was sealed with a cap containing a PTFE septum and removed from the drybox. The reaction mixture was heated to 40 °C for 12 h (85% consumption of methyl vinyl ketone was observed by GC). (The following corresponds to “Method B” in the text.) The reaction vessel was then charged with NaOH (10 mg, 0.25 mmol), ethylene diamine (3.1 \(\mu\)L, 0.047 mmol) and isopropanol (5 mL) and a balloon of H\(_2\) was attached via a syringe needle. The reaction was stirred at room temperature for 12 h. The reaction mixture was then diluted with CH\(_2\)Cl\(_2\) (5 mL), washed with H\(_2\)O (3 x 3 mL), and then dried over K\(_2\)CO\(_3\). The reaction mixture was then reduced in volume to 0.5 mL and purified directly on a silica gel column. The product was
eluted with 10:1 hexanes:ethyl acetate to afford 110 mg (83%, 97% by conversion of methyl vinyl ketone) of compound 41 as a clear, colorless oil. $^1$H NMR (300 MHz, CDCl$_3$, ppm): $\delta$ 7.26-7.10 (m, 5H), 6.44 (dd, $J$=15.9 Hz, $J$=0.8 Hz, 1H), 6.13 (dd, $J$=15.9 Hz and 6.3 Hz, 1H), 4.36 (qd, $J$=6.3 Hz and 1.1 Hz, 1H), 1.46 (bs, 1H), 1.24 (d, $J$=6.3 Hz, 3H); $^{13}$C {$^1$H} NMR (75 MHz, CDCl$_3$, ppm): $\delta$ 133.5, 129.4, 128.6, 128.4, 127.6, 126.4, 68.9, 23.4; IR (neat): 3356 (vs), 3084 (m), 3060 (m), 3028 (s), 2973 (s), 2926 (m), 2872 (m), 1958 (w), 1878 (w), 1814 (w), 1704 (w), 1658 (w), 1599 (w), 1578 (w), 1494 (m), 1480 (m), 1450 (m), 1368 (m), 1331 (w), 1298 (m), 1205 (w), 1180 (w), 1142 (s), 1059 (s), 968 (s), 943 (m), 876 (w), 855 (w), 825 (w), 749 (s), 694 (s), 680 (s).

4-Phenyl-butan-2-ol (42).$^{23}$ The following procedure corresponds to Method A + Method B as described in the text. Methyl vinyl ketone (75 µL, 0.9 mmol), styrene (200 µL, 1.75 mmol), mesitylene (30 µL, 0.22 mmol), and (H$_2$IMes)(PCy$_3$)Cl$_2$Ru=CHPh (2, 38 mg, 45 µmol) were dissolved in 5 mL of 1,2-dichloroethane in a screw top vial. The vial was sealed with a cap containing a PTFE septum and removed from the drybox. The reaction mixture was heated to 40 °C under Ar for 12 h (85% consumption of methyl vinyl ketone was observed by GC). The reaction was then transferred to a Fisher-Porter bottle and pressurized with 100 psi of H$_2$. Heating at 70 °C for 10 h quantitatively afforded 38 (by GC analysis). The reaction was then transferred to a vial containing NaOH (10 mg, 0.25 mmol) ethylene diamine (3.1 µL, 0.047 mmol) and isopropanol (5 mL) and sealed with a cap containing a PTFE septum. A balloon of H$_2$ was attached via syringe and the reaction was stirred at room temperature for 12 h. The reaction mixture was then diluted with CH$_2$Cl$_2$ (5 mL), washed with H$_2$O (3 x 3 mL), and then dried over K$_2$CO$_3$. Purification by column chromatography (silica gel, hexanes/ethyl acetate as eluent) afforded 41 mg (30%) of compound 42.

Alternatively, after cross metathesis between methyl vinyl ketone and styrene, the reaction was transferred to a Fisher-Porter bottle containing NaOH (10 mg, 0.25 mmol), ethylene diamine (3.1 µL, 0.047 mmol) and isopropanol (5 mL). The flask was pressurized with 100 psi of H$_2$ and heated to 70 °C for 10 h to afford compound 42 in 30% yield. $^1$H NMR (300 MHz, CDCl$_3$, ppm): $\delta$ 7.22-7.07 (m, 5H), 3.74 (d, $J$=6.3 Hz, 2H), 3.39 (s, 1H), 2.72-2.53 (m, 2H), 1.72-1.64 (m, 2H), 1.14 (d, $J$= 6.3 Hz, 3H);
$^{13}$C {${}^1$H} NMR (75 MHz, CDCl$_3$, ppm): $\delta$ 142.2, 128.6, 128.5, 126.0, 67.7, 41.1, 32.4, 23.8;  IR (neat): 3416 (vs), 3087 (m), 3083 (m), 2967 (s), 2928 (s), 1959 (w), 1812 (w), 1637 (s), 1604 (m), 1496 (m), 1479 (w), 1454 (m), 1375 (m), 1311 (w), 1080 (w), 1129 (s), 1082 (w), 1055 (m), 1032 (m), 955 (w), 935 (w), 907 (w), 856 (w), 746 (w), 699 (w), 679 (w).

Cyclohept-4-enol (43).$^{24}$ In a N$_2$-filled drybox, 1,8-nonadien-5-one (6, 60 mg, 0.43 mmol), mesitylene (15 $\mu$L, 0.11 mmol), and (H$_2$IMes)(PCy$_3$)Cl$_2$Ru=CHPh (2, 10 mg, 12 $\mu$mol) were dissolved in 25 mL of 1,2-dichloroethane in a screw top vial. The vial was sealed with a cap containing a PTFE septum and removed from the drybox. The reaction mixture was heated under Ar to 40 °C for 3 h (93% consumption of starting material was observed by GC). The reaction was transferred to a two-neck round bottom flask containing K$_2$CO$_3$ (20 mg, 0.14 mmol) and isopropanol (20 mL) and equipped with a reflux condenser. The reaction was refluxed for 3 days to afford a 60% yield of cyclohept-4-enol (43) (by GC/GC-MS analysis).

Acetic acid 7-oxo-oct-5-enyl ester (35).$^6$ A screw-top vial was charged with 3-butene-2-ol (200 $\mu$L, 2.31 mmol), 5-acetoxy-1-hexene (165 mg, 1.16 mmol), mesitylene (50 $\mu$L, 0.35 mmol), and (H$_2$IMes)(PCy$_3$)Cl$_2$Ru=CHPh (2, 50 mg, 59 $\mu$mol) and dissolved in 6 mL of 1,2-dichloroethane. The vial was sealed with a cap containing a PTFE septum and removed from the drybox. Heating the reaction mixture to 40 °C under Ar for 8 h afforded alcohol 44$^{25}$ (89% conversion as determined by GC). The reaction was then transferred to a two-neck round bottom flask containing NaOH (10 mg, 0.25 mmol) and 3-pentanone (20 mL) and equipped with a reflux condenser. After heating the reaction to reflux for 3 days, the solvent was removed and the reaction was purified using column chromatography (silica gel, hexanes/EtOAc as eluent) to afford 164 mg of acetic acid 7-oxo-oct-5-enyl ester (35)$^6$ in 86% yield. $^1$H NMR (300 MHz, CDCl$_3$, ppm): $\delta$ 6.78 (dt, $J$=15.9 Hz and 6.9 Hz, 1H), 6.07 (dt, $J$=15.9 Hz and 1.4 Hz, 1H), 4.07 (t, $J$=6.3 Hz, 1H), 2.27-2.21 (m, 2H), 2.24 (s, 3H), 2.04 (s, 3H), 1.72-1.48 (m, 4H); $^{13}$C {${}^1$H} NMR (75 MHz, CDCl$_3$, ppm): $\delta$ 198.4, 171.0, 147.4, 131.5, 64.0, 32.0, 28.2, 27.0, 24.5, 21.1.
(R)-3-Methyl-1-cyclopentadecanone or (R)-(−)-Muscone.26 (6R)-2,6-Dimethyl-2,17-octadecadien-8-ol26 (44) (50 mg, 0.17 mmol), mesitylene (10 µL, 0.072 mmol), and (H2IMes)(PCy3)Cl2Ru=CHPh (2, 10 mg, 12 µmol) were dissolved in 200 mL 1,2-dichloroethane in a 500 mL round bottom flask. The reaction was heated to 50 °C for 12 h (74% conversion to RCM product 45,26 monitored by GC). The flask was then charged with NaOH (10 mg, 0.25 mmol) and 3-pentanone (50 mL) and equipped with a reflux condenser. The reaction was heated to reflux for 1 d (76% conversion to the oxidized product (R)-3-methylcyclopentadec-6-en-1-one (46),26 by GC) and then cooled to room temperature. The reaction mixture was transferred to a Parr bomb, pressurized to 800 psi with H2, and heated to 80 °C for 1 d (quantitative conversion to (R)-Muscone, by GC). After cooling to room temperature, the reaction mixture was washed with H2O (3 x 30 mL) and then dried over MgSO4. Purification by column chromatography (silica gel, hexanes/ethyl acetate as eluent) afforded 29 mg (56% overall isolated yield from 44) of (R)-(−)-Muscone as a fragrant, colorless oil. Higher overall yields (75%) of (R)-(−)-Muscone were obtained from (6R)-2,6-dimethyloctadeca-2,17-octadien-8-one26 (obtained via Jones oxidation of 44) using the general tandem RCM – hydrogenation protocol described above. [α]D = -12.3 (c 0.9 in CH3OH) (lit.27 –12.5 in CH3OH); 1H NMR (300 MHz, CDCl3, ppm): δ 2.45–2.38 (m, 3H), 2.18 (dd, J=15.1 Hz and 5.2 Hz, 1H), 2.12–1.88 (bm, 1H), 1.50–1.75 (bm, 2H), 1.1–1.5 (bs, 20H), 0.93 (d, J=6.6 Hz, 3H); 13C {1H} NMR (75 MHz, CDCl3, ppm): δ 211.9, 50.4, 42.1, 35.6, 29.10, 27.6, 27.2, 26.8, 26.6, 26.6, 26.3, 26.2, 25.1, 23.1, 21.2; IR (neat): 2928 (s), 2856 (s), 1712 (s, C=O), 1607 (w), 1517 (w), 1460 (m), 1408 (w), 1367 (m), 1274 (w), 1172 (w), 1128 (w), 1055 (w), 722 (w); HR-MS calcd for C16H30O (M+): 238.2297, found 238.2295.

(12) (a) Choi, T. L.; Chatterjee, A. K.; Grubbs, R. H. unpublished results. (b) trans-4-Phenyl-but-3-en-2-one is commercially available from Aldrich.